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Exploring students' perceptions and performance on predict-observe-explain tasks in high school chemistry laboratory

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EXPLORING STUDENTS' PERCEPTIONS AND PERFORMANCE ON PREDICT-OBSERVE-EXPLAIN TASKS IN HIGH SCHOOL CHEMISTRY LABORATORY

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ABSTRACT

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This study sought to understand the impact of gender and reasoning level on students' perceptions and performances of Predict-Observe-Explain (POE) laboratory tasks in a high school chemistry laboratory. Several literature reviews have reported that students at all levels have not developed the specific knowledge and skills that were expected from their laboratory work. Studies conducted over the last several decades have found that boys tend to be more successful than girls in science and mathematics courses. However, some recent studies have suggested that girls may be reducing this gender gap. This gender difference is the focal point of this research study, which was conducted at a mid-western, rural high school. The participants were 24 boys and 25 girls enrolled in two physical science classes taught by the same teacher. In this mixed methods study, qualitative and quantitative methods were implemented simultaneously over the entire period of the study. MANOVA statistics revealed significant effects due to gender and level of reasoning on the outcome variables, which were POE performances and perceptions of the chemistry laboratory environment. There were no significant interactions between these effects. For the qualitative method, IRB-approved information was collected, coded, grouped, and analyzed. This method was used to derive themes from students' responses on questionnaires and semi-structured interviews. Students with different levels of reasoning and gender were interviewed, and many of them expressed positive themes, which was a clear indication that they had enjoyed participating in the POE learning tasks and they had developed positive perceptions towards POE inquiry laboratory learning environment. When students are capable of formal reasoning, they can use an abstract scientific concept effectively and then relate it to the ideas they generate in their minds. Thus, instructors should factor the nature of students' thinking abilities into their instructional strategies and strive to create a learning environment where students are engaged in thinking, learning, and acting in meaningful and beneficial ways. POE learning tasks enhance students' laboratory experiences and can help deepen their understanding of the empirical nature of science.

Key words: predict observe explain, gender, science laboratory inquiry, reasoning ability, social constructivism, mixed methods.

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CHAPTER I

INTRODUCTION

A significant issue in science education is to understand how learners gain knowledge and to help them attain this goal. In the teaching and learning of science, laboratory work has been considered a very productive method (Kipnis & Hofstein, 2007). Science laboratories have been a unique place for instruction, and laboratory activities have played distinctive and vital roles in high school science curricula. Science educators have agreed that these activities have proven very beneficial to students (Hofstein & Lunetta, 1982, 2004; Lunetta, 1998; Pickering, 1980; Tobin, 1990). One purpose of science laboratories has been to provide students with an opportunity to become involved in scientific investigations and inquiry, which could result in increased learning of science content and processes.

Meaningful learning and understanding of scientific knowledge in the laboratory have occurred when students posed questions and had their doubts clarified (Hofstein & Lunetta, 2004; Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005). Proper use of the laboratory activities could help students more fully develop the appropriate concepts while learning scientific procedures and investigative skills (Bybee, 2000; Suits, 2004). However, in reality, some activities were better than others; moreover, some were more effective for some students rather than others. Thus, laboratory activities must also help students develop the right attitudes and interests in learning chemistry (Tobin, 1990). Overall, when laboratory instruction has emphasized active student participation, it was seen as a better method than “teacher-directed instruction,” such as lectures and other passive approaches.

Statement of the Problem

The abstract nature of chemistry has made it a difficult subject for students to understand (Johnstone, 1984). Research has indicated that the quality of the high school laboratory environment needs drastic improvement. Although classroom learning often has met expectations, traditionally structured laboratory learning has failed to do so (National Research Council, 1996). Moreover, expert recommendations for improvement of the laboratory conditions have shown many discrepancies. According to Roth (1994), “although laboratories have long been recognized for their potential to facilitate the learning of science concepts and skills, this potential has yet to be realized” (p. 197). Clearly, a more effective learning environment must be created in the laboratory to enable a better understanding of the nature of scientific investigations.

Another problem has resided in the types of research studies that have attempted to investigate the effectiveness of laboratory instruction. Numerous reviews of these studies (Blosser, 1983; Bryce & Robertson, 1985; Hodson, 1993; Hofstein & Lunetta, 2004; Lazarowitz & Tamir, 1994) have made it clear that, in general, research studies of the science laboratory have not met the goal of clarifying its distinctive role in science education. That is, these studies have not documented the simple relationships between experiences in the laboratory and student learning of science topics. They could not convincingly report on the effects of laboratory instruction as compared to other instructional modes.

Background of the Problem

Predict-Observe-Explain (POE) is an instructional method that requires students to be more active in the learning process while helping them grasp scientific concepts more effectively (White & Gunstone, 1992). White and Gunstone (1992) originally developed POE tasks by modifying the DOE (Demonstrate-Observe-Explain) method. In POE tasks, students *predict* the outcome of an event, make *observations*, and *explain* this process. Besides laying the foundation for future learning of science concepts, this method is central to scientific investigations. The POE method is consistent with the theory of constructivism (Piaget & Inhelder, 1969), which stresses the importance of prior knowledge and the construction of conceptual knowledge and meaningful learning. Kearney (2004) found that when students are prompted by POE tasks, they can be encouraged to justify, articulate, and reflect on their own ideas, while engaging in meaningful discussions with their peers.

When Fraser and his colleagues (Fraser, McRobbie, & Giddings, 1993) developed an assessment that gauges student perceptions in the laboratory, the result was the Science Laboratory Environment Inventory (SLEI). It demonstrated that students' perceptions became positive when suitable learning environment was created in the laboratories. The SLEI has been proven to be useful in several countries worldwide and has been used to assess students' perceptions of their chemistry laboratory experiences (Fraser & McRobbie, 1995).

In past studies done within a particular grade, boys have performed better than girls. However, over the last decade the academic achievement gap between the boys and girls has almost closed and, in some cases, has reversed (Livingston & Wirt, 2004). In the physical sciences, male students tended to outperform female students, while in the life sciences, the differences were negligible (Beller & Gaffni, 1991; Hamilton, 1998; Hedges & Howell, 1995; Linn, Baker, & Dunbar, 1991). Studies have shown that boys possessed more positive attitudes towards science than girls as early as in elementary school (Clarke, 1972; Clark & Nelson, 1972; Kotte, 1992). More boys than do girls have opted for college majors in the natural sciences or engineering (Keeves, 1991; Kotte, 1992; National Research Council, 1996; National Science Board, 1998; Rosser, 1995).

Many research studies have found a positive correlation between reasoning ability and science achievement (Bird, 2010; Bitner, 1986; Glasson, 1989; Lawson, 1983, Lawson et al., 1989). Piaget established the validity of ”reasoning ability” or ”cognitive developmental level” for adolescents and adults as being an age-dependent progression from concrete operational reasoning to formal operational reasoning (Piaget, 1964; Piaget & Inhelder, 1969). One instrument designed to measure this construct was the Group Assessment of Logical Thinking (GALT)--a paper-and-pencil test developed by Roadrangka, Yeany, and Padilla (1983). Learning chemistry has generally involved understanding abstract concepts and processes (Johnstone, 2000). Numerous studies involving high school students have shown a strong correlation between successful academic performance and formal reasoning skills (Bitner, 1986, 1991; Glasson, 1989; Lawson, 1985; Steinkamp & Maehr, 1983).

Rationale for the Study

Despite the fact that extensive research has examined student perceptions of chemistry laboratory tasks, very few studies have addressed perceptions of POE chemistry laboratory tasks. Currently, no research has focused specifically on the performances and perceptions of students on POE chemistry laboratory tasks within the high school physical science laboratory environment. Also, there was an obvious gap in the literature on how gender and reasoning ability of high school physical science students affected their perceptions and performances on POE tasks. This study was designed to fill this gap in the science education literature.

Purpose of the Study

In a high school physical science course, student performances on POE tasks and their perceptions of those tasks in a chemistry laboratory environment have had a direct bearing on their overall achievement. The main objective of this study was to examine the influence of gender and reasoning skills on these performances and perceptions. High school instructors have faced many challenges in trying to provide high-quality, effective laboratory experiences. Also, very few laboratory activities have resulted in meaningful learning. So, this study used an instructional intervention in which POE tasks encouraged students to think about the nature of their scientific investigations. Obviously, students are not identical in their abilities and interests in doing POE tasks. Their reasoning skills vary, and some students think in a more abstract manner than do others. Moreover, boys and girls learn in different ways. This study considered student reasoning levels and gender as factors that could affect the effectiveness of POE interventions. Finally, the researcher was challenged to develop accurate assessments of student learning from inquiry and laboratory work.

The methodology used in this study featured a concurrent triangulation mixed method (Creswell & Miller, 2002) to investigate effectiveness of laboratory instruction as described above. The following quantitative methods were used to investigate this goal:

published POE laboratory activities, a researcher-developed POE perceptions questionnaire, the Science Laboratory Environment Inventory (SLEI), and Group Assessment of Logical Thinking (GALT). Concurrently, qualitative methods were as follows: semi-structured interviews to explore students' perceptions and observations of students participating in POE tasks. In short, the best way to understand this multi-faceted research problem was to synthesize (triangulate) findings from both the quantitative results and the qualitative findings (Greene, Caracelli, & Graham, 1989). The results of this study can help high school chemistry teachers become more aware of the influence of gender and reasoning levels on students' perceptions of the POE laboratory environment and their laboratory performance skills.

Research Questions

Q1 What is the effect of gender, reasoning ability and their interactions on student perceptions and performances on Predict, Observe, Explain (POE) chemistry laboratory tasks?

Q2a For those students who were interviewed, what were their perceptions of POE tasks within chemistry laboratory environment?

Q2b Among the interviewed students, were there any differences in perceptions of POE chemistry laboratory environment tasks across gender and reasoning level?

Dependent Variables: There were two sets of dependent variables--student performance on a sequence of POE chemistry laboratory activities performed throughout the semester (i.e., achievement outcome measures) and measures of student perceptions of the laboratory environment.

Independent variables: The two different independent variables were students' gender and reasoning ability (formal and concrete levels). The Group Assessment of

Logical Thinking (GALT) was used to classify students' general reasoning ability as either concrete or formal.

Theoretical Framework

In school learning environments, it is rare for individual students to learn and acquire knowledge by working in isolation from each other. More frequently, knowledge is co-constructed by the students and their teacher, based on the needs of the society (Ernest, 1999; Gredler, 1997; Prawat & Floden, 1994). Thus, in this research study, social constructivist epistemology was used as the theoretical framework for this study (Vygotsky 1962). It describes the impact of cultural factors that influence young people as they are acculturated into a society (Derry, 1999; McMahon, 1997). When the students of the same age group interact in their physical and social environments, the learning process becomes more meaningful (McMahon, 1997). This framework is elaborated in Chapter III.

Limitations and Assumptions

A potential limitation of the study was the question of reliability and validity of the instrument adapted or developed by the researcher for use in this study. Another limitation was that the researcher was also the teacher for the general chemistry course at the same school where the study was conducted. Because the convenience sampling was used in the quantitative phase of the study, the researcher could not say with confidence that the sample would be representative of the population (Creswell, 2002). In any quantitative study, there could always be an inherent non-response limitation (Dillman, 2000). Assumptions for all statistical analyses were met. Limitations and assumptions are elaborated in Chapter III.

Definitions of Terms

Concurrent triangulation: This represented the simultaneous use of qualitative and quantitative methods in which there was limited interaction between the two sources of data during the data collection stage, but the findings complemented one another at the data interpretation stage (Morse, 1991).

Constructivism: Learning is a set of constructive processes in which the individual student (alone or socially) builds, activates, elaborates, and organizes knowledge structures. From this conception of learning, it followed that teaching should maximize the opportunity for students to engage in activities that promote higher order learning (Brown, Collins, & Duguid, 1989; De Corte, Verschaffel, Entwistle, & Merrienboer, 2003; Donovan & Bransford, 2005; Greeno & Wing, 1996).

Critical thinking: This was defined as "reasonable, reflective thinking that is focused on deciding what to believe or do" (Ennis, 1985, p. 54).

Formal reasoning ability: This was defined as ability to think, analyze, and solve problems at a complex level that required skills to apply (Lawson, 1985).

Concrete reasoning ability: This was defined as the ability to think, analyze, and solve problems at a basic level (Lawson, 1985).

Laboratory activity: This was defined as "learning experiences in which students interact with materials and/or with models to observe and understand the natural world" (Hofstein & Lunetta, 2004; p. 31).

Learning environment: This was defined as "the interpersonal relationship among pupils, relationship between pupils and their teachers, relation-ship among pupils and both the subject matter studied and the method of learning and finally, pupil reception of the structural characteristics of the class" (Anderson, 1973, p. 1).

Mixed method: This was broadly defined as "the combination of methodologies in the study of the same phenomenon" (Denzin, 1978; p. 291).

Predict-Observe-Explain: This was defined as a pedagogical approach that served as an efficient teaching strategy for eliciting students' ideas and also promoting student discussion about their ideas. (White & Gunstone, 1992)

Social constructivism: This was defined as the construction of knowledge which took place within the community of students in a classroom. In various classroom settings, students were encouraged to build knowledge within the community of learners, to explicate their knowledge, and to regulate and monitor their learning processes (Brown et al., 1989; Palincsar & Brown, 1984; Slavin, 1995).

Triangulation design: This was defined as "a validity procedure where researchers search for convergence among multiple and different sources of information to form themes or categories in a study" (Creswell & Miller, 2002, p. 126).

CHAPTER II

REVIEW OF THE LITERATURE

In this chapter, a review of the literature summarizes research studies that have focused on various constructivist-oriented instructional and assessment strategies. These strategies include the use of the GALT to categorize reasoning abilities, the use of POE instructional strategies to promote conceptual understanding and to predict students' perceptions and performance across gender and reasoning ability. This review was conducted to gain an understanding of variety of factors that contribute to student learning in high school chemistry laboratories.

Significance of Laboratory Activities

How do students learn science content and skills in the laboratory? Educators have pondered this question and sought to improve knowledge acquisition by students within the educational settings of the science laboratory instruction (DeBoer, 1991; Hofstein & Lunetta, 1982; Hurd, 1969; Schwab, 1962). Science instructors have used laboratory projects to increase learning by involving students in scientific investigations and inquiry (Hofstein & Lunetta, 1982; Suits, 2004). Historically, instructors have assumed that laboratory projects bring about deeper learning than lectures or other instructor-led activities. Yet, as Roth (1994) succinctly put it, "although laboratories have long been recognized for their potential to facilitate the learning of science concepts and skills, this potential has yet to be realized" (p. 197). In fact, laboratory instruction quite often fails to maximize learning due to ineffective yet long-held instructional practices

(National Research Council, 2006). Although science instructors and their students have raised doubts about the value and effectiveness of laboratory instruction (Hofstein & Lunetta, 1982; Johnstone & Wham, 1982; Klainin, 1988; Pickering, 1980), some instructional strategies can be used to address this concern. Researchers have found that instruction based on constructive learning theory has resulted in more meaningful learning outcomes (Taylor & Fraser, 1991; Tsai, 1998, 1999; Tsai & Tsai, 2003). For example, Nakhleh and Krajcik, (1993, 1994) examined three instructional modes where acid/base concepts were presented using different technologies. The most effective mode in terms of integrating acid/base concepts allowed students to actively observe the phenomenon while also viewing its graphic representation. Bucat (1983) found that chemistry laboratory experiments were perceived as being more meaningful when they were structured to help students develop and express clearer relationships between their actions and observations. Another study noted that student's chemistry laboratory reports prompted an increase in laboratory learning outcomes (Hofstein & Lunetta, 2004).

Chemistry students who initiated their own queries and took charge of posing questions performed better than those in the control group (Hofstein et al., 2005). In another study, chemistry students who experienced the guided inquiry laboratory format for the entire semester exhibited much greater scientific investigative skills than those in the verification-based control group (Suits, 2004). Overall, laboratory instruction in chemistry should be designed to engage students in both thinking about and organizing their observations during their laboratory work with chemical phenomena.

Social Constructivism

Constructivist learning theory focuses on instruction that supports students as they actively build their own knowledge (Bettencourt, 1993; Bodner, 1986; Fosnot, 1996). In fact, a student's prior knowledge is considered to be an essential element of any new learning (Ausubel, 1968; Bischoff & Anderson, 2001; Driver & Bell, 1986). In spite of criticism (e.g., Gil-Pérez et al., 2002), constructivism has nonetheless impacted current instructional practices in science classrooms (Niaz et al, 2003; Staver, 1998). These constructivist-based instructional modes include “concept mapping” (Novak & Gowin, 1984), “the learning cycle” (Lawson, 2001), and “POE strategy” (Palmer, 1995; White & Gunstone, 1992).

In constructivist-based education, students are encouraged to exchange their own insights via both oral and written assignments (Warner & Wallace, 1994). Also, rather than discounting their own prior knowledge and past experiences, they are taught to see them as building blocks to be integrated with the new material as it is encountered in the classroom (Tobin, Tippins, & Gallard, 1996). Thus, different learning outcomes require different assessment techniques, including “student interviews, concept maps, student journals and diagnostic multiple-choice tests” (Duit, Treagust, & Mansfield, 1996). To promote the implementation of constructivist learning in science classrooms, science educators are recommending more research into science laboratory instruction and the resultant student discourse during that instruction (Hofstein & Lunetta, 1982; Roth, 1999; Tobin, 1990).

Student discourse is highlighted when class discussions provide a forum where students can “identify and articulate their own views, exchange ideas and reflect on other students' views, reflect critically on their own views and when necessary, reorganize their own views and negotiate shared meanings" (Kearney, Treagust, Yeo, & Zadnik, 2001, p. 64). All of these activities are forms of social interactions where students construct their own understandings (McRobbie & Tobin, 1997; Prawat, 1993; Solmon, 1987; Staver, 1998). Students benefit because they begin to internalize and apply their learning beyond the classroom, and they get opportunities to practice their oral communication skills (Reznitskaya, Anderson, & Kuo, 2007). Other research studies have found that student discourse is effective in helping students test their ideas, synthesize the ideas of others, and build deeper understanding of what they are learning (Corden, 2001; Reznitskaya et al., 2007; Weber, Maher, Powell, & Lee, 2008).

Constructivist-based instruction also helps students develop personal qualities that make them better learners. These instructional activities challenge students to develop their self-regulation, self-determination, and their perseverance in completing learning tasks (Matsumara, Slater, & Crosson, 2008). Also, a discussion-based environment allows students to become more motivated to engage in problem-solving and collaboration activities (Dyson, 2004; Matsumara et al., 2008). Moreover, when they discuss science topics they are encouraged to articulate and exchange ideas, which, in turn, call upon their reasoning skills and persuasive speaking abilities (Reznitskaya et al., 2007). Finally, students enjoy the additional benefit of developing a communal feeling in the classroom (Barab, Dodge, Thomas, Jackson, & Tuzun, 2007; Weber et al., 2008).

According to constructivist advocates, culture and context are keys to building knowledge (Derry, 1999; McMahon, 1997). These two factors are found in Vygotsky's and Bruner's understandings of cognitive development as well as Bandura's social cognitive theory (Schunk, 2000). For these social constructivists, knowledge is not the possession of the instructor to dole out to passive students; rather, knowledge is a human construction, in which students play an active role (Ernest, 1999; Gredler, 1997; Prawat & Floden, 1994).

Constructivism requires teachers to relinquish their authority over what is considered to be scientific knowledge. By recognizing the value of students' prior experiences, instructors must offer opportunities that allow students' own ideas to emerge (Duit & Confrey, 1996). In fact, students' views should provide the framework for a teacher's future lesson plans. This student-centered approach reduces passivity among learners (McMahon, 1997). Instead, students can do hands-on projects that involve testing hypotheses, comparing the observed results with the expected results, and so on (Gredler, 1997; Prawat & Floden, 1994).

Within the social environment of the constructivist classroom, student groups work together to gain understanding of the scientific content. The interrelationship between learning and the environment is recognized as both valid and vital for human learning. As group members' relationships grow and change, an individual's role within a group project changes. To determine if learning activities need to be modified, the classroom environment should be re-evaluated from time to time (Bredo, 1994; Gredler, 1997).

Clearly, ongoing research is needed to evaluate the quality of student discourse within science courses (Hofstein & Lunetta, 1982; Tobin, 1990). Science educators can use their awareness of knowledge-construction and individual learning differences to inform teachers on how to properly structure their classrooms (Anderson, 1992; Bodner, 1986). Overall, constructivist-learning theory clearly benefits both students and teachers.

Perceptions of Learning Environments

Many years ago, Shulman and Tamir (1973) recognized the importance of student perceptions: “we are entering an era in which we will have to acknowledge the importance of students’ attitudes, interests, needs and intuition as important outcomes of science instruction (Hofstein & Lazarowitz, 1986, page 190).” The way students perceive their learning environment must be considered (Fraser, 1981). Researchers need to devote themselves to finding better ways to evaluate the learning environments in the sciences (Anderson & Walberg, 1974; Chávez, 1984; Fraser, 1981). Recently there has been a movement to implement this research in the science classroom (Fraser, 1981). This means that information on students’ perception of their learning environment (Walberg, 1970) is treated as seriously as are instructional methods. Both curriculum developers and instructors can use this information to change and improve their teaching methods.

Theoretical Basis for Perceptions of Learning Environments

Piaget’s (1969) theory posits that students, through spontaneous interaction with their learning environment, discover themselves. Alongside this, most educators agree that science is better taught using the discovery method (guided or open inquiry) or the experimental approach. The learning environment is a key component of the discovery method. The discovery method stimulates interaction among the students, their teacher, the scientific discipline, the available resources and the learning environment (Adelson 2004; Aladejana 2006; Mayer 2003). Fraser (1986) analyzed more than 60 studies on the science classroom environment’s impact on student learning outcomes. He noted that carefully designed classroom environments have enhanced learning outcomes and attitudes in the sciences. Many other studies (Chin & Chia, 2004; Goh, Young, & Fraser, 1995; McRobbie & Fraser 1993; Wong & Fraser 1996) have supported this relationship.

The social cognitive theory posited by Bandura (1997) centers on the concept of *reciprocal determinism*, that is, personal, environmental, and behavioral factors influence student learning. For example, environmental factors include the quality of instruction, teacher feedback, access to information, and help from peers and parents. Similarly, the extent to which students are satisfied with their learning is based on factors such as teaching styles, classroom design, and the learning environment (Dorman, 2002; Zandvliet & Buker, 2003). With regard to laboratory work, students preferred more open-ended and integrated inquiry-type investigations as compared to those in the control group. They also perceived themselves as actively involved in their inquiry-based learning environment (Hofstein & Lunetta, 2004).

Perceptions of Science Learning Environments

For the last 25 years, researchers have focused on investigating the student perceptions of the “psychosocial environment” of science classrooms (Fraser, 1986; Fraser & Walberg, 1991; McRobbie & Fraser, 1993). The classroom learning environment is closely associated with cognitive and attitudinal outcomes (Haertel, Walberg & Haertel, 1981). Getzels and Thelen (1960) developed a framework to understand the nature of the classroom environment that can determine students’ achievement and attitudes**.** This conceptual framework provided the foundation for the development of the Learning Environment Inventory (Anderson, 1973). However, this instrument has only limited value for science educators because it was not developed specifically for the science classroom.

The influence of educational environments has been studied for many years (Anderson & Walberg, 1974; Moos 1968, 1974a, 1974b; Moos & Trickett, 1987). The focus of most of this research has involved investigations of relationships between student outcomes and the nature of the classroom environment (e.g., Fraser 1994; Fraser & Fisher 1982a, 1982b; Haertel et al, 1981). Since the landmark use of classroom environment assessments to evaluate Harvard Project Physics (Walberg & Anderson, 1968a, 1968b), research on learning environment has increased over the last three decades.

In the sciences, research studies of students' perceptions of the learning environment have been conducted in many countries, such as Australia (Fisher & Fraser, 1983), the U.S. (Moos, 1979), and Israel (Hofstein, 1983). Overall, these studies have revealed that students' perceive science as a difficult subject (e.g., Hofstein & Welch, 1984; Hueftle, Rakow, & Welsh, 1983).

Researchers in the sciences have identified laboratory activities as providing a learning environment that is clearly distinct from other classroom activities. Specifically, the laboratory can help students improve their cognitive abilities, which can in turn help them develop problem-solving skills (Woolnough, 1991). However, DeCarlo and Rubba (1991) note a dearth of research on the laboratory as a learning environment and its effect on learning outcomes (Fraser et al., 1993). Thus, this pedagogic value must be accompanied by *standards for evaluation*, which have been described for a variety of physics, chemistry and biology courses (Lunetta & Tamir, 1979). Fraser and his colleagues (Fraser, Giddings, & McRobbie, 1991) responded to this need by developing and validating an instrument that assesses learning outcomes: the S*cience Laboratory Environment Inventory* (SLEI).

The Science Laboratory Environment Inventory: Assessing Perceptions of Learning Environments

Fraser et al. (1991) used the SLEI and found significant relationship between the dimensions of SLEI and students' cognitive outcomes. The SLEI was originally validated in six countries for two different populations: a sample of 3727 senior high school students in 198 science laboratory classes, and another sample of 1720 students in 91 university science laboratory classes (Fraser, Giddings, & McRobbie, 1992). Subsequently, several follow-up studies were used to cross-check its validity: one with 1,594 Australian students in 92 classes (Fraser et al., 1993), another with 489 senior high-school biology students in Australia (Fisher, Henderson, & Fraser, 1995), and a third study with 1,592 Grade 10 chemistry students in Singapore (Wong & Fraser, 1995).

Both qualitative and quantitative methods have established the SLEI as a valid instrument to assess and investigate learning environments (Tobin & Fraser, 1998). The scores on each scale of SLEI distinguished the perceptions of students in various classrooms. Also, each scale of SLEI showed good factorial validity and internal consistency (Riah & Fraser, 1998). The SLEI was found to have good internal consistency as shown by Cronbach's alpha ($\alpha = 0.835$), which indicated that the SLEI items were closely related together as a construct. Most classroom environment research looked at the relationships between student outcomes and the nature of the classroom environment (e.g., Fraser & Fisher, 1982a, 1982b).

Findings from a previous study revealed that students perceived their science classes as challenging and difficult (Lawrenz, 1976). Also, SLEI detected that different science content areas produce different student perceptions of the laboratory environment. Specifically, they saw biology as being less contentious than their chemistry and physics classes. The SLEI study included a quantitative analysis of laboratory environments that compared student perceptions in physics and biology classes. Those in physics laboratory classes perceived higher levels of integrated scientific concepts as opposed to perceptions of lower levels in biology (Hofstein & Lunetta, 1982).

With respect to this dissertation study, use of the SLEI with students in chemistry laboratory environments found that favorable levels of all SLEI items were linked with positive chemistry related attitudes. This study's findings showed an impact on learning outcomes such as the actual quality of the laboratory environment, but also the learners' perception of that environment. In agreement with numerous other studies (Chin & Chia, 2004; Combs & Snugg, 1995; Fraser & O'Brien, 1985; Wong & Fraser, 1996), the learning environment's quality contributes to the student's understanding and memory of the subject. Science achievement strongly correlated with how integrated student perceptions of the learning environment were to the actual environment in the classroom (Aladejana & Aderibigbe, 2007). Both boys and girls, whether they are high school or university students, gave high scores on SLEI (Fraser, 1982a, 1982b; 1986). Girls perceived a "more favorable classroom environment" than did boys on most SLEI categories. Overall, girls hold more positive perceptions than do boys of the learning environment (McRobbie & Fraser, 1993). In conclusion, the researcher supports Fraser's

(1981) call for research on the learning environments to address practical matters such as the need for classroom environments evolve and change in response to research studies on student perceptions.

Gender and Science Classes

Both education research and the popular media discuss the role and achievement levels of women in science study and scientific careers (Lee & Burkam, 1996). As early as age nine, boys outperform girls in science achievement. This trend continues throughout junior high and high school (Jones, Mullis, Raizen, Weiss, & Weston, 1992). For the most part, research studies have failed to accurately characterize the gender gap; possibly because most look at science in general. The gender gap within specific scientific disciplines is less studied.

Gender and Science Achievement

Numerous science assessment studies consistently revealed that male students outperform female students (Beller & Gafni, 1991; Korporshoek, Kuyper, Van der Werf & Bosker, 2011; Neuschmidt, Barth, & Hastedt, 2008). Such differences are less noticeable to researchers who examine assessments by content area. In physics and chemistry, male students have excelled more than female students. Meanwhile, in biology and psychology, the gender achievement differences were minimal (Beller & Gafni, 1991; Hamilton, 1998; Hedges & Howell, 1995; Linn et al., 1991). Overall, studies show that male students usually outperform female students on math and science assessments.

Lee and Burkam (1996) used data from the National Assessments of Educational Progress (NAEP) to study gender differences by content area. They looked at effect of grade level and gender. They found that in the physical sciences, female students achieve well at lower grade levels; however, after the eighth grade, achievement levels in the physical sciences were much lower for girls than they were for boys. Researchers have also studied the effects of schools on the gender gap, for example: ‘differential teacher expectations’ (Grossman, 1987; Jones & Wheadley, 1990; Spear, 1987), and ‘classroom influences and environment’ (Eccles & Midgley, 1989; Jones & Wheadey, 1990; Morse & Handley, 1985). An additional achievement gap is revealed in studies when high schools designate science classes as electives rather than as required courses (Brickhouse, Carter, & Scandebury, 1990; Lovely, 1987). Other reasons for achievement differences by gender in the sciences are as follows: participation (Kahle, Matyas, & Cho, 1985), cultural and social expectations (Jones & Kirk, 1990; Jones & Wheatley, 1990; Kelly, 1981; Morse & Handley, 1985), and individual characteristics such as attitudes, motivation, spatial ability, and interest (Cannon & Simpson, 1985; Jones & Wheatley, 1990; Simpson & Oliver, 1985, 1990).

Tobin’s (1990) findings revealed that female students are less involved in using laboratory equipment than males. With respect to participation in the sciences, researchers found little disparity between the self-efficacy of males and females (Karaarslan & Sungar, 2011). Other findings suggest that some female students, personally motivated to excel in a predominately male field of study, do succeed in the harder sciences like chemistry (Grunert & Bodner, 2011). Countering this, Boli, Allen, and Payne (1985) notes that many female students had taken a less rigorous math curriculum, “and this was having a flow-on effect in the latter’s studies of both mathematics and science.” Likewise, Blickenstaff (2005) and Spelke (2005) see that the lack of preparation at the school level as one of the major factors responsible for keeping females away from taking science and mathematics courses at the undergraduate level. The end effect of this gender gap is that low achievement levels for females leads to lower numbers of women entering into physical science and engineering careers.

Gender and Perceptions Towards Science

Gender differences also apply to student perceptions of the learning environment in the sciences. Girls reported positive learning environment perceptions more so than boys (Fraser, 1986). In another study, Owens and Stratton (1980) observe girls' preference for cooperation, and boys' preference for 'competition and individualization.' The general trend shows that girls perceive the learning environment more positively than boys, even while being in the same classes. Teachers should take advantage of these studies in order to understand gender differences in science learning. This awareness would allow teachers to develop a guideline for designing a supportive learning environment for both genders.

Research reports on attitudes among high school students show that the physical sciences are seen as more masculine than the biological sciences. Biology is thought of as a "softer" science than chemistry or physics. Moreover, students view biology as a people-oriented, nurturing, helping field; such characteristics are typically characterized as more feminine than masculine (Jones & Wheatley, 1990).

The relationship between gender and perceptions of the classroom environment has been studied in many countries (Fisher, Fraser, & Rickards, 1997; Fisher, Rickards, Goh, & Wong, 1997; Fraser, Giddings, & McRobbie, 1995; Fraser & Chionh, 2000; Goh & Fraser, 1998; Henderson, Fisher, & Fraser, 2000; Khine & Fisher, 2001, 2002; Khoo & Fraser, 1998; Kim, Fisher, & Fraser, 2000; Margianti, Fraser, & Aldridge, 2001a, 2001b;

Quek, Wong, & Fraser, 2002; Riah & Fraser, 1998; Wong & Fraser, 1996; Wong, Young, & Fraser, 1997). Generally, studies of students' perceptions have revealed that females typically have more favorable views of their classroom learning environments than do males. The classroom's social environment differs from that which the students experience outside of school (Getzels & Thelen, 1960). Moreover, in the classroom, girls and boys encounter science for the first time, and their perceptions of these early encounters influence the choices they make about future science classes and careers.

Theory and Measurement of Reasoning Ability

Existing literature reveals no current studies about the predictability of using formal operational reasoning strategies as predictors of students' abilities to think critically. However, this dissertation study theorized that formal operational reasoning modes are indicators of higher-level thinking abilities. In fact, the core of this study investigated these modes as predictors of grades assigned by science and mathematics teachers. Numerous studies involving college students have established a positive correlation between academic performance and formal reasoning ability (Bird, 2010; Bunce & Hutchinson, 1993; Niaz, 1989; Steinkamp & Maehr, 1983; Valanides, 1996).

Reasoning Ability: Theoretical Foundations

The term *critical thinking* is defined as "reflective and reasonable thinking that is focused on deciding what to believe or do" (Ennis, 1985, p. 45). This term includes the skills such as understanding, analyzing and evaluating the information using metacognition (Brookfield, 1987; King & Kitchener, 1994). Formal operational reasoning ability is thought to be cultivated in early adolescence, and it facilitates both abstract and deductive reasoning (Inhelder & Piaget, 1958). This ability can be described as the "ability to reason in the abstract level beyond the bounds of specific contexts" (Jiang, Xu, Garcia, & Lewis, 2010, p. 1430). Formal reasoning ability involves the *structured whole* (Inhelder & Piaget, 1958), which allows someone to "synthesize inversions and reciprocities in a unitary system of transformations" (Bitner, 1991, p. 266). It is an essential ability needed to foster student achievement in science and chemistry. Students with formal-reasoning skills also have better comprehension and generalization abilities.

Based on Piaget's theory of cognitive development, formal operations consist of five reasoning components: proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial logic (Herron, 1975; Inhelder & Piaget, 1958; Jiang et al., 2010). Piagetian theory assumes that most high school students can display formal reasoning abilities. In fact, deficiency in these reasoning skills can inhibit learners from mastering abstract scientific concepts (Inhelder & Piaget, 1958). These reasoning processes rely on both declarative and procedural knowledge (Lawson et al., 1989). Thus, science educators should recognize that science achievement requires not only a set of facts (i.e., declarative knowledge) but also thinking processes (i.e., procedural knowledge; Marzano & Arredondo, 1986). Consequently, formal operational reasoning and critical thinking skills are essential abilities for success in advanced high school science and mathematics courses.

Chemistry is abstract by nature and requires advanced and sophisticated formal thinking ability. Students lacking this ability face a formidable barrier to learning abstract chemical conceptions. Also, science achievement can be predicted by factors other than formal operational reasoning. Specifically, Lawson (1983) found that field independence, mental capacity, prior relevant knowledge, and beliefs predicted achievement in science. For example, learning styles (Gregory, 1982; Kolb, 1976) and the amount of structure required by students (Hunt, 1979) can also influence science learning. Other factors include students' physical needs and perceptions and their impact on learning and achievement. These results suggest that teaching strategies can be designed to improve student learning.

Group Assessment of Logical Thinking (GALT): A Reasoning Ability Instrument

The abbreviated GALT (Group Assessment Logical Thinking; Roadrangka & Padilla, 1982) is an instrument that assesses logical thinking consists of six modes of reasoning: one concrete operational (i.e., conservation) and five formal operational (i.e., proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial logic). The GALT is a 12-item paper-and-pencil test where the basic format for each item consists of an illustration of the problem and multiple-choice responses for both the correct answer and justification. The GALT was selected for this dissertation study because the validity and reliability of its formal reasoning constructs are firmly established (Roadrangka et al., 1983) for a wide range of students ranging from sixth grade through college level.

Roadrangka et al. (1983) described the construction and validation of the Group Assessment of Logical Thinking (GALT) test. Validity as determined by Piagetian interview classification was reported as $r = 0.80$. Total alpha reliability for the test was, $\alpha = 0.85$. The scores on this test classify students into three Piagetian thinking levels: concrete 0-8, transitional 9-15, and formal 16-21 (Roadrangka et al., 1983). The construct validity of GALT was determined via the principal components method of factor analysis and its convergent validity with Piagetian Interview Tasks ($r = 0.80$). The criterion-related validity of the GALT was established using the scores on the Test of Integrated Process Skills (TIPS_II). The correlation coefficient between the total GALT score and the total TIPS_II score was $r = 0.71$. To measure reliability, the researchers used Cronbach's alpha, which indicated a good level of internal consistency, $r = 0.85$ (Roadrangka et al., 1983).

The GALT has been used to match instructional strategies with the cognitive development level of the students (Roadrangka & Padilla, 1982, p.1). In their development of the GALT, the researchers noted that there was an overall increase in the cognitive ability with grade level and increase in age. However, most middle school students exhibited conservation skills (i.e., a concrete reasoning task) while being weakest at probabilistic and correlational reasoning (i.e., formal reasoning tasks). In addition, high school students showed gains in these skills but exhibited the same pattern of weaknesses (Roadrangka & Padilla, 1982, p. 9). More than half of the students interviewed and tested with the GALT (Roadrangka et al., 1983) were classified as being concrete learners. These results have prompted educators to make multiple suggestions on how to help concrete-level students learn science. Also, since these reasoning skills predict academic performance, science educators should teach science as a way of cultivating the creative and critical thinking processes (Lawson, 1980; Lawson et al., 1989).

These formal reasoning modes were statistically significant predictors of science and mathematics achievement (Bitner, 1986; Hofstein & Mandler, 1985; Howe & Durr, 1982; Lawson, 1983; Lawson, Lawson, & Lawson, 1984). Especially noteworthy was the fact that these modes could explain the major percentage of variance (62%) in science achievement. This result was expected because success in upper-level science courses requires application of these formal reasoning modes (Capie, Newton, & Tobin, 1981; Carcer, Aguirre, Gabel, & Staver, 1978; Inhelder & Piaget, 1958; Lawson, 1982, 1985; Linn, 1992). For grades 9-12, Bitner (1991) found that GALT scores predicted both students' critical thinking abilities as well as their grades in science and mathematics courses. Bitner (1986) has revealed that the GALT is a measure of logical thinking ability of eighth grade students and a predictor of mathematics and science achievement. This finding is relevant to this dissertation study where reasoning ability is an important factor, and the study's students are enrolled in ninth grade physical science classes.

POE: Predict-Observe-Explain Strategy

The use of traditional instructional activities, such as cookbook laboratory experiments, has been unsuccessful in bringing about long-term change in student misconceptions (Driver & Easley, 1978). In the laboratory, this type of cookbook strategy does not help students develop their scientific investigative skills (Suits, 2004). Thus, there is a need for a laboratory-based instructional strategy that focuses on the essence of scientific investigations. This need prompted Champagne, Klopfer, and Anderson (1980) to develop a DOE (demonstrate-observe-explain) strategy, which was then revised by White and Gunstone (1992) to become the POE strategy (i.e., predict-observe-explain).

With this POE strategy, students were asked to *predict* what would happen before an event was performed, *observe* it and *explain* what happened (White & Gunstone, 1992). The researchers hoped students would make predictions based on their real-world experiences and then to reflect on their predictions. That is, students' initial beliefs and ideas allow them to make predictions, which become the foundation for future learning. In general, this procedure is based on the classical model of research where a hypothesis is stated, the relevant data are gathered, and the results are discussed (White, 1988). POE was developed explicitly for use in science laboratories as a means to expose cognitive conflicts and to provide aids for students to move towards more accurate science conceptions (White & Gunstone, 1992).

The POE method has been widely reported in science education research literature. Researchers used it to help determine students' misconceptions (i.e., alternative conceptions; Champagne, Klopfer, Desena, & Squires, 1981; Gunstone & White, 1981). Also, White and Gunstone (1992) have advocated use of the POE technique as an effective approach to help students develop valid science conceptions and to examine student ideas (Baird & Mitchell, 1986; Gunstone & White, 1981; Liew & Treagust, 1995; Palmer, 1995). Since the 1980s, POE has been used as an instructional strategy to help students achieve *conceptual change* (Searle & Gunstone, 1990). Specifically, Searle's (1995) qualitative research on the effectiveness of the POE technique in college physics showed that it facilitated discussions, aided students in becoming aware of their alternative conceptions, and helped them actively reconstruct their understanding of the concepts.

Moreover, Kearney et al. (2001) have deliberated about student and teacher perceptions of POE tasks embedded in a multimedia computer program. Using qualitative research methods, Searle (1995) found that when the POE strategy was used with college physics students, this strategy facilitated discussions that helped students become aware of their alternative concepts (i.e., misconceptions). In addition, these students were more active in reconstructing their understanding of the physics concepts. Likewise, Liew and Treagust (1998) examined high school students' heat and temperature concepts using the POE strategy. They found that it was effective in helping students gain a correct understanding of the concepts. Additionally, Kearney and Treagust (2000) have used the POE strategy to structure the learners' engagement with instructional video-clips. It was found that POE tasks helped students test their predictions, reflect on their ideas, learn and understand from meaningful discussions (Kearney, 2004). Finally, Wu and Tsai (2005) have explored the effects of long-term constructivist-oriented science instruction on elementary school students' process of constructing cognitive structures.

Learning from POE tasks was supported within a multimedia instructional context when combined with a social constructivism-centered learning environment (Kearney, 2004). Significantly, multimedia-supported POE tasks provided an advance in the instruction of science education. These tasks provide new opportunities for students to engage in the critical observation stage, when instruction augmented the quality and detail of feedback given to students after they had made predictions. These tasks involving computer promote learner control of the POE strategy, granting students' time to discuss and reflect on their views. Multimedia supported POE also allows stimulating; real-world contexts that can help students feel confident and comfortable, particularly in the initial prediction phase. Data from this study has suggested that these qualities are a positive development in the use of the POE strategy in science classrooms, making a noticeable impact overall in the classroom environment. Data have suggested that the digital clips were an appropriate medium for demonstrating the POE tasks, providing an effective tool for students to observe phenomena (Kearney et al., 2001). In addition, McGregor and Hargrave (2008) conducted a study using the "predict-observe-explain" strategy involving simulations and discussions. Significant differences in conceptual understanding between treatment and control groups were observed.

Overall, the POE strategy has been shown to be a very significant technique, especially in the physical sciences and at high school and college levels. Tsai (2001a, 2001b) has suggested that the use of POE instructional activities is useful for augmenting students' information processing levels. It has been shown that constructivist classrooms rely on students sharing and discussing their own interpretations (McRobbie & Tobin, 1997; Parker, 1992; Warner & Wallace, 1994). Research has also shown that peer interactions and cooperation are tools to promote conceptual understanding and conceptual change (Searle & Gunstone, 1990; Tao & Gunstone, 1999; Zacharia, 2005).

Results imply that the POE tasks can be used to design learning activities that start with the viewpoints of students rather than those of teachers or scientists. Research findings suggest that POE procedures are effective in enhancing student achievement and in profiling student progress. Finally, POE methods are valuable in diagnosing students' ability to apply their own "ontological and epistemological understanding" in order to explain scientific phenomena (Liew & Treagust, 1998**)**.

Summary

Overall, this chapter reviewed the importance of studying high school chemistry students' perceptions of and performance in predict-observe-explain (POE) tasks within a laboratory-based learning environment. Also, it described the theory and measurement of how the GALT delineates concrete and formal-reasoning students and their construction of knowledge in science classrooms. The classroom environment in science laboratories (i.e., SLEI) was demonstrated as an important determinant of student learning, which can interact with and predict the achievement and attitudes of students. Also, studies were reviewed that explored the different learning needs of boys and girls with respect to different learning environments. POE instructional strategy was demonstrated to be a very powerful technique, especially for use in the physical sciences and at high school and college levels.

CHAPTER III

METHODOLOGY

This chapter includes the discussion of the chosen research methodology and design, the selection process for participants, and the materials and instruments that were used in the experiment. Further data collection procedures, limitations and assumptions, and ethical assurances are presented. A summary of the research methodology concludes this chapter.

Research Design

This study employed Tashakkori and Teddlie's (2003) concurrent triangulation mixed methods design. In understanding the research problem, interpreting data, and answering questions, this method is useful for collecting and analyzing both quantitative and qualitative data (Creswell & Plano Clark, 2007). Quantitative and qualitative methods offset one another and invite in-depth analysis (Greene et al., 1989, Tashakkori & Teddlie, 1998). Denzin (1978) describes the method as "the combination of methodologies in the study of the same phenomenon" (p. 291). This study relied equally and simultaneously on quantitative and qualitative methods. Interpretation involved a comparison-contrast of quantitative statistical results and qualitative quotes that support or contradict the results from both data types. Visual model of mixed methods design is provided in Appendix D.

The strengths of quantitative methods (large sample size, trends, and generalizations) complement the strengths of qualitative methods (Greene et al., 1989;

Jick, 1979; Morse, 1991; Patton, 1990). This dissertation study used concurrent triangulation design to compare and contrast quantitative statistical results against qualitative findings. Moreover, this design permits validation or expansion of the quantitative results with the qualitative findings. Overall, the goal was to seek different types of data that complement one another, providing a fuller picture of the factors affecting the perceptions and performances of the students. Constructivist theory informed the approach used in this study (Guba & Lincoln, 1982).

Setting

The setting for this study was within a physical science course at a rural high school in the Midwest US. The target population was freshmen who were enrolled in the physical science course during the school year 2011-2012. At this high school about 40-45 students graduate each year. The dropout rate was less than 5%. The school is eligible for a federal reduced/free lunch program. The majority of students are Anglos, but with a sizable Hispanic population. The school science curriculum follows the sequence of physical science (freshman), biology (sophomore), chemistry (junior), and physics (senior). The high school had about 55% male and 45% female students. Nearly 80% of the graduates go to college for further education while 5% join the armed forces, and 15% enter the workforce. This physical science course is required for graduation. The course enrollment is about 50 students every year.

Participants

All students who were enrolled in second semester physical science classes and who returned their consent and assent forms participated in this study. Participant demographic information is presented in Table 1. This sample of 49 students was subdivided into two categories: (a) male and female students who were admitted in the course and (b) students' concrete or formal reasoning levels.

Table 1

Participant Information

Gender	Reasoning Level		
	Formal	Concrete	Total
Male	11	13	24
Female	11	14	25
Total	22	27	49

A "convenience sample" (Dillman, 2000) was selected for the quantitative method, and a "purposeful sample" strategy was used for the qualitative study. For the purposeful sample strategy, the goal was to select individuals in order to learn and understand the central phenomenon of this study (McMillan & Schumacher, 2006). The idea was to select students who were "information rich" and provide the information that can help answer the research questions (Patton, 1990, p. 169).

Twenty-four students, six participants from each group, were asked to volunteer for semi-structured interviews. These six participants belong to each of the following groups: male formal, male concrete, female formal and female concrete students. This strategy allowed multiple perspectives of individuals in order to "represent the complexity of our world" (Creswell, 2002, p. 194). The participants had already experienced several science courses at the middle school level plus one semester of the two-semester physical science course at the high school level.

Theoretical Framework

The framework for this study is social constructivism, which focuses on "learning as a social process" (Ernest, 1999; Gredler, 1997; Prawat & Floden, 1994). Specifically, both the learning environment and learners' backgrounds influence what is learned (McMahon, 1997). This dissertation study focused on the students rather than the teacher. It is assumed that students can understand the science concepts in meaningful ways when they interact with each another and with their teacher. From this perspective, it is clear that learning and environment go together hand in hand and they cannot be isolated from each other (Bredo, 1994; Gredler, 1997).

Social constructivists believe that meaningful learning occurs through discussions, which in turn can help students exchange their views, develop reasoning and problem solving skills and transfer of knowledge (McRobbie & Tobin, 1997; Prawat, 1993; Reznitskaya et al., 2007; Solmon, 1987).

Since the constructivists, who adhere to the theory of social constructivism, believe in the role of individual differences in cognition (Anderson, 1992; Bodner, 1986) and that knowledge is constructed by the individual learner, there is a need to identify how students learn science from their laboratory experiences. Hence, science educators are interested in the type of knowledge students construct in science classrooms, and how students construct this knowledge (Hofstein & Lunetta, 1982; Tobin, 1990). In this dissertation study, the POE instructional strategy was grounded in social constructivism.

Method

This study used a mixed-model methodological framework (Johnson, Onwuegbuzie, & Turner, 2007) in which data obtained from the quantitative analysis (i.e., descriptive statistics, MANOVA, and correlations) was subjected to an in-depth basis via qualitative means (i.e., interviews, surveys, and written explanations). The same independent variables (gender and reasoning ability) were used for all research questions. The GALT was used to measure pre-treatment reasoning ability. As with most measures of reasoning level, the GALT is a fairly stable parameter over relatively short time periods (i.e. several months) even for high school populations.

To acquire the desired information, this study utilized Science Laboratory Environment Inventory (SLEI), test of logical thinking (the GALT), semi-structured student interviews, and POE chemistry laboratory activities adapted from the book *POE: Activities Enhancing Scientific Understanding* by John Haysom and Micheal Bowen (2010).

Research Questions

Q1 What is the effect of gender, reasoning ability and their interactions on student perceptions and performances on Predict, Observe, Explain (POE) chemistry laboratory tasks?

Q2a For students who were interviewed, what were their perceptions of POE chemistry laboratory environment tasks?

Q2b Among the interviewed students were there any differences in perceptions of POE chemistry laboratory environment tasks across gender and reasoning level?

In the quantitative realm, the first research question, Q1, was studied via the use of MANOVA, chi-square analyses, and Pearson correlations among the variables. The first dependent variable was student performances on a set of POE chemistry laboratory tasks (no pre-treatment measure) as gauged by a scoring rubric designed by the researcher and used by the teacher. The second dependent variable was student perceptions on POE laboratory environment as gauged by SLEI. Also, the interaction effects between gender and reasoning ability with respect to the dependent variables were explored.

In the qualitative realm, the first part of the second research question, Q2a, was studied using the responses from a written POE perceptions questionnaire and transcripts from semi-structured interviews. The dependent variable was student perceptions of POE chemistry laboratory tasks. Also, to answer the second part of the second research question, Q2b, the researcher used quantitative data obtained from the students' scores on the SLEI and qualitative findings derived from the POE questionnaire and student interviews to interpret the results.

Instrumentation

The following established instruments were used in this study:

1. *Demographic form:* The participants were asked to provide their year in school, gender, major, previous science lecture and laboratory courses, and course expectations (Appendix E).

2. *Science Laboratory Environment Inventory (SLEI):* The SLEI was used to obtain students' perceptions of the existing chemistry laboratory environment. The response format of the SLEI is a 5-point frequency rating scale, consisting of *Very Often, Often, Sometimes, Seldom,* and *Almost Never*. The 35 items were arranged in cyclic order in groups each comprising 1 item from each of the 5 scales (Appendix F). Content validity showed the extent to which the survey items and the scores from these questions are representative of all the possible questions about students' perceptions of laboratory learning environment. Permission to use SLEI (Appendix K) was obtained from the author, Barry J. Fraser.

3. *Group Assessment of Logical Thinking (GALT):* This instrument was used to categorize students into formal and concrete reasoning levels (Appendix G). Previous research studies on the GALT have categorized the students' reasoning abilities: scores of 0 to 4 as concrete-operational, 5 to 7 as transitional, and 8 to 12 as formal-operational reasoners (Bird, 2010; Bitner, 1991). In this dissertation study, a frequency distribution of scores (Table 2) was used to determine the categories.

Table 2

Frequency Distribution of Group Assessment of Logical Thinking GALT Scores

	0 - 5	6 - 12
Females, formal (F, f)	---	11
Females, concrete (F, c)	17	
Males, formal (M, f)		10
Males, concrete (M, c)	11	---

Frequency distribution of GALT cutoff score is presented in Table 3. Due to the small number of students in the transitional category, students were re-categorized as concrete- (scores of 0 to 5) or formal- (6 to 12) operational reasoners.

Table 3

Frequency Distribution of Group Assessment of Logical Thinking GALT Cut-off Scores

	5	6	7
Female, formal (F, f)	---	0	3
Female, concrete (F, c)	0	---	---
Male, formal (M, f)	---	1	2
Male, concrete (M, c)	1	---	---

The GALT was chosen to measure formal reasoning because of the validity and reliability results obtained by Roadrangka et al. (1983) on a sample of students ranging from sixth grade through college. In addition, the GALT has one measure of concrete reasoning. Construct validity was established by determining convergent validity with Piagetian Interview Tasks (r = 0.80) and by using the principal components method of factor analysis.

4. *Predict-Observe-Explain (POE) perceptions questionnaire:* Students' perceptions of POE chemistry laboratory tasks were explored qualitatively using POE questionnaire (Appendix H) developed by the researcher and used by the physical science teacher. This questionnaire was tested for 'content validity' and agreed to, by the two science teachers whose combined experience is about 30 years.

5. *Predict-Observe-Explain (POE) semi-structured interview questions:* In order to acquire an in-depth understanding of students' perceptions of POE chemistry laboratory tasks and the environment, researcher and the participant teacher developed follow-up questions based on students' responses on POE questionnaire. Here are a few questions asked in the semi-structured interviews:

a. What is your most favorite science? Why?

b. What are your perceptions about chemistry?

c. What did you not like about these POE activities?

d. What did you like about these POE activities?

e. What do you think is the difficulty level of each stage (P, O,) which one is easy and which one is difficult?

Instructional Materials

POE Laboratory Tasks: The participant teacher used six POE laboratory tasks that have been previously used and evaluated in POE programs. Table 4 provides the title and a summary of description for each of the six POE laboratory tasks used by the participant teacher in this study. Permission was obtained to use POE tasks from the publisher (Appendix I) and the author (Appendix J). All participants had multiple opportunities to experience the POE laboratory-instructional strategy during the regular class time.

The scoring rubric for POE laboratory tasks is given in Table 5. In this study, inter-rater reliability was checked with a graduate student and two experienced science teachers. Multiple checks of inter-rater reliability were also done to make sure that all the coders address the confirmation criterion of trustworthiness.

Johnstone (2009) identifies that deep conceptual and scientific understanding in chemistry requires the use of connections between three levels of chemical representation: symbolic, macroscopic, and submicroscopic (particulate). These three levels were incorporated into the scoring rubric used for the POE laboratory tasks. Examples of macroscopic representations include gasoline, food, plastics, drinks, and their chemical interactions. Symbolic representations include chemical formulae, equations, and mathematical relationships. Sub-microscopic understanding could be represented through sketches of atoms, molecules, and ions (i.e., “o” and “•” for different atoms and elements; Suits, 2000).

Table 4

Summary of Six Predict-Observe-Explain Laboratory Tasks

Lab #	Title	Description
1	Can things really disappear?	Do you think mass will change when aluminum foil and copper chloride solution react? Is apparent change of mass evidence of chemical change?
2	Chemical changes	The goal is to identify chemical changes using observations in the experiments such as baking soda plus water; heating a piece of steel wool, etc.
3	Dissolving sugar cube	Using a double pan balance, predict what would happen to the balance if the sugar on one side is dissolved in water.
4	Don’t confuse mass and volume	Two metal objects, brass and aluminum of same size and shape are placed in water in two graduated cylinders respectively. Predict what will happen to the level of water?
5	Dissolving: Is there a volume change? (Solutions)	Will the volume of sugar plus the volume of water be equal to volume of sugar solution?
6	Can you tell the difference	Predict what will happen to the temperature when doubling the heat and doubling the volume of water.

Table 5

Scoring Rubric for the Predict-Observe-Explain Laboratory Tasks

Score	Response	Description
0	No or incorrect response	left blank, "I don't know," or incorrect
1	Prediction matched their OBS*	Incorrect explanation
2	Explanation matched their OBS	OBS & any explanation but not predicted
3	Prediction matched explanation & OBS	Macroscopic explanation
		Submicroscopic explanation
		Symbolic explanation

* OBS = Observation(s)

Experimental Procedures

The researcher utilized a concurrent triangulation mixed-methods design (Creswell, 2002; Creswell & Plano Clark, 2007). The three main considerations in mixed methods design are priority, implementation, and integration (Creswell, Plano Clark, Gutman, & Hanson, 2003). This study assigned equal *priority* to both quantitative and qualitative methods, while *implementing* concurrent data collection and analysis. During the results interpretation phase, the researcher *integrated* both the quantitative and qualitative data. In isolation, neither quantitative nor qualitative methods can fully explain trends in student perceptions of the POE learning environment of the chemistry laboratory.

The researcher recruited a physical science teacher, who agreed to use a set of established POE laboratory tasks (Haysom & Bowen, 2010). Students who enrolled in second semester of Physical Science course completed and returned Institutional Review Board (IRB) consent and assent forms (Appendices A, B, and C). All participants received a 6-digit random code in an effort to keep the data confidential. Then they completed demographics form, the GALT and the SLEI (original form). The "content validity" of these activities was confirmed by the teacher and a second science teacher. These two teachers had a total of 30 years of experience in teaching science.

After the completion of all the POE chemistry laboratory activities, the researcher invited 24 volunteers, 6 from each group, to participate in semi-structured interviews on an individual basis. Six of these students were selected from each of the following groups: male formal, male concrete, female formal and female concrete groups. Interview questions were based on queries about their perceptions of the POE tasks and the GALT and SLEI instruments. Participant teacher's perceptions were also included.

Data Collection Procedures

The visual model of data collection procedures for the concurrent triangulation mixed-methods design of this study are presented in Appendix D. Quantitative data collection included the following:

1. Student scores from the POE laboratory rubric
2. Student scores from SLEI
3. Student scores from GALT test

Qualitative: During the spring 2012 semester, the researcher collected qualitative data from the POE laboratory task questionnaire, classroom observations, and semi-structured interviews. To maintain anonymity, students were asked to create a pseudonym during interviews. The interview questions were based on student responses from the SLEI, POE perception questionnaire, and their laboratory task experiences. Interviews were recorded digitally for subsequent transcription. The interviews helped explore students' perceptions of POE chemistry laboratory tasks and how these perceptions affected their performance skills. Qualitative data were also collected by the researcher from classroom observations, journals, and his reflections on laboratory experiences.

The semi-structured interview protocol consisted of open-ended questions. The participants were informed that the interview would be digitally-recorded and transcribed verbatim. Respondents had an opportunity to review and, if necessary, correct the contents of the interview after the information was transcribed. The interview protocol was pilot-tested on three test participants selected from the same target population, but these students were excluded from the full study. Debriefing with the test participants was conducted to obtain information on the clarity of the interview questions and their relevance to the study aim.

Data Analysis--Mixed Methods

The researcher analyzed both quantitative and qualitative data using matrices, which were adjusted to accommodate both quantitative results and qualitative findings. Regarding quantitative data, it offered an overall perspective on the factors that affect student perceptions and performance in POE chemistry laboratory tasks. Meanwhile, analysis of qualitative data nuanced and explained the statistical results with an in-depth picture of student perceptions (Caracelli & Greene, 1993, Creswell & Plano Clark, 2007, Tashakkori & Teddlie, 1998).

Quantitative Data Analysis

Screening of the data was conducted on the univariate and multivariate levels (Tabachnick & Fidell, 2000). Data screening included the descriptive statistics for all the variables. Also, check for assumptions of multivariate statistics such as linearity, homoscedasticity, normality, multi-collinearity was performed (Tabachnick & Fidell, 2000).

Box’s M test was used to test if the covariance of dependent variables was equal across the independent variables (Härdle, 1990). Levene’s test was used to determine if the error variance of the dependent variables is equal across groups (Zimmerman, 2004). Chi-square test was used to determine the relationship between the two independent variables while the Pearson correlation analysis was used to see if the dependent variables were correlated. Data screening helped identify potential multi-collinearity in the data because multivariate tests are sensitive to extremely high correlations among predictor variables. All statistical analysis of the quantitative results was conducted using SPSS software (IBM SPSS Statistics, Version 21).

The data obtained in this study were analyzed quantitatively using MANOVA statistics to determine whether the mean scores on the dependent variables of the groups differ statistically with respect to gender and reasoning ability and to find any interactions between them. The scores from the writing tasks of POE laboratory tasks were analyzed using MANOVA and were used to assess the performance of students across gender and reasoning ability. The scores from SLEI were analyzed using MANOVA and were used to assess students’ perceptions of POE chemistry laboratory learning environment.

Correlation statistics were used to determine any correlation between the students' perceptions and performance across gender and reasoning abilities.

Qualitative Data Analysis

In the qualitative analysis, data collection and analysis should always proceed simultaneously (Merriam, 1998). The steps in qualitative analysis (Creswell, 2002) include the following: (a) preliminary exploration of the data by reading through transcripts, (b) coding the data by segmenting and labeling text, (c) using codes to develop themes by aggregating similar codes together, (d) connecting and interrelating themes, and (e) constructing a narrative. The text and image data obtained through the interviews, and surveys were coded and analyzed for themes in a similar manner.

Qualitative data were analyzed using the constant-comparative method (Strauss & Corbin, 1998) to discover themes within interview and transcript data. The data were analyzed through the constant comparative method using responses of the POE tasks perceptions questionnaire, transcriptions of semi-structured interviews, and the primary researcher's notes and journals. The analytical process was based on immersion in the data and repeated sortings, codings, and comparisons that characterized the grounded theory approach (Morrow & Smith, 2000). The survey responses explored the students' perceptions of POE tasks as to how their experiences influenced their perceptions of the laboratory environment.

Interview transcripts were interpreted using discourse analysis within a narrative perspective (Mishler, 1986). The data were constantly compared to each other to observe commonalities; coding and re-coding of data was done until common themes were identified. Theory was developed from the data rather than attempting to validate or refute a specific hypothesis. Semi-structured student interviews were transcribed and read carefully by the primary researcher to find common themes. Next, categories for the responses were developed, and each comment within the responses was assigned to one or several categories. The comments from different participants were then compared based on their assigned categories to look for common trends in the participants' responses.

Analysis began with *open coding*, which was the examination of sections of text consisting of individual words, phrases, and sentences. Strauss and Corbin (1990) described open coding as that which "fractures the data and allows one to identify some categories, their properties and dimensional locations" (Strauss & Corbin, 1990, p. 97). The language of participants in the interview and the survey responses guided the development of categories.

Open coding was followed by *axial coding*, which puts data back together in new ways by making connections between a category and its subcategories (Strauss & Corbin, 1990, p. 97). Finally, *selective coding* was used as an integrative process of selecting the core category, systematically relating it to other categories, validating those relationships, filling in categories that needed further refinement and development (Strauss & Corbin, 1990, p. 97). Categories were sorted and compared until saturation. Later all the data were accounted for in categories of the grounded theory paradigm model (Morrow & Smith, 2000). This process of taking information from data collection and comparing it to emerging categories is called the *constant comparative* method of data analysis. The substantive theory results from the process of data collection and analysis (Morrow & Smith, 2000).

The data sources allowed the identification of a number of themes from the categories, which, in turn, revealed aspects of students' perceptions of POE tasks and the laboratory learning environment. All the data were read carefully and notes were taken about the factors involved in different participant's experiences. A coding matrix was developed to rank themes in terms of prevalence. The interview transcripts were also coded and studied for added richness.

Limitations

Qualitative research has its limitations for advancing generalizations from the findings (Stake, 1995). Furthermore, quantitative research is limited because it does not provide deep understandings of particular settings or participants. Mixed methods, although used to reduce the limitations of one single approach, also includes the limitations of each of those approaches but to a lesser degree (Creswell, 2003). A potential limitation of the study is the reliability and validity of the instruments adapted or developed by the researcher for use in this study. Since the instruments were used with only approximately fifty students, reliability cannot be established until further samples are analyzed. This is because multiple data sets need to be collected to determine if the results repeat from one class to the next. Also, the researcher was the chemistry teacher at the same high school and this could have influenced students' perceptions or performance. This potential bias may be overcome by using fair policies such as informing the students that participation does not affect course grades, maintaining confidentiality of the data, and providing students equal treatment in the class irrespective of whether or not they participate in the study.

Since the convenience sampling was used in the quantitative phase of the study, the researcher cannot say with confidence that the sample was the representative of the population (Creswell, 2002). In the quantitative phase of the study, there was a potential risk of a non-response error, i.e. in the event of a low response rate, discrepancies between those who responded and those who did not (Dillman, 2000). These limitations have the potential to limit the generalizability of the study. Thus, the use of quantitative measures and methods will help ensure that any potential generalizations are statistically supported.

Establishing Credibility

Participants were provided equal treatment and were well informed of the intentions of this study. Ethical guidelines were followed in this study by providing equal treatment for each participant and making intentions and procedures of the study clear to all of them. To validate the findings and whether it matched reality (Merriam, 1998), four primary forms were used in the qualitative part of this study: (a) triangulation--converged different sources of information (interviews, documents, and artifacts); (b) member checking--received feedback from the participants on the accuracy of the identified categories and themes; (c) providing rich descriptions to convey the findings; and (d) completing external auditing by a person outside the project by conducting a thorough review of the study and submitting a report (Creswell, 2003; Creswell & Miller, 2002).

The “validity and reliability” of the qualitative aspects of this study were obtained through the use of the following characteristics: trustworthiness, authenticity, and the benefits of the hermeneutic process (Guba & Lincoln, 1989). The findings were interpreted through the lens of social constructivism.

Summary

In this chapter, the methodology to be used in this study was described. The proposed research questions require that a mixed methods approach be used, where both quantitative and qualitative approaches provide complementary information. The first research question, Q1, used a quantitative design to study the main and interaction effects of the independent variables (i.e., gender and reasoning ability) upon the dependent variables (i.e., performance and perceptions within a POE laboratory learning environment). The two parts of the second research question, Q2a and Q2b, allowed in-depth qualitative analysis of interviews to see how different students perceive the POE laboratory learning environment.

CHAPTER IV

RESULTS

This chapter includes the results and findings obtained from the analyses of quantitative and qualitative data respectively. Quantitative results obtained from correlational analyses, descriptive, univariate and multivariate statistics were presented. Qualitative findings derived from different themes and codes were provided. Overall, qualitative findings supported the quantitative results and the triangulation of these two methods in the interpretation phase of this study provided an in-depth understanding of the research questions. A summary of quantitative results and qualitative findings along with the assumptions of multivariate statistics concludes this chapter.

Descriptive Statistics:

Descriptive data for the first dependent variable, students' performance in the POE laboratory tasks across gender and reasoning level, is provided in Table 6. This was measured from the scores on six POE laboratory tasks. For the second dependent variable, students' perceptions of POE laboratory learning environment across gender and reasoning level, descriptive data is provided in Table 7. Students' perceptions were measured using Science Laboratory Environment Inventor (SLEI).

Table 6

Descriptive Statistics for the Dependent Variable: Performance

Performance	Gender	Level	N	Mean	Standard Deviation
Predict	Female	Concrete	14	1.99	0.41
		Formal	11	2.46	0.30
	Male	Concrete	13	1.40	0.30
		Formal	11	1.85	0.55
Observe	Female	Concrete	14	2.01	0.45
		Formal	11	2.50	0.30
	Male	Concrete	13	1.34	0.40
		Formal	11	1.92	0.56
Explain	Female	Concrete	14	1.70	0.46
		Formal	11	2.73	0.27
	Male	Concrete	13	0.78	0.45
		Formal	11	1.73	0.59
Overall Performance	Female	Concrete	14	1.90	0.44
		Formal	11	2.47	0.30
	Male	Concrete	13	1.40	0.30
		Formal	11	1.84	0.55

Table 7

Descriptive Statistics for the Dependent Variable: Perceptions

	Gender	Level	N	Mean	Standard Deviation
Perceptions	Female	Concrete	14	3.54	0.40
		Formal	11	3.86	0.18
	Male	Concrete	13	3.38	0.30
		Formal	11	3.50	0.36

Multivariate Assumptions

Prior to conducting multivariate analysis (MANOVA), the assumptions of normality, homogeneity of variance, and error variance across the variables were tested and observed to be satisfied. Box's test and Levene's tests were conducted to check for the above assumptions. Box's test was used to test the null hypothesis that the observed covariance matrices of the dependent variables are equal across independent variables. From Table 8, the value of Box's M test = 40.25, $F(30, 5092) = 1.11$, was not significant ($p > 0.05$), hence, observed covariance matrices of the dependent variables (predict, observe, explain, and perceptions) were equal across independent variables (gender and level).

Table 8

Box's Text of Equality of Covariance Matrices

Box's M	*F*	*df*1	*df*2	Significance*
40.25	1.11	30	5092	0.32

* $p < 0.05$

Levene's test was to verify the null hypothesis that the error variance of the dependent variable is equal across groups. From Table 9, a non-significant *p*-value ($p > 0.05$) for the dependent variables in the Levene's test revealed that the the error variance of the dependent variable does not have significant departures from equality across groups. Assumptions of 'distribution of dependent variables is normal' and 'Error variance-covariance is homogenous' were considered satisfied. These are important assumptions that need to be addressed in multivariate analyses (Tabachnick & Fidell, 2001, p. 81).

Table 9

Levene's Test of Equality of Error Variance

	F	*df*1	*df*2	Significance*
Predict	2.67	3	45	0.060
Observe	1.09	3	45	0.359
Explain	1.17	3	45	0.332
Perceptions	1.60	3	45	0.202

* $p < 0.05$

Correlation of dependent variables must be considered with care because when dependent variables are highly correlated, there is not enough variance left over after the first dependent variable is fit and if the dependent variables are not correlated, the multivariate tests will lack power. Hence, Pearson correlations were performed between all of the dependent variables in order to test if there was an issue that the dependent variables show the correlation of 0.80 or higher. Moderate correlation (< 0.80) was observed between the two dependent variables. Presence of more than one dependent variable and moderate correlation between the two dependent variables were a few reasons for using MANOVA instead of separate ANOVA's. MANOVA takes this correlation into account which in turn, increases the power of the test. Meaningful patterns of correlation among the dependent variables that were observed are presented in Table 10.

Chi-square test of independence (IV relationship) was performed to evaluate the relationship between independent variables for any group differences. From Table 11, it can be noted that the probability of the test statistic was greater than the probability of the alpha error rate; consequently, it can be concluded that the two variables (gender and level) were not significantly dependent.

Table 10

Pearson Correlation

		Predict	Observe	Explain	Perceptions
Predict	Pearson Correlation	1	0.952**	0.874**	0.376**
	Significance (2-tailed)		0.000	0.000	0.008
Observe	Pearson Correlation	0.952**	1	0.894**	0.307**
	Significance (2-tailed)	0.000		0.000	0.032
Explain	Pearson Correlation	0.874**	0.894**	1	0.487**
	Significance (2-tailed)	0.000	0.000		0.000
Perceptions	Pearson Correlation	0.376	0.307**	0.487**	1
	Significance (2-tailed)	0.008	0.032	0.000	1

** correlation is significant at the 0.05 level

Table 11

Chi-square Test of Independence

	Value	*df*	Asymp Significance (2-sided)	Exact Significance (2-sided)
Pearson Chi-square	0.017[a]	1	0.897	
Fisher's Exact Text				1.00
N of Valid Cases	49			

[a] = 4 cells have expected count more than 5

Multivariate Statistics

In order to determine the effect of gender and reasoning ability and their interactions on the combined dependent variables (perceptions and performance), a two-way multivariate analysis of variance (MANOVA) was conducted using an alpha level of 0.05. This will test the hypothesis that there would be no significant mean differences between the four dependent variables (predict, observe, explain, and perceptions) and two independent variables (gender and level).

Q1 What is the effect of gender, reasoning ability and their interactions on student perceptions and performances on Predict, Observe, Explain (POE) chemistry laboratory tasks?

Wilks' lambda (λ) was the most widely used test statistic in multivariate analysis of variance (MANOVA) to test whether there were differences between the means of independent variables on a combination of dependent variables (Everitt & Dunn, 1991; Polit, 1996). A two-way MANOVA indicated a non-significant interaction effect (Wilks' $\lambda = 0.948$, $F(4, 42.0) = 0.57$, $p > 0.05$). While a significant multivariate main effect for gender, Wilks' $\lambda = 0.448$, $F(4, 42.0) = 12.94$, $p < 0.05$ was observed. This significant *p*-value indicated that there were significant differences between male and female students on a linear combination of four dependent variables. The multivariate effect size (eta squared) was estimated at 0.550, which implied that 55.0% of the variance in the dependent variables was accounted for by gender. Also, a significant multivariate main effect for reasoning level, Wilks' $\lambda = .416$, $F(4, 42.0) = 14.76$, $p < 0.05$ was observed.

This significant *F* indicated that there were significant differences between formal and concrete reasoning level students on a linear combination of the four dependent variables. The multivariate effect size (eta squared) was estimated at 0.580, which implied that 58% of the variance in the dependent variables was accounted for by reasoning level. Wilks' lambda was a direct measure of the proportion of variance in the combination of dependent variables that is unaccounted for by the two independent variables. The results of the two-way MANOVA are presented in Table 12.

Table 12

Multivariate Analysis for Perceptions and Performance

Effect	Wilks Lambda	*F*	Significance*	Partial Eta squared	Power
Gender	0.448	12.94	0.000	0.55	1.00
Level	0.416	14.76	0.000	0.58	1.00
Gender* Level	0.948	0.57	0.686	0.05	0.175

* $p < 0.05$

Because MANOVA was significant, univariate ANOVA (tests of between-subjects effects) results were examined to determine how the dependent variables differ for the independent variable**.** Given the significance of the overall test, a series of one-way ANOVA's on each of the four dependent variables was conducted as follow-up tests to the MANOVA. The univariate ANOVA main effects were examined. These effects are given in Tables 13 through 16.

Significant univariate main effects of gender and type were obtained for all the four dependent variables (predict, observe, explain and feelings). As can be seen in Tables 15 through 18, all of the ANOVA's were statistically significant, with effect sizes (partial η^2) ranging from a low of 0.15 (perceptions) to a high of 0.536 (explain). For the dependent variables Predict, Observe, Explain and Perceptions, R-Square = 0.486, 0.487, 0.700, and 0.231 which means 48.6%, 48.7%, 70%, and 23.1% of the proportion of variability in all the four dependent variables that can be explained by the model.

Finally, as the assumption of homogeneity of variance-covariance was met, a series of post-hoc analyses (Fisher's LSD) and pairwise comparisons were performed to test the significance of the linearly independent pairwise comparisons among the estimated marginal means across gender and type and all four dependent variables (Tables 17 and 18).

The results revealed that all post-hoc mean comparisons were statistically significant ($p < 0.05$). Significant pairwise mean differences were obtained between male and female students. It can be observed that the largest effects tended to be associated with the verbal subscales with average Cohen's *d* values equal to 0.65 to 0.70, which is a larger effect according to Cohen's (1990) guidelines.

Table 13

Tests of Between-Subjects Effects for the Dependent Variable: Predict

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Significance	Partial Eta squared	Observed Power
Gender	4.442	1	4.442	27.375	0.000	0.378	0.999
Level	2.543	1	2.543	15.669	0.000	0.258	0.972
Gender * Level	0.002	1	0.002	0.012	0.913	0.000	0.051

* = interaction effect

Table 14

Tests of Between-Subjects Effects for the Dependent Variable: Observe

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Significance	Partial Eta squared	Observed Power
Gender	4.802	1	4.802	24.905	0.000	0.356	0.998
Level	3.448	1	2.543	17.882	0.000	0.284	0.985
Gender * Level	0.028	1	0.028	0.143	0.707	0.003	0.066

* = interaction effect

Table 15

Tests of Between-Subjects Effects for the Dependent Variable: Explain

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Significance	Partial Eta squared	Observed Power
Gender	11.169	1	11.169	51.956	0.000	0.536	1.000
Level	11.756	1	11.756	54.685	0.000	0.549	1.000
Gender * Level	0.019	1	0.019	0.089	0.766	0.002	0.060

* = interaction effect

Table 16

Tests of Between-Subjects Effects for the Dependent Variable: Perceptions

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Significance	Partial Eta squared	Observed Power
Gender	0.872	1	0.872	7.982	0.007	0.151	0.789
Level	0.550	1	0.550	5.030	0.030	0.101	0.593
Gender * Level	0.019	1	0.019	0.089	0.287	0.025	0.184

* = interaction effect

Table 17

Pairwise Comparison—Gender

Dependent	Gender		Mean Difference	Standard Error	Significance	95% Confidence Interval for Difference[a]
	I	J	(I-J)			Lower Bound
Predict	Female	Male	0.060*	0.116	0.000	0.372
	Male	Female	-0.606*	0.116	0.000	-0.839
Observe	Female	Male	0.63*	0.126	0.000	0.375
	Male	Female	-0.630*	0.126	0.000	-0.884
Explain	Female	Male	0.960*	0.133	0.000	0.692
	Male	Female	-0.960*	0.133	0.000	-2.228
Perceptions	Female	Male	0.268*	0.095	0.007	0.007
	Male	Female	-0.268*	0.095	0.007	-0.460

[a] = Adjustment for multiple comparison: Least Significant Difference (equivalent to no adjustments)

Table 18

Pairwise Comparison—Level

Dependent	Gender		Mean Difference	Standard Error	Significance	95% Confidence Interval for Difference[a]
	I	J	(I-J)			Lower Bound
Predict	Concrete	Formal	-0.458*	0.116	0.000	-0.691
	Formal	Concrete	0.458*	0.116	0.000	0.225
Observe	Concrete	Formal	-0.533*	0.126	0.000	-0.788
	Formal	Concrete	0.533*	0.126	0.000	0.279
Explain	Concrete	Formal	-0.985*	0.133	0.000	-1.253
	Formal	Concrete	0.985*	0.133	0.000	0.717
Perceptions	Concrete	Formal	-0.213*	0.095	0.007	-0.404
	Formal	Concrete	0.213*	0.095	0.007	0.022

[a] = Adjustment for multiple comparison: Least Significant Difference (equivalent to no adjustments)

Since all pairwise comparisons were statistically significant at all levels, females performed on average 0.606 in predict, 0.630 in observe, 0.960 in explain and 0.268 in perceptions better than their male counterparts. Females did better than males across all dependent variables. Also, formal students performed on average 0.458 in predict, 0.533 in observe, 0.985 in explain and 0.213 in perceptions better than their concrete counterparts. Formal students did better than concrete students across all dependent variables.

The main focus of the two parts of the second research question (Q2a/b) was to understand the nature of students' perceptions of POE chemistry laboratory tasks and the differences, if any, among the groups (gender and reasoning ability). The data collected from the POE tasks perceptions questionnaire (written responses) and semi-structured interviews (oral responses) were used to study these two parts of second research question (Q2a/b).

Q2a For students who were interviewed, what were their perceptions of Predict, Observe, Explain chemistry laboratory tasks?

Q2b Among the interviewed students, were there any differences in perceptions of Predict, Observe, Explain chemistry laboratory tasks across gender and reasoning level?

Four themes that were emerged from the qualitative data analysis are: a) learn and understand b) fun/think c) hands on d) hard and unable to understand. The first three themes focused on which aspects of the Chemistry POE laboratory tasks the students perceived as worthwhile while the fourth theme focused on students' perception as difficult. An in-depth discussion of these themes was provided in an effort to converge the findings. Each of these themes was described and illustrated with student quotes from the interviews.

Theme #1: Learn and Understand

Qualitative data revealed that most of the participants think the nature of the POE laboratory tasks (predict, observe, explain) provided opportunities to learn and understand the concepts. The following students' quotes were from different groups where *F* = Female; *f* = formal reasoning student; *M* = Male; student; *c* = concrete reasoning student.

F, f: "POE helped me **learn** more because I am doing it myself."

F, f: "I **understood** the experiment a lot more after I did the POE lab than the traditional because observing helps you like learn more."

F, f: "I **learned** from predictions. If your predictions are wrong you always learn from your mistakes."

F, f: "In POE environments, I **understood** a lot more."

F, f: "I think they are really easy to **understand** how to do."

F, f: "I am able to **understand** it better because I can see it happening."

M, f: "In POE, you make your own predictions; do the experiments so it helps you **learn** better. POE's are pretty good. I feel like I **learned** more than I did with traditional."

M, f: "Learning by doing I did **understand** more. The more I observed the more I **learned**."

M, f: "It is easier to **understand** and to do POE tasks."

F, c: "I **learned** more, lot more than just reading out of the book or by doing worksheet."

F, c: "I **learned** more instead of the traditional."

F, c: "I think they are really easy to **understand** and how to do."

F, c: "I think you **learn** more that way because you interact more in POE."

F, c: "In POE we would predict and write down what happened so we **learn**."

M, c: "I seem to like it because I never liked science but after doing these I started to **learn** better now."

M, c: "Through POE, I **learned** more about stuff you are learning in class."

Theme #2: Fun/think

Some participants believed that their positive perceptions of POE laboratory tasks are because they felt that these tasks are fun and provided opportunities for them to think.

F, f: "I think POEs (are) much **fun**. Because you have to be interactive, challenge yourself and you have to **think**. They are a lot more **fun** than traditional."

F, f: "POE was more fun than traditional activities because they weren't as long."

F, f: "In POE you have to **think** more about the experiment."

F, f: "Most of them pretty **fun**. Doing these POEs kind of made feel like I kind of wanted to be scientist now because it is **fun** doing this stuff. It's more **fun** than doing worksheets."

M, f: "They are **fun** and we make things happen that you would never see if you didn't perform the POE lab activities"

M, f: "I like POE activities may be because they are easier and **fun.**"

M, f: "They are **fun** to do. Actually are quite **fun**. They were really short. You don't have to write long lab reports. I think it was easier. It is **fun**. I like to see this again."

M, f: “It is **fun** to see what they do and it’s interesting when things like you know fizz and bubble.”

M, f: “More **fun**, I guess and encourage you to **think**.”

M, f: “POE is **fun** and interesting because it showed us how to do experiments in science and how to use chemicals.”

M, f: “I Prefer POE because you have to **think** more. It wasn’t harder to do but it made you **think** more and tested your knowledge.”

F, c: “POE activities, that was **fun** and I enjoyed doing those.”

F, c: “It’s just really **fun**.”

F, c: “They were really **fun**.”

F, c: “most of them pretty **fun**.”

F, c: “I think POEs much **fun.** Because you have to be interactive, challenge yourself and you have to **think**. Better environment in POE because everybody else will be having **fun** and in traditional one it will be probably quiet and not as fun.”

M, c: “POE’s are lot **fun**. You guess first and see if your prediction is right.”

M, c: “POE was more **fun** than traditional activities because they weren’t as long.”

M, c: “I like POE more, it’s **fun** than traditional I think.”

Theme #3: Hands On

Positive perceptions of POE chemistry laboratory tasks for some of the participants were also attributed to their hands-on experiences.

F, f: “I like those because they are more **hands on**.”

F, f: "I think it helped us think more about what we do (**hands on**) and why things happen."

M, f: "I Learned more by being able to experience first-hand [**hands on]** rather read someone else's experiences and/or observations."

M, f: "In POE you get to observe and it is just more **hands on** stuff."

M, f: "In traditional I almost didn't connect in to science classes easy but you know with these POE's I can connect to science classes real easy because they are **hands on**."

F, c: "In POE you get to do more **hands on.**"

F, c: "POE is a lot of **hands on** and you get to observe it more."

F, c: "I like POE activities because they are **hands on**."

F, c: "I like about POE that you have to be involved **[hands on]**."

M, c: "You get to do bunch of experiments and **hands on**."

Theme #4: Hard and Unable to Understand

A few participants believed that they had negative perceptions of chemistry which in turn led to negative feelings about POE activities. These perceptions were developed because physical science is hard, difficult to understand and that the participants require more teachers' help.

M, f; "The only negative perception of chemistry is that it is **hard** to remember equations."

F, c: "It will ask you questions like how did you observe it? I thought explaining was pretty **hard** because I have trouble putting things into words."

F, c: "It's **hard** so, need more teacher help."

F, c: "I don't like it because it's **hard**."

M, c: "because math part is **hard** and math sucks."

M, c: "It is duplicate work and some of it we **don't understand**. I didn't like explaining because I **didn't fully understand** things."

M, c: "It was just **hard** to understand the concepts of some stuff."

M, c: "I **don't understand** it {POE tasks}."

Overall findings revealed that female students perceived POE tasks worthwhile because the tasks helped them learn, think, and understand. This is evidenced by a clear majority of positive comments accompanied by appropriate reasoning to support their experiences. On the other hand, though male students perceived POE tasks positively, their responses lack appropriate reasoning.

Summary

The quantitative results of this multivariate analysis of variance were presented as follows: A two-way multivariate and between-groups univariate analyses of variance were performed respectively to investigate two independent variables (gender and reasoning ability) differences in four dependent variables (predict, observe, explain, and perceptions). Statistically significant differences were observed between male and female students, Wilks' $\lambda = .448$, $F(4, 42.0) = 12.94$, $p < 0.05$ and between formal and concrete reasoning students, Wilks' $\lambda = .416$, $F(4, 42.0) = 14.76$, $p < 0.05$ on combined dependent variables.

Preliminary assumption testing was conducted to check for homogeneity of variance-covariance matrices, normality, linearity, independence, univariate and multivariate outliers, and multi-collinearity with no major violations noted. Follow-up univariate ANOVA’s and post-hoc tests (pairwise comparisons) supported multivariate results. Inspection of mean scores indicated that females reported higher perceptions and performance than males and formal students reported higher perceptions and performance than concrete students.

CHAPTER V

CONCLUSIONS

This dissertation study focused on the predict-observe-explain (POE) chemistry laboratory inquiry activities in order to explore students' perceptions of and performances on the POE laboratory tasks. Students of both genders and different reasoning abilities were included. The results revealed significant differences in perceptions and performance between male and female students and between formal and concrete reasoning students. These results provided a more nuanced picture than previous research centered on gender alone. Quantitative results showed that females outperformed males, while students with formal reasoning skills outperformed those with concrete reasoning skills. The qualitative results revealed positive perceptions of POE activities by females, which supported the quantitative results. These females spoke positively of POE laboratory tasks. Likewise, students with formal reasoning skills, irrespective of gender, shared positive perceptions of POE laboratory tasks. Finally, students varied in their ability to articulate their perceptions relative to POE, a variance that was dependent upon gender and reasoning ability.

Q1: Effects of Gender and Reasoning Ability on Predict-Observe-Explain Performance and Perceptions

Gender and the Predict-Observe-Explain Strategies

The results of this dissertation study showed significant differences for perceptions and performance in POE across gender. A two-way MANOVA, used to measure the effect of gender and reasoning level on performance and perceptions, indicated that females scored higher in SLEI that measured their perceptions and also females scored higher in POE chemistry laboratory tasks that measured their performance. No interaction effect between gender and reasoning ability was observed.

Gender and perceptions of Predict-Observe-Explain tasks: Previous research, conducted in various countries, focused on gender-specific student perceptions of the chemistry laboratory. These findings further support previous related research (Fraser et al., 1992; Henderson, Fisher & Fraser, 1995; Lawrenz 1987; Rickards & Fisher, 1997, Wong et al., 1997) in science laboratory learning environments. Girls perceived their learning environment more favorably than boys and such differences were statistically significant (Quek, Wong, & Fraser, 2005).

In Australia, Fraser et al. (1993) found that students' perceptions contributed greatly to variances in performance. Also, perceptions affected performance even more than ability. The findings of this dissertation study provided more nuanced data by going beyond the male-female dichotomy to consider reasoning abilities as influential upon perceptions and performance by both genders. While finding clear differences in perceptions and performance by males and females, this study further categorized each gender by reasoning ability. These findings indicated that the females possessed more positive perceptions of the POE laboratory tasks, which may have contributed to their increased learning from POE tasks as compared to that of boys.

Gender and performance on Predict-Observe-Explain tasks: This study showed that females gained new knowledge through their experiences with POE tasks, and to a greater extent than did the boys. This bodes well as a means of encouraging female persistence in subsequent science classes while encouraging them to pursue STEM careers. Another study (Burkam, Lee, & Smerdon, 1997) found that eighth-grade physical science laboratory work enhanced female students' science achievement, while failing to impact the male students' achievement. These findings suggested that constructivist classrooms, such as POE environments, permit student cooperation in discussing their personal interpretations of scientific phenomena (McRobbie & Tobin, 1997; Parker, 1992; Warner & Wallace, 1994). These factors, in turn, can establish a cooperative learning environment in which females typically do well.

Furthermore, peer interactions and cooperation during science activities can promote conceptual understanding and conceptual change (Searle & Gunstone, 1990; Tao & Gunstone, 1999; Zacharia, 2005) which are rarely found in traditional chemistry classroom environments. Students in this study and others (Kearney, 2004) clearly benefitted cognitively from the meaningful discussions prompted by POE tasks. These discussions include justification of their predictions, reflection on their individual and group ideas, and co-construction of their ideas. Tsai (2001b) has suggested that the use of POE instructional activities is useful for enhancing students' information processing levels. In this study, female students praised the POE activities, which helped them understand the concepts of chemistry. The cooperative nature of the POE tasks was observed in school science laboratories (Hofstein & Lunetta, 2004). Moreover, when POE tasks are featured in a more structured scientific investigation, females can understand science concepts (Suits & Lagowski, 1994) and excel within a POE laboratory environment (Kerr & Svebak, 1989).

Reasoning Ability and the Predict-Observe-Explain Strategies

In this study, significant differences for the perceptions and performance on POE tasks across reasoning levels of concrete- and formal-reasoning students were observed. As expected, a two-way MANOVA indicated that students who possess formal-reasoning skills scored higher than students who possess concrete-reasoning skills. This difference was observed for all of the dependent variables (POE perceptions and performances). No interaction effect between reasoning level and gender was observed.

Reasoning ability and perceptions of Predict-Observe-Explain tasks: The findings of this study revealed that formal-reasoning students have more positive perceptions than concrete-reasoning students regardless of gender. In the past, a very few studies have focused on the effect of reasoning abilities on students' perceptions of POE, in particular. Currently, no research has focused on the students' perceptions of POE tasks in a science laboratory environment across reasoning levels. Considering perceptions in general, Dunn and Dunn (1979) argued that students' perceptions influence their learning. They also recommended ways to incorporate reasoning skills with learning styles and teaching styles. Clearly, students' reasoning abilities must be considered for science teaching to be effective.

Reasoning ability and performance on Predict-Observe-Explain tasks: The results of this study revealed that formal thinkers outperformed concrete thinkers on POE laboratory tasks. Previous studies have found that formal-operational reasoning can predict achievement in science and mathematics courses (Bitner, 1986; Hofstein & Mandler, 1985; Howe & Durr, 1982; Lawson, 1983; Lawson et al., 1984). Thus, one goal of science instructors should be to factor in the needs of both formal and concrete thinkers, especially when they are attempting to close the gender gap in science achievement. To help both females and concrete thinkers of both genders, Suits and Lagowski (1994) called for a more explicitly structured learning environment in which help is given as prerequisite knowledge, cues to focus attention, and immediate feedback.

Q2a/b: Qualitative Findings of Perceptions of Predict-Observe-Explain Tasks Across Gender and Reasoning Ability

Qualitative Themes in the Predict-Observe-Explain Perceptions of Students

To search for themes regarding student perceptions of chemistry POE laboratory tasks, the following qualitative research methods were used: oral semi-structured student interviews and a written student questionnaire. Four trends emerged as themes that cross lines of gender and reasoning abilities. The first three themes are positive perceptions while the fourth is negative.

Theme #1: Learn and understand. Students' positive feedback on learning through POE tasks aligns with science education research. One female formal thinker reported understanding an experiment "a lot more after I did the POE lab." This is "because *observing* helped me learn more." Another female formal thinker expressed that she was "able to understand it better because I can see it happening." Likewise, Millar (2004) stated that "doing" and "observing" experiments teach much more than mere “representation[s] of these processes.” Making predictions was significant for a female formal thinker who reported learning even from “mistakes” (incorrect predictions). Millar (2004) noted that POE gives students room to “endorse one prediction and refute another.” A male formal thinker found that “the more I *observed*, the more I learned.” The relationship between the student’s “actions and observations” (Bucat, 1983) clearly led to learning. Another male formal thinker was “encouraged to think” by the POE tasks, which has been described as a benefit of “inquiry-type laboratories” (Hofstein et al., 2005; Krajcik, Mamlok, & Hug, 2001). A female concrete thinker reported gaining a better understanding than she had ever gained from “doing worksheets”.

Theme #2: Fun/think. Student comments on POE’s being fun span across gender and reasoning categories. Formal thinkers--male and female--offered deeper insight than did concrete thinkers, but most of the perceptions are positive. A female formal thinker found it more “fun” to “think and be interactive” than to do “traditional” classwork. This student was echoing the findings of several studies (Searle & Gunstone, 1990; Tao & Gunstone, 1999; Zacharia, 2005), who all cited “peer interactions and cooperation”, as strengths of POE. Another female formal thinker shared positive perceptions that demonstrate Grunert and Bodner’s (2011) assessment on motivation as key to females’ success in chemistry: “Doing these POEs kind of made [me] . . . want to be a scientist now because it is fun doing this stuff. It’s more fun than worksheets.” Two male formal thinkers used “fun” and “interesting” to describe POE tasks. “You don’t have to write long lab reports,” stated one. “It’s interesting when things, like, fizz and bubble,” noted the other male formal thinker. White and Gunstone (1992) described such fun and meaningful experiences as the heart of POE, which "provide[s] aids for students to move towards more accurate science conceptions."

A female concrete thinker simply "enjoyed" POE tasks while a male concrete thinker expressed that POE tasks are "a lot of fun" and was more specific: "You guess first and see if your prediction is right or wrong." White (1998) noted the power of predictions and she called them "the foundation of future learning." In another previous study, the students who experienced guided inquiry laboratory exhibited more scientific investigation skills, which were similar to POE skills, as compared to students who participated in verification-based laboratory (Suits, 2004).

Theme #3: Hands on. All interviewed students responded that doing science was engaging and worthwhile – hands-on. A female formal thinker preferred POE activities due to their hands-on nature while another female formal thinker reflected that POE "helped us think more about what we do and why things happen." POE, in fact, does help students "develop problem-solving skills" (Woolnough, 1991) and allows them "to test their predictions, reflect on their ideas, learn, and understand from meaningful discussions" (Kearney, 2004). A male formal thinker lauded the first-hand experience he gained, which advanced his learning more than would from reading "someone else's experiences and/or observations." Similarly, another male formal thinker commented that "I almost didn't connect in [traditional] science classes," but he found a strong connection during his POE experiences. These students' comments validate that "the discovery method stimulates interaction" (Adelson, 2004; Aladejana, 2006; Mayer, 2003). Female and male concrete thinkers credited POE as real-life and hands-on: "I like that [we] have to be involved. You have to come up with your own hypothesis; the conclusion is what makes you think. I like to challenge myself to think and, if I am wrong, I can fix it." Hofstein and colleagues (2005) spoke of the performance outcomes of students "who initiated their own queries" and found that they outperformed a control group. Clearly, the hands-on nature of POE leads to student learning in this study.

Theme #4: Hard and unable to understand. Not all students praised POE activities as shown by some of the negative perceptions that were shared by concrete thinkers of both genders. Only one formal thinker, a male, found that "physical science is just boring." Female concrete thinkers described POE tasks as "pretty hard" and requiring them to "need more teacher help." One female concrete thinker noted she has "trouble putting things into words." Hueftle et al. (1983) and Hofstein and Welch (1984) have documented students' perception of science as being difficult. POE tasks require creative and critical thinking processes (Lawson, 1980; Lawson et al, 1989) which can obviously challenge concrete thinkers. Several male concrete thinkers cited the following reasons for their negative perceptions: "all mathematics," "I didn't like explaining things," and "it was just hard to understand the concept[s]." Piaget assumed that all high school students have acquired formal reasoning skills; however, he eventually realized that not all of those under age 16 have reached the abstract thinking stage (Piaget, 1964). The concrete thinkers' reasoning abilities can inhibit them from mastery of "abstract scientific concepts" (Inhelder & Piaget, 1958).

Summary of Themes Found for Predict-Observe-Explain Perceptions Across the Four Categories:

Findings revealed that female students perceived POE tasks worthwhile because the tasks helped them learn and understand. This is evidenced by a clear majority of positive comments accompanied by appropriate reasoning. Most female students' positive perceptions surpassed those of male students' perceptions in both depth and level of analysis. Notably, the female students articulated and verbalized their experiences. They evaluated the degree of difficulty of POE tasks, citing the benefits of observation, hands-on performance of lab duties (versus teacher demos), making predictions, and forming explanations. Overall, a larger number of female students expressed positive perceptions of POE than did male students. A few female students expressed their negative perceptions as POE as hard and necessitating the teacher's help.

Although most male students perceived POE tasks positively, their responses lacked the articulation and verbal elaboration of their experiences compared to female students. In sharing their positive perceptions, male students often reported that they found POE tasks to be enjoyable and helpful for learning. These students offered no critical evaluation of POE, nor did they comment on specific POE tasks as being either positive or negative experiences. However, a few male students reported that POE tasks overall were "difficult, boring, and hard to understand."

Overall, formal-thinking students perceived POE tasks more positively than did their concrete-thinking classmates. Concrete thinkers shared perceptions that ranged from negative to indifferent. These students described POE tasks as "hard;" in particular, they dismissed explain and predict steps as too "difficult." Perhaps, due to their lack of understanding, concrete thinkers reported their need for frequent instructor assistance. While remaining somewhat indifferent in their POE perceptions, these concrete thinkers appeared to be slowly accepting POE laboratory tasks as being valuable learning experiences because they stated the desire to “challenge myself” now that the chemistry environment was “more fun” and they could “learn more.”

Meanwhile, the formal thinkers were obviously more positive. More importantly, the formal thinkers could report more in-depth perceptions of POE and relate their own learning to POE tasks. First, formal thinkers compared past science class experiences to their POE experiences. Formal thinkers reported that POE “encourages us to think and understand better than traditional chemistry experiments done using laboratory manual and worksheets.” They could name the steps and their perceptions of those steps: “learned more from predictions, observations, and explanations.” Also, formal thinkers detailed their positive perceptions based, ironically, on the concrete nature of POE: “more hands on,” “experience firsthand,” “think more about what we do and why things happen.” Formal thinkers found easy “connections to real life experiences” and reported feeling “like a scientist.” The specific nature of formal thinkers’ positive perceptions suggests that POE is well-suited for formal thinkers.

Teachers’ Experiences with Predict-Observe-Explain Laboratory Tasks

Two Teachers volunteered and provided feedback on open ended questions that sought their personal experiences of POE laboratory tasks. Teacher 1 was a participant in this study while Teacher 2 was a colleague who was inspired and used POE tasks with his students in laboratory. Here are the experiences in their own words:

1) What difference did the POE instructional strategy make in your classroom environment in general (compared to traditional lab environment)?

Teacher 1:

Using POE labs helped my students to think for themselves. They had to draw on previous experiences and knowledge to make predictions. I feel this helped them to use critical thinking skills. Their predictions were not always right but they learned from each of the POE labs that they did.

Teacher 2:

The biggest difference was the degree to which my students were involved with POE labs. With our traditional labs my students tend to walk through the labs without much thought. POE labs require more student involvement with the lab.

2) What difference did the POE instructional strategy make in your students' perceptions of POE tasks and Performance in the POE lab tasks (compared to traditional lab performance and perceptions)?

Teacher 1:

I think my students as a whole enjoyed the POE lab experience more than the traditional lab for the most part. One reason they liked it better was because we spent more time in the lab covering several topics. The POE labs allowed more time to cover many details but I feel my students still gained valuable information and knowledge. In the past we would spend a minimal time in the lab and the lab activities were longer and more in depth. My students enjoyed more hands on activities!

Teacher 2:

My students enjoyed the POE labs. These labs can be done quickly and are good reinforcement for key concepts. The students felt the labs in the POE lab manual were planned for students of a younger age. When I use the POE techniques with our other labs, the students are less insulted. I need to rework the labs from the lab manual for my students, as these are really great labs.

3) What difference did the POE instructional strategy make in your perceptions and philosophy of 'how to teach and how students learn'?

Teacher 1:

The POE labs were very beneficial and I have continued to use them throughout the year. Throughout the 13 years that I have taught my teaching philosophy has changed from time to time. After doing POE labs I believe my students are more likely to remember the information taught.

My philosophy has changed in the fact that I have let go and let the students work harder than I do. I truly believe that if my students can do what is listed below they are more likely to understand and retain the information being taught.

- draw on prior knowledge
- make predictions
- do a hands on activity
- analyze the data
- understand why their predictions were right or wrong

Teacher 2:

The POE labs helped me realize that it is often better to simplify labs so that students can focus on specific concepts. Making student predict, observe, and explain really does involve students in lab work to a greater extent than having student follow a series of directions with little thought.

4) What difference did the POE instructional strategy make personal comments on striking differences between POE labs vs Traditional labs

Teacher 1:

I enjoyed using the POE labs in my classroom. The hands on activities kept my students engaged and interested. I have and will continue to use them in my class.

Teacher 2:

Working with POE labs and adapting my labs to POE techniques has help me think about how and why lab work is a critical part of a student’s scientific education. “Cook Book” labs too often allow student to walk through an experiment seeking the right answer but missing critical scientific discovery. If we can help students recognize the connections of scientific concepts, we have served those students far better. The POE approach is a tool that can help us better achieve this goal.

Q1 & Q2a/b: Mixed Methods: Overall Comparison of This Study’s Results with Those of Previous Studies

In the past, researchers agreed that it was males who outperformed females in mathematics and science (Hudson, 2012). Within the sciences, males showed more interest than females in physics and chemistry (Becker, 1989). Males excelled over females in chemistry grades (Felder, Felder, Mauney, Hamrin, & Dietz, 1995), interpreting scientific tasks and communicating results (Lock, 1992), and solving problems (Adigwe, 1992). Also, more males than females opted for STEM careers (Keeves, 1991; Kotte, 1992; National Science Board, 1998; Rosser, 1995).

Researchers did find that females excel in the life sciences and preferred these to physics and chemistry (Baker & Leary, 1995). Females did develop more perceptive capabilities than males in the science classroom environment (Fisher, Fraser, et al., 1997; Fisher, Rickards, et al., 1997; Fraser et al., 1995; Henderson et al., 2000). In the laboratory environment, females' perceptive capacities equaled but did not exceed that of males (Fraser et al., 1992; Rickards & Fisher 1997; Wong et al., 1997). However, this study revealed that the POE laboratory levels the playing field for females.

Quek et al. (2005) have previously documented that females display higher perceptive capacities than males in the POE laboratory environment. Consistent with this result, this study showed that the POE method can bring females on par with males. In particular, female formal thinkers recognized and commented upon their increased learning from scientific activities. Their natural perceptive qualities benefitted them because POE calls upon these very qualities. Moreover, females valued making predictions and re-evaluating when those predictions proved to be wrong.

This study also considered reasoning skills among all students, seeking to understand chemistry achievement beyond gender categories. Females who are formal thinkers excelled in performing POE tasks. This success can help them overcome their lack of self-confidence in chemistry and physics courses. This deficiency is illustrated by findings such as that girls handled laboratory equipment less frequently than boys (Jovanovic & King, 1998). Moreover, POE is metacognitive, incorporating the manipulation of ideas instead of simply materials and procedures (White & Gunstone, 1992), which may have appealed to the intellectual strengths of female formal thinkers in this study. The collaboration work inherent in POE tasks means that concrete thinkers, if paired with formal-thinking partners, can learn better (Webb & Palincsar, 1996). Overall, students of both gender and reasoning ability can benefit from POE tasks.

This study’s findings suggest that POE tasks should begin to take center stage in science laboratory education. Historically, high school chemistry laboratory instruction has lacked connection to classroom lecture topics (*America’s Lab Report*). When laboratory work is deemed to be a “tacked on” activity, it has failed to result in student mastery of scientific concepts. Moreover, the laboratory activities themselves have been limited to step-by-step, “cookbook” activities as described in *America’s Lab Report* (National Research Council, 2005). Overall, laboratory work has been task-oriented in terms of teaching specific scientific procedures and techniques, while ignoring the prediction, observation, and evaluation that define authentic scientific investigations.

Meanwhile, research has focused on males’ outperformance of females’ in science learning without considering reasoning abilities and individual perceptions of the students. Instructors have thus been unable to truly understand the differing needs of boys and girls, and the differing needs of concrete and abstract thinkers. In this study, both boys and girls learned more from POE activities, which offered several pedagogic benefits. POE activities involve boys and girls in engaging in authentic scientific investigations, which can be coordinated with lecture content to reinforce learning and extend it to include investigative skills, such as predict-observe-explain scientific phenomena. In addition, it can provide concrete thinkers with sensory, hands-on encounters with abstract scientific concepts.

Attainment of authentic scientific investigation skills is the heart of science. POE is the heart of a scientific investigation because it involves *predicting* an outcome of a scientific event, making *observations* during the event, and *explaining* the outcome of the event as well as explaining any discrepancies between the predicted and actual outcomes. In this study, students were involved in POE activities that helped them develop authentic scientific investigation skills. The POE sequence did create the opportunity for some students to reconstruct and change their prior conceptions as a result of inconsistencies and/or contradictions between observations and predictions. POE tasks provided a vehicle by which girls gained better understanding of science. Despite the fact that most published studies have reported that males outperform females in the sciences, these results show that females responded to the inherent nature of scientific investigations through their engagement in POE tasks.

The results and findings of this study suggest that girls can learn more from POE tasks than they can from traditional laboratory activities. These POE activities required collaboration, which resonated with how girls prefer to learn. These activities allowed girls to “do science,” which can spark their interest in pursuing post-secondary science studies. Also, these POE activities were learner-centered, which empowered girls to work with confidence in the laboratory and to construct knowledge as they worked out any discrepancies between predictions and results. Thus, POE laboratory activities helped students achieve the goals for science laboratory learning experiences. Therefore, the findings of this study on the success of POE activities offer important insight for instructors. Clearly, students from both (gender & reasoning ability) groups benefitted from POE activities. Their positive perceptions of POE activities aligned with the pleasure most scientists take when they engage in scientific investigations. As students learn in a meaningful way, they became more poised to develop a love for and understanding of science, which can help girls and boys develop an increased interest in pursuing STEM careers.

Implications

Results of this study revealed that most students developed positive perceptions towards the POE inquiry method of laboratory instruction. Most all of the students found POE tasks to be meaningful and quite relevant to their real-life experiences. Thus, instructors should strive to create a learning environment where students are engage in thinking, learning, and acting in meaningful and beneficial ways. To do so, instructors need both an effective instructional method and a sound knowledge of their subject in order for teaching to yield successful science learning (Shulman, 1986).

Past research has revealed that the learning environment in laboratory settings has had its own impact on the classroom performance of the students. Future studies should explore the nature of these relationships so that laboratory instruction can be carefully monitored and improved. When students are capable of formal reasoning, they can use an abstract scientific concept effectively and then relate it to the ideas they generate in their minds. Student performances and perceptions depend on their level of reasoning--concrete or formal. Chemistry instructors should factor the nature of their students' thinking abilities into their instructional strategies. They should customize their teaching styles to match the cognitive phases of their students in order to improve and enhance student learning (Bird, 2010). Therefore, chemistry teachers should improve their teaching techniques and domain scholarship (i.e., knowledge of chemistry topics) in order to match the needs of their students.

Chemistry education research should continue to focus on the variance in the performance of students (both males and females). Researchers must notice that variations in perceptions among males and females are linked to mathematical ability. Mathematical abilities are a strong factor in performance variations. The self-confidence and problem-solving capability are greater in males than in females, impacting their average performance in various math-related subjects. The way that students are engaged and motivated plays a vital role in their perception capability. Student interest in STEM careers has its bearing on the classroom learning climate (Clewell & Campbell, 2002; Trenor, 2007). The science achievement of females is affected by the manner in which the subject matter is covered in science classrooms. Various methods, approaches, and capabilities--such as previous experiences of the students, the ability to ask questions during the lessons, to manipulate science materials and incorporating instructional technology into lessons--all have an impact on science achievement of females (Schroeder, Scott, Tolson, Huang, & Lee, 2007).

Employing different methods of teaching and assessment methods can positively impact girls, which, in turn, can narrow the gap of perceptions and performances between the genders (Schroeder et al., 2007). In this study, students who felt that the chemistry and POE tasks are difficult often have a poor knowledge of chemistry concepts and skills. They should be aware that the role of teachers is not simply to transmit information but rather to facilitate the learning process in the classroom environment. Boys, while working with science materials, engage seriously with the equipment, whereas girls are content to record observations. If they involve themselves in the way boys do, girls can increase their performance and interest in science.

The findings of this dissertation study offer several important suggestions to make for both science curriculum developers and chemistry teachers. Curriculum developers must plan carefully, with the content portion of the study in mind. Instructors must adopt suitable methods of teaching according to the learning conditions of students. Unlike in the past, curriculum should be developed to suit the needs of a now-diverse student population. Simultaneously, students' abilities and interests should be factored into curriculum development. If educators design effective instructional methods, the learning of chemistry can take place.

Recommendations for Further Research

The main focus of this was on the correlation of variables of interest. It is recommended that further research be carried out to investigate the causal relationships among the variables. This information would help researchers understand the pattern of student achievement in chemistry. A comparative study to assess and explore students' perceptions and performances of POE versus traditional laboratory tasks is required. A qualitative study to explore cognitive abilities is recommended. Observations of students' learning activities can provide insights into their cognitive abilities. Additional research is needed to further examine gender differences in the performances in a chemistry laboratory using larger samples. The nature of the relationships among the dimensions of learning environment should be probed further (using qualitative and quantitative methods) as these dimensions were proved to improve performance in the laboratory.

The researcher hopes that the findings of this dissertation research study will help future researchers and science teachers to provide students with cognitively rich experiences by making full use of POE laboratory tasks. Also, these findings can positively impact both the practical aspects of science laboratory education and future research in science education.

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APPENDIX A

STUDENT CONSENT FORM FOR HUMAN PARTICIPANTS

IN RESEARCH

UNIVERSITY *of* NORTHERN COLORADO

CONSENT FORM FOR HUMAN PARTICIPANTS IN RESEARCH
UNIVERSITY OF NORTHERN COLORADO

Project Title:	Assessing Students' Performance in & Perceptions of POE tasks in High School Physical Science and Chemistry Laboratory Learning Environments
Researcher:	Praveen K. Vadapally, doctoral student in the chemistry education program
Email:	vada8825@bears.unco.edu
Research Advisor:	Dr. Jerry Suits
Phone Number:	(970) 351-1169; Jerry.Suits@unco.edu

With the help of several of my students I am researching students' performance in and perceptions of Predict-Observe-Explain (POE) tasks. If you grant permission and if your child indicates to us a willingness to participate, here is the summary of the research procedure.

The purposes of the proposed research are to explore the high schools students' performance in and perceptions of Predict Observe Explain (POE) tasks in High School Physical Science and Chemistry classes across the schools located in Southwest Kansas.

White and Gunstone (1992) have proposed the POE (Prediction-Observation-Explanation) procedure as an efficient teaching strategy for eliciting students' ideas and also promoting student discussion about their ideas. Predict-observe-explain (POE) tasks are implemented by presenting the learner with a prompt, which the learner responds to by predicting the outcome of the event using any knowledge deemed relevant and applied by the learner. The learner is then presented with the actual outcome of the event (the *observe* phase) and is asked to reconcile any differences between his or her prediction and the observed outcome.

During fall 2011 and spring 2012 semesters, your child along with the other willing participants will complete the demographics form which should take no more than 10 minutes to complete. The information asked in the demographic form will be completely general such as GPA, previous chemistry courses, career goals, and course expectations and would not be possible to identify any of the students based on the demographic characteristics. Then complete the Group Assessment of Logical Thinking (GALT) which should take about 20 minutes to complete. The GALT consists of 12 questions which determine students' logical reasoning skills and scientific reasoning. The goal of the GALT, in this research is to categorize the students based on their levels of reasoning ability as Formal or Concrete.

The students will be given Science Lab learning Environment, SLEI (Actual and Preferred forms) as pre and post-tests. The goal of this SLEI is to measure their actual and preferred perceptions of POE learning environment.

During fall 2011 and spring 2012 semesters, your child along with all the willing participants will be taught using POE tasks to teach the laboratory-based content. All the teacher participants will treat all the student participants equally in all terms such as nature & amount of topics covered, same assessment materials etc. No deceptive practices of any kind will be used in the course of the proposed research study.

The students who do not participate in the research study will follow instructions from the instructor and will not be asked to complete surveys or questionnaire or tests related to this research. All the surveys and questionnaires will be completed at minimally disruptive times in order to avoid the risk of losing valuable class time.

The participant will use their random 6-digit code assigned to them individually by the primary researcher (P. Vadapally) to maintain confidentiality. Qualitative data collection will be done by the Instructor/ researcher. This data includes the analyses of POE perceptions questionnaire, Student interviews about the POE lab tasks and lab learning environment, student observations during the POE lab activities. The interview questions will be based on the student responses in the given inventory and questionnaire. These interviews help explore students' perceptions of POE lab tasks. Qualitative data will also be collected by classroom observations. Interview questions will focus on research questions and students' experiences about learning environments.

Confidentiality will be maintained during the entire course of data collection and analysis. Consent forms will be stored separately (in locked cabinets which are very safe and secure) from the data so that names cannot be linked to the information collected. Each participant shall have a random six digit code assigned to them for data analysis purposes and participants will be asked to create their own pseudonyms for interview purposes. Any participant may seek guidance from the primary researcher (P. Vadapally) during the research period and may make appointment with the primary researchers in his office (SCI 106) for assistance. Further, no identifiers will link individuals to their responses, and the data will be collected in a normal educational setting.

Therefore, no special arrangements are needed as the sample is not a special population. Interview data and audio files will be secured in a locked cabinet in the office of the lead researcher or on his personal computer. Audio data will be destroyed after three years.

I may audiotape the activities to back up my notes. Be assured that I intend to keep the contents of these tapes private, unless you give permission below for their use in my research study. Please feel free to phone me if you have any questions or concerns about this research and please retain one copy of this letter for your records.

Thank you for assisting me with my research.

Sincerely,

Participation is voluntary. You may decide not to allow your child to participate in this study and if she/he begins participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research. A copy of this form will be given to you to retain for future reference. If you have any concerns about your selection or treatment as a research participant, please contact the Office of Sponsored Programs, 25 Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-2161.

____
Child's Full Name (please print)

____ ________________
Parent/Guardian's Signature Date

____ ________________
Researcher's Signature Date

If you give permission for Mr. Vadapally to use the audiotape of your child's discussion for qualitative analysis in his research, please initial here:

______
Initials

APPENDIX B

ASSENT FORM FOR HUMAN PARTICIPANTS IN RESEARCH

UNIVERSITY of NORTHERN COLORADO

ASSENT FORM FOR HUMAN PARTICIPANTS IN RESEARCH
UNIVERSITY OF NORTHERN COLORADO

Project Title:	Assessing Students' Performance in & Perceptions of POE tasks in High School Physical Science and Chemistry Laboratory Learning Environments
Researcher:	Praveen K. Vadapally, doctoral student in the chemistry education program
Email:	vada8825@bears.unco.edu
Research Advisor:	Dr. Jerry Suits
Phone Number:	(970) 351-1169: Jerry.Suits@unco.edu

Dear Student:

As a part of my research project, I am interested in assessing students' performance in and perceptions of Predict-Observe-Explain (POE) tasks. That means I study the way students perform and experience POE learning environment. In order to do this, I will be arranging some student interviews, audio-record some in-class discussions to understand experiences. So, you can be one of the students to be interviewed.

The purposes of the proposed research are to explore the high schools students' performance in and perceptions of Predict Observe Explain (POE) tasks in High School Physical Science and Chemistry classes across the schools located in Southwest Kansas.

White and Gunstone (1992) have proposed the POE (Prediction-Observation-Explanation) procedure as an efficient teaching strategy for eliciting students' ideas and also promoting student discussion about their ideas. Predict-observe-explain (POE) tasks are implemented by presenting the learner with a prompt, which the learner responds to by predicting the outcome of the event using any knowledge deemed relevant and applied by the learner.

The learner is then presented with the actual outcome of the event (the *observe* phase) and is asked to reconcile any differences between his or her prediction and the observed outcome.

If you want to participate in the interviews, in-class discussions and talk with me, you will be asked to share your experiences about the classroom learning environments. But, this is not a test or anything like that. There is no right or wrong answer and there will not be any score or grade for your answers. I will write down what you say, but I will not even write down your name. You will be assigned random 6-digit code during data analysis and a pseudonym of your choice will be used during interviews. The whole process will mostly take place during the class time and might demand some extra time after school on a couple of occasions when I did not get a chance to talk to you.

During fall 2011 and spring 2012 semesters, you will complete the demographics form which should take no more than 10 minutes to complete. The information asked in the demographic form will be completely general such as GPA, previous chemistry courses, career goals and course expectations and would not be possible to identify any of the students based on the demographic characteristics followed by Chemistry Concept Inventory (CCI) which should take about 15 minutes and then complete the Group Assessment of Logical Thinking (GALT) which should take about 20 minutes to complete. The GALT consists of 12 questions which determine students' logical reasoning skills and scientific reasoning. The goal of the GALT, in this research is to categorize the students based on their levels of reasoning ability as Formal or Concrete.

Then you will be given ‘Science Lab learning Environment, SLEI’ (Actual and Preferred forms) as pre and post-test which takes about 15 minutes to complete. The goal of this SLEI is to measure their actual and preferred perceptions of POE learning environment.

During fall 2011 and spring 2012 semesters, you will be taught using POE tasks to teach the laboratory-based content. If you do not participate in the research study, you will follow instructions from the instructor and will not be asked to complete surveys or questionnaire or tests related to this research. All the surveys and questionnaires will be completed at minimally disruptive times in order to avoid the risk of losing valuable class time. Completion of SLEI questionnaire, GALT, CCI, POE lab task questionnaire and Interviews will be part of data collection process. No deceptive practices of any kind will be used in the course of the proposed research study.

The participant will use their random 6-digit code assigned to them individually by the primary researcher (P. Vadapally) to maintain confidentiality. Qualitative data collection will be done by the Instructor/ researcher. This data includes the analyses of POE perceptions questionnaire, Student interviews about the POE lab tasks and lab learning environment, student observations during the POE lab activities. The interview questions will be based on the student responses in the given inventory and questionnaire. These interviews will be audio recorded and stored in secure place until they were destroyed. These interviews help explore students' perceptions of POE lab tasks. Qualitative data will also be collected by classroom observations. Interview questions will focus on research questions and students' experiences about learning environments.

Talking with me probably will not hurt you. But it might help in understanding your learning style and your perceptions of inquiry lab learning environment. Your parents have said it is okay for you to talk with me, but you do not have to. It is up to you. Also, if you say "yes" but then change your mind, you can stop any time you want to. Do you have any questions for me about my research?

If you want to be in my research and share with me your experiences about classroom learning environment, sign your name below and write today's date next to it.

Thank You!

_______________________________________ ________________

Student's Signature Date

_______________________________________ ________________

Researcher's Signature Date

APPENDIX C

TEACHER CONSENT FORM FOR HUMAN PARTICIPANTS

IN RESEARCH

UNIVERSITY of NORTHERN COLORADO

TEACHER CONSENT FORM FOR HUMAN PARTICIPANTS IN RESEARCH

UNIVERSITY OF NORTHERN COLORADO

Project Title: Assessing Students' Performance in & Perceptions of POE tasks in High School Physical Science and Chemistry Laboratory Learning Environments

Researcher: Praveen K. Vadapally, doctoral student in the chemistry education program

Email: vada8825@bears.unco.edu

Research Advisor: Dr. Jerry Suits

Phone Number: (970) 351-1169; Jerry.Suits@unco.edu

Purpose: The purposes of the proposed research are to explore the high schools students' performance in and perceptions of Predict Observe Explain (POE) tasks in High School Physical Science and Chemistry classes across the schools located in Southwest Kansas. As an instructor, you solely determine the use of POE-based methodologies in your specific classroom.

White and Gunstone (1992) have proposed the POE (Prediction-Observation-Explanation) procedure as an efficient teaching strategy for eliciting students' ideas and also promoting student discussion about their ideas. Predict-observe-explain (POE) tasks are implemented by presenting the learner with a prompt, which the learner responds to by predicting the outcome of the event using any knowledge deemed relevant and applied by the learner. The learner is then presented with the actual outcome of the event (the *observe* phase) and is asked to reconcile any differences between his or her prediction and the observed outcome.

Procedure: The research will rely on a teacher cohort from a variety of high schools across Southwest Kansas who agree to implement POE labs in their classrooms during the 2011-12.

Data collection will occur primarily through observations of the classroom by any one of the researchers listed above. The researchers expect to observe each classroom approximately four times per academic school year (i.e. once per quarter).

Your students will be asked to complete a series of validated assessments pertaining to chemistry subject matter (Chemistry Concept Inventory, CCI), logical thinking ability (Group Assessment of Logical Thinking, GALT), and lab learning environment (Science lab Learning environment Inventory, SLEI). You will be asked to complete these assessments as pre-post in one academic year. The integrity of the research-based conclusions will be strictly maintained by minimizing researcher bias as much as possible. You will not be asked to evaluate other students or other instructors.

During fall 2011 and spring 2012 semesters, your student participants will complete the demographics form which should take no more than 10 minutes to complete. The information asked in the demographic form will be completely general such as GPA, previous chemistry courses, career goals, and course expectations and would not be possible to identify any of the students based on the demographic characteristics. Then complete the Chemistry Concept Inventory (CCI) which takes about 15 minutes and Group Assessment of Logical Thinking (GALT) which should take about 20 minutes to complete. The goal of the GALT, in this research is to categorize the students based on their levels of reasoning ability as Formal or Concrete. The students will be given 'Science Lab learning Environment, SLEI' (Actual and Preferred forms) as pre and post-test. The goal of this SLEI is to measure their actual and preferred perceptions of the POE learning environment.

During fall 2011 and spring 2012 semesters, you will teach your student participants, the laboratory-based content using POE tasks. All the teacher participants will treat all the student participants equally in all terms such as nature & amount of topics covered, same assessment materials etc. No deceptive practices of any kind will be used in the course of the proposed research study.

The students who do not participate in the research study will follow instructions from the instructor and will not be asked to complete surveys or questionnaire or tests related to this research. All the surveys and questionnaires will be completed at minimally disruptive times in order to avoid the risk of losing valuable class time.

The student participant will use their random 6-digit code assigned to them individually by the primary researcher (P. Vadapally) to maintain confidentiality. Qualitative data collection will be done by the Instructor/ researcher.

This data includes the analyses of POE perceptions questionnaire, Student interviews about the POE lab tasks and lab learning environment, student observations during the POE lab activities. The interview questions will be based on the student responses in the given inventory and questionnaire. These interviews help explore students' perceptions of POE lab tasks.

Qualitative data will also be collected by classroom observations. Interview questions will focus on research questions and students' experiences about learning environments.

The researchers will use individual interviews with randomly selected teachers to assess their feedback on their individual and student's perceptions of POE-based lab tasks. Teachers and Students will not be asked to evaluate other teachers and students. Selected students and teachers will be asked to participate in an interview two times per academic school year. The interview will take approximately 30-45 minutes and will be audio taped. A member of the research team will transcribe the audiotapes; all tapes will be destroyed within three years of collection.

Risks and Benefits to Participants: There are no anticipated risks to you and the participants. Your student's explanations will not be used in the determination of their grade. It is possible that students may benefit from new insights regarding their understanding of the chemistry concepts. All materials related to the research will be identified by a 6-digit confidential code. This code will be assigned to each participant, and will only be known to the researchers and the specific participant. Participation in this research will have no influence on the grade that participating students will earn in this class.

Compensation: Teachers will be provided access to all research summaries of their classrooms that are compiled by the researchers. These reports will allow the teacher to understand the effectiveness of POE-based instruction in their specific classrooms.

Confidentiality: Confidentiality will be maintained during the entire course of data collection and analysis. Consent forms will be stored separately (in locked cabinets which are very safe and secure) from the data so that names cannot be linked to the information collected. Each participant shall have a random six digit code assigned to them for data analysis purposes and participants will be asked to create their own pseudonyms for interview purposes. Any participant may seek guidance from the primary researcher (P. Vadapally) during the research period and may make appointment with the primary researchers in his office (SCI 106) for assistance. Further, no identifiers will link individuals to their responses, and the data will be collected in a normal educational setting. I may audiotape the activities to back up my notes. Be assured that I intend to keep the contents of these tapes private, unless you give permission below for their use in my research study

Interview data and audio files will be secured in a locked cabinet in the office of the lead researcher or on his personal computer. Audio data will be destroyed after three years.

Please feel free to phone me if you have any questions or concerns about this research and please retain one copy of this letter for your records.

Questions: If you have any questions about the design or results of this study, or about the nature of your participation, please ask either the primary researcher or research advisor at any time. You may contact these researchers at the phone numbers or email addresses indicated at the top of this form.

Thank you for considering participation in our research.

Sincerely, ________________________

Participation is voluntary. You may decide not to participate in this study and if you begin participation you may still decide to stop and withdraw at any time. Your decision will be respected. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research. A copy of this form will be given to you to retain for future reference. If you have any concerns about your selection or treatment as a research participant, please contact the Office of Sponsored Programs, 25 Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-2161.

Print Name: ____________________________

____ _______________

Teacher's Signature Date

____ _______________

Primary Researcher Date

If you give permission for Mr. Vadapally to use the audiotape of your discussion for qualitative analysis in his research, please initial here:

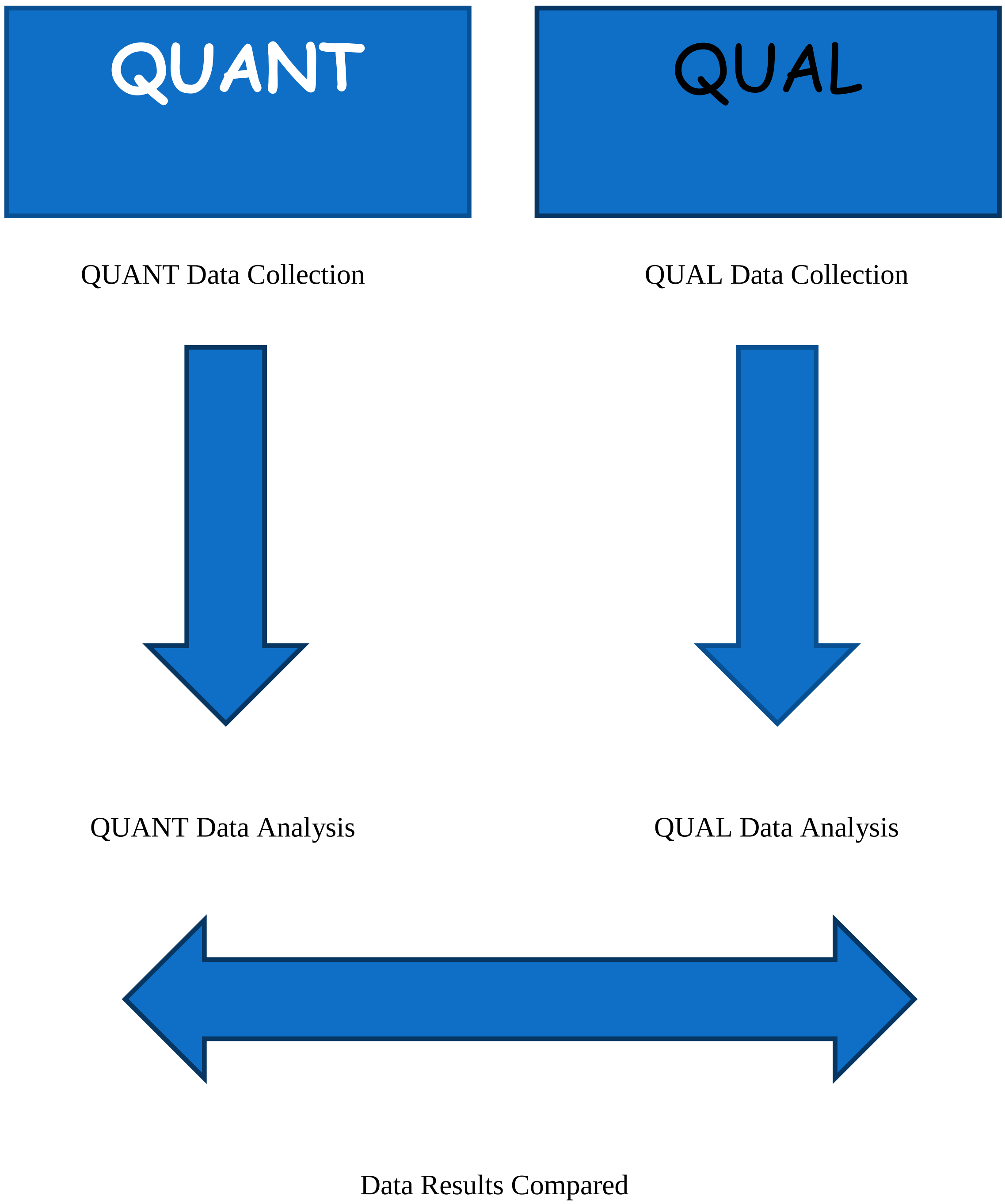
______

Initials

Please initial here to indicate that you have read the IRB consent form

APPENDIX D

CONCURRENT TRIANGULATION DESIGN (A)


QUANT
QUAL
QUANT Data Collection
QUAL Data Collection
QUANT Data Analysis
QUAL Data Analysis
Data Results Compared

APPENDIX E

DEMOGRAPHICS

DEMOGRAPHICS

Year in College ________________________________ (ex: Freshman, etc)

Declared Major ____

Current GPA ___________

Previous Science Courses (College Level and High School):

________________________________ ________________________________
________________________________ ________________________________
________________________________ ________________________________

Previous Science Laboratories (including High School):

________________________________ ________________________________
________________________________ ________________________________
________________________________ ________________________________

What do you hope to get out of your studies in the sciences?

____
____
____
____
____
____

What are your career goals?

____
____
____
____
____
____

APPENDIX F

SCIENCE LABORATORY ENVIRONMENT INVENTORY

(SLEI)

Source: Fraser, B. J., Giddings, G. J., & McRobbie, C. J. (1992). Assessment of the psychosocial environment of university science laboratory classrooms: A cross-national study. *Higher Education*, *24*(4), 431-451.

Directions

This questionnaire contains statements about practices which could take place in this laboratory class. You will be asked how often each practice actually takes place.

There is no "right" or "wrong" answers. Your opinion is what is wanted.

Please do not write on this questionnaire. All answers should be given on the separate Answer Sheet.

Think about how well each statement describes what your laboratory class is actually like. Draw a circle around

1 if the practice actually takes place ALMOST NEVER
2 if the practice actually takes place SELDOM
3 if the practice actually takes place SOMETIMES
4 if the practice actually takes place OFTEN
5 if the practice actually takes place VERY OFTEN

Be sure to give an answer for all questions. If you change your mind about an answer, just cross it out and circle another.

Some statements in this questionnaire are fairly similar to other statements. Do not worry about this. Simply give your opinion about all statements.

Practice Example. Suppose that you were given the statement: "Students choose their partners for laboratory experiments." You would need to decide whether you thought that students actually choose their partners "Almost Never," "Seldom," "Sometimes," "Often," or "Very Often." For example, if you selected "Very Often," you would circle the number *5* on your Answer Sheet.

Remember that you are being asked how often (Almost Never, Seldom, Sometimes, Often, Very Often) that each of the following practices actually takes place in this laboratory class.

1. Students in this laboratory class get along well as a group.

2. There is opportunity for students to pursue their own science interests in this lab class.

3. What we do in our regular science class is unrelated to our laboratory work.

4. Our laboratory class has clear rules to guide student activities.

5. The laboratory is crowded when we are doing experiments.

6. Students have little chance to get to know each other in this laboratory class.

7. In this laboratory class, we are required to design our own experiments to solve a given problem.

8. The laboratory work is unrelated to the topics that we are studying in our science class.

9. This laboratory class is rather informal and few rules are imposed.

10. The equipment and materials that students need for laboratory activities are readily available.

11. Members of this laboratory class help one another.

12. In our laboratory sessions, different students collect different data for the same problem.

13. Our regular science class work is integrated with laboratory activities.

14. Students are required to follow certain rules in the laboratory.

15. Students are ashamed of the appearance of this laboratory.

16. Students in this laboratory class get to know each other well.

17. Students are allowed to go beyond the regular laboratory exercise and do some experimenting of their own.

18. We use the theory from our regular science class sessions during laboratory activities.

19. There is a recognized way of doing things safely in this laboratory.

20. Laboratory equipment is in poor working order.

21. Students are able to depend on each other for help during laboratory classes.

22. In our laboratory sessions, different students do different experiments.

23. The topics covered in regular science class work are quite different from topics dealt with in laboratory sessions.

24. There are few fixed rules for students to follow in laboratory sessions.

25. The laboratory is hot and stuffy.

26. It takes a long time to get to know everybody by his/her first name in this laboratory class.

27. In our laboratory sessions, the teacher/instructor decides the best way to carry out the laboratory experiments.

28. What we do in laboratory sessions helps us to understand the theory covered in regular science classes.

29. The teacher/instructor outlines safety precautions before laboratory sessions commence.

30. The laboratory is an attractive place in which to work.

31. Students work cooperatively in laboratory sessions.

32. Students decide the best way to proceed during laboratory experiments.

33. Laboratory work and regular science class work are unrelated.

34. This laboratory class is run under clearer rules than other classes.

35. The laboratory has enough room for individual or group work.

Scoring:

Items without their item numbers underlined are scored 1, 2, 3, 4, and *5*, respectively, for the responses Almost Never, Seldom, Sometimes, Often, and Very Often.

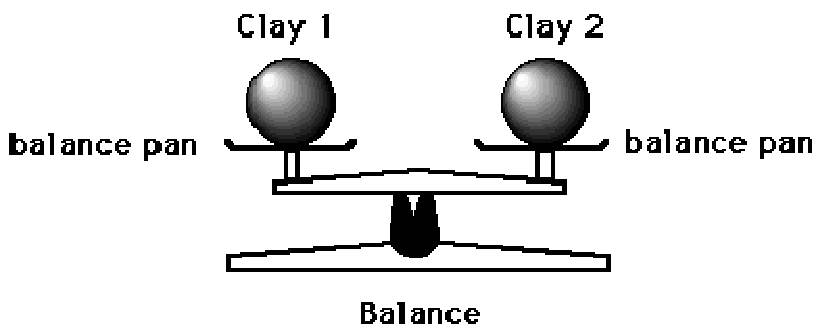
Underlined items are scored in the reverse manner. Omitted or invalidly answered items are scored 3**.**

APPENDIX G

GROUP ASSESSMENT OF LOGICAL THINKING (GALT) TEST

Question 1 (1 point)
Piece of Clay

Tom has two balls of clay. They are the same size and shape. When he places them on the balance, they weigh the same.



The balls of clay are removed from the balance pans. Clay 2 is flattened like a pancake.

WHICH OF THESE STATEMENTS IS TRUE?

A. The pancake-shaped clay weighs more.

B. The two pieces weigh the same.

C. The ball weighs more.

SELECT THE REASON FOR YOUR ANSWER:

1. You did not add or take away any clay.

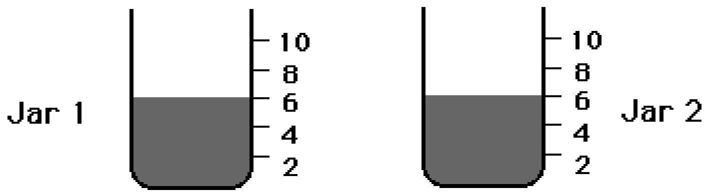
2. When clay 2 was flattened like a pancake, it had greater area.

3. When something is flattened, it loses weight.

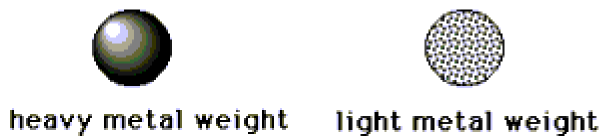
4. Because of its density, the round ball had more clay in it.

Question 2 (1 point)
Metal Weights

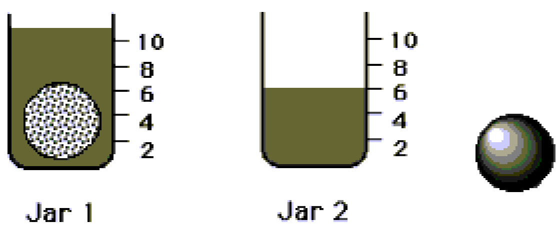
Linn has two jars. They are the same size and shape. Each is filled with the same amount of water.



She also has two metal weights of the same volume. One weight is light. The other is heavy.



She lowers the light weight into jar 1. The water level in the jar rises and looks like this:



IF THE HEAVY WEIGHT IS LOWERED INTO JAR 2, WHAT WILL HAPPEN?

A. The water will rise to a higher level than in jar 1.

B. The water will rise to a lower level than in jar 1.

C. The water will rise to the same level as in jar 1.

SELECT THE REASON FOR YOUR ANSWER:

1. The weights are the same size so they will take up equal amounts of space.

2. The heavier the metal weight, the higher the water will rise.

3. The heavy metal weight has more pressure, therefore the water will rise.

4. The heavier the metal weight, the lesser the water will rise.

Question 3 (1 point)
Glass Size #2

The drawing shows two glasses, a small one and a large one. It also shows two jars, a small one and a large one.

It takes 15 small glasses of water or 9 large glasses of water to fill the large jar. It takes 10 small glasses of water to fill the small jar.

HOW MANY LARGE GLASSES DOES IT TAKE TO FILL THE SAME SMALL JAR?

A. 4

B. 5

C. 6

D. other

SELECT THE REASON FOR YOUR ANSWER:

1. It takes five less small glasses of water to fill the small jar. So it will take five less large glasses of water to fill the same jar.

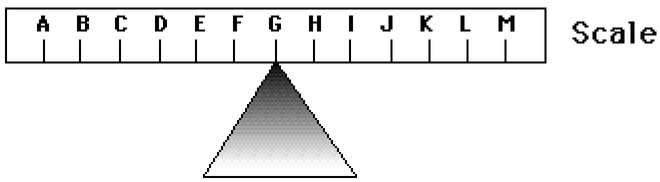
2. The ratio of small to large will always be 5 to 3.

3. The small glass is half the size of the large glass. So it will take about half the number of small glasses to fill up the same small jar.

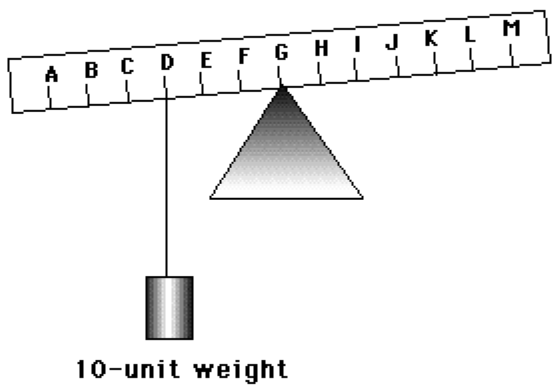
4. There is no way of predicting.

Question 4 (1 point)
<u>Scale #1</u>

Joe has a scale like the one below.



When he hangs a 10-unit weight at point D, the scale looks like this:



WHERE WOULD HE HANG A 5-UNIT WEIGHT TO MAKE THE SCALE BALANCE AGAIN?

A. at point J

B. between K and L

C. at point L

D. between L and M

E. at point M

SELECT THE REASON FOR YOUR ANSWER:

1. It is half the weight so it should be put at twice the distance.

2. The same distance as 10-unit weight, but in the opposite direction.

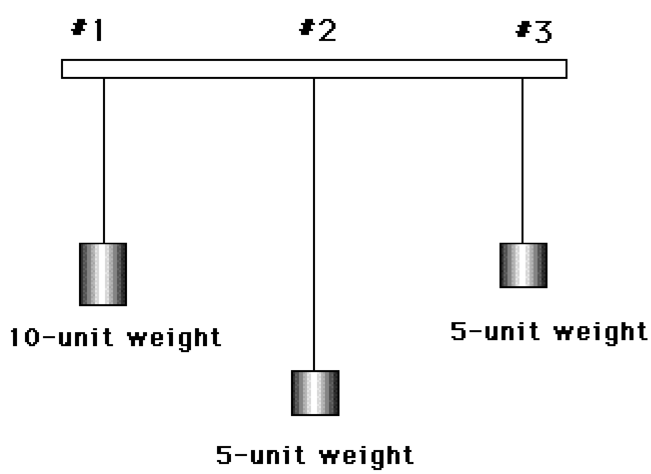
3. Hang the 5-unit weight further out, to make up for its being smaller.

4. All the way at the end gives more power to make the scale balance.

5. The lighter the weight, the further out it should be hung.

Question 5 (1 point)
Pendulum Length

Three strings are hung from a bar. String #1 and #3 are of equal length. String #2 is longer. Charlie attaches a 5-unit weight at the end of string #2 and at the end of string #3. A 10-unit weight is attached at the end of string #1. Each string with a weight can be swung.



Charlie wants to find out if the length of the string has an effect on the amount of time it takes the string to swing back and forth.

WHICH STRING AND WEIGHT WOULD HE USE FOR HIS EXPERIMENT?

A. string #1 and #2

B. string #1 and #3

C. string #2 and #3

D. string #1, #2 and #3

E. string #2 only

SELECT THE REASON FOR YOUR ANSWER:

1. The length of the strings should be the same. The weights should be different.,

2. Different lengths with different weights should be tested.

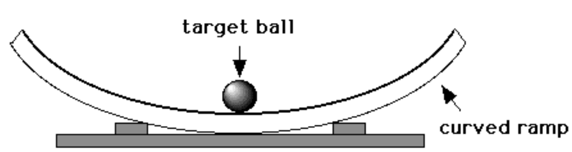
3. All strings and their weights should be tested against all others.

4. Only the longest string should be tested. The experiment is concerned with length not weight.

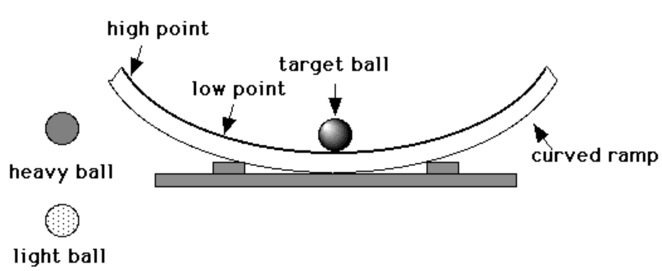
5. Everything needs to be the same except the length so you can tell if length makes a difference.

Question 6 (1 point)
Ball #1

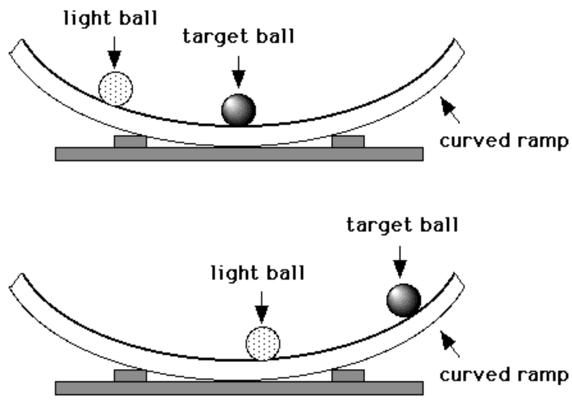
Eddie has a curved ramp. At the bottom of the ramp, there is one ball called the target ball.



There are two other balls, a heavy one and a light one. He can roll one ball down the ramp and hit the target ball. This causes the target ball to move up the other side of the ramp. He can roll the balls from two different points, a low point and a high point.



Eddie released the light ball from the low point. It rolled down the ramp. It hit and pushed the target ball up the other side of the ramp.



He wants to find out if the point a ball is released from makes a difference in how far the target ball goes.

TO TEST, THIS WHICH BALL WOULD HE NOW RELEASE FROM THE HIGH POINT?

A. the heavy ball B. the light ball

SELECT THE <u>REASON</u> FOR YOUR ANSWER:

1. He started with the light ball, he should finish with it.

2. He used the light ball the first time. The next time he should use the heavy ball.

3. The heavy ball would have more force to hit the target farther.

4. The light ball would have to be released from the high point in order to make a fair comparison.

5. The same ball must be used as the weight of the ball does not count.

Question 7 (1 point)
Squares and Diamonds #1

In a cloth sack, there are

All of the square pieces are the same size and shape. The diamond pieces are also the same size and shape. One piece is pulled out of the sack.

WHAT ARE THE CHANCES THAT IT IS A SPOTTED PIECE?

A. 1 out of 3

B. 1 out of 4

C. 1 out of 7

D. 1 out of 21

E. other

SELECT THE REASON FOR YOUR ANSWER:

1. There are 21 pieces in the cloth sack. One spotted piece must be chosen from these.

2. One spotted piece needs to be selected from a total of seven spotted pieces.

3. Seven of the 21 pieces are spotted pieces.

4. There are three sets in the cloth sack. One of them is spotted.

5. 1/4 of the square pieces and 4/9 of the diamond pieces are spotted.

Question 8 (1 point)
Squares and Diamonds #2

In a cloth sack, there are

All of the square pieces are the same size and shape. The diamond pieces are also the same size and shape. Reach in and take the first piece you touch.

WHAT ARE THE CHANCES OF PULLING OUT A SPOTTED DIAMOND OR A WHITE DIAMOND?

A. 1 out of 3

B. 1 out of 9

C. 1 out of 21

D. 9 out of 21

E. other

SELECT THE REASON FOR YOUR ANSWER:

1. Seven of the twenty-one pieces are spotted or white diamonds.

2. 4/7 of the spotted and 3/8 of the white pieces are diamonds.

3. Nine of the twenty-one pieces are diamonds.

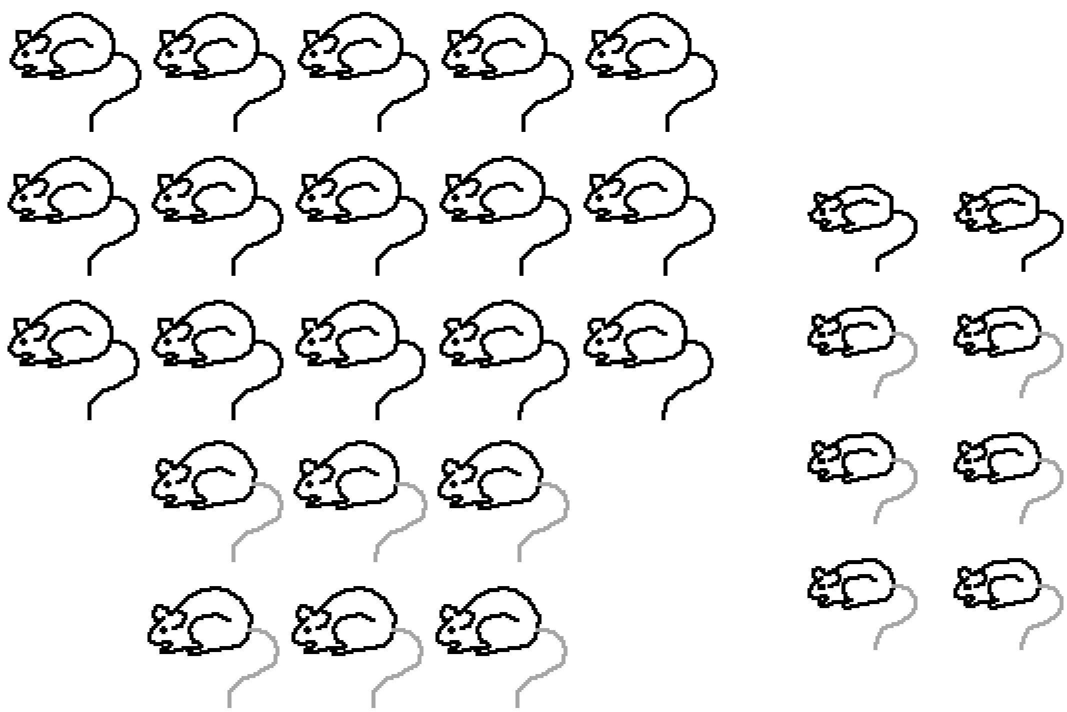
4. One diamond piece needs to be selected from a total of twenty-one pieces in the cloth sack.

5. There are 9 diamond pieces in the cloth sack. One piece must be chosen from these.

Question 9 (1 point)
<u>The Mice</u>

A farmer observed the mice that live in his field. He found that the mice were either fat or thin. Also, the mice had either black tails or white tails.

This made him wonder if there might be a relation between the size of a mouse and the color of its tail. So he decided to capture all of the mice in one part of his field and observe them. The mice that he captured are shown below.



DO YOU THINK THERE IS A RELATION BETWEEN THE SIZE OF THE MICE AND THE COLOR OF THEIR TAILS (THAT IS, IS ONE SIZE OF MOUSE MORE LIKELY TO HAVE A CERTAIN COLOR TAIL AND VICE VERSA)?

A. Yes

B. No

SELECT THE REASON FOR YOUR ANSWER:

1. 5/7 of the fat mice have black tails and 3/4 of the thin mice have white tails.

2. Fat and thin mice can have either a white tail or a black tail.

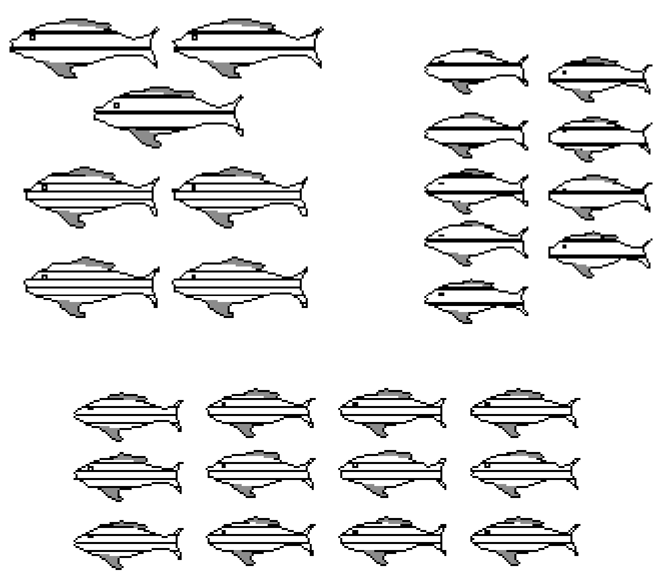
3. Not all fat mice have black tails. Not all thin mice have white tails.

4. 17 mice have black tails and 12 have white tails.

5. 21 mice are fat and 8 mice are thin.

Question 10 (1 point)
The Fish

Some of the fish below are big and some are small. Also some of the fish have wide stripes on their sides. Others have narrow stripes.



IS THERE A RELATIONSHIP BETWEEN THE SIZE OF THE FISH AND THE KIND OF STRIPES IT HAS (THAT IS, IS ONE SIZE OF FISH MORE LIKELY TO HAVE A CERTAIN TYPE OF STRIPES AND VICE VERSA)?

A. Yes

B. No

SELECT THE REASON FOR YOUR ANSWER:

1. Big fish and small fish can have either wide or narrow stripes.

2. 3/7 of the big fish and 9/21 of the small fish have wide stripes.

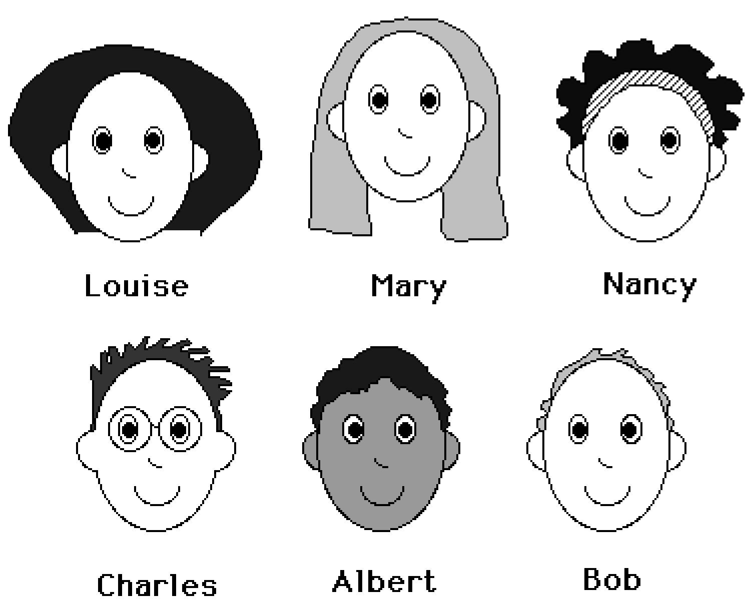
3. 7 of the fish are big and 21 are small.

4. Not all big fish have wide stripes and not all small fish have narrow stripes.

5. 12/28 of fish have wide stripes and 16/28 of fish have narrow stripes.

Question 11 (1 point)
The Dance

After dinner, some students decide to go dancing. There are three boys: Albert (A), Bob (B), and Charles (C), and three girls: Louise (L), Mary (M) and Nancy (N).



One possible pair of dance partners is A-L, which means ALBERT and LOUISE.

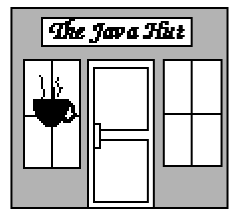
<u>LIST ALL OTHER POSSIBLE PAIRS</u> OF DANCE PARTNERS. TO REDUCE THE NUMBER OF POSSIBLE ANSWERS TO THIS QUESTION, YOU CAN RESTRICT THE POSSIBLE COMBINATIONS TO BOYS AND GIRLS DANCING WITH EACH OTHER.

Question 12 (1 point)
<u>The Shopping Center</u>

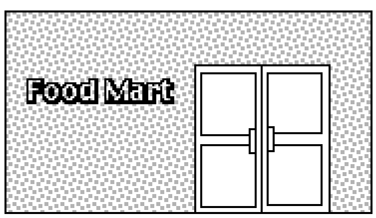
In a new shopping center, 4 stores are going to be placed on the ground floor. A BARBER SHOP (B), a DISCOUNT STORE (D), a GROCERY STORE (G), and a COFFEE SHOP (C) want to locate there.

Barber Shop (B)

Discount Store (D)



Coffee Shop (C)



Grocery Store (G)

One possible way that the stores could be arranged in the 4 locations is BDGC. Which means the BARBER SHOP first, the DISCOUNT STORE next, then the GROCERY STORE and the COFFEE SHOP last.

LIST ALL THE POSSIBLE WAYS THAT THE STORES CAN BE LINED UP IN THE FOUR LOCATIONS.

GALT: Group Assessment of Logical Thinking

Teacher Use Only

CODE ________

ITEM		BEST ANSWER	REASON
1.	Piece of Clay	________	BEST REASON ________
2.	Metal Weights	________	________
3.	Glass Size #2	________	________
4.	Scale #1	________	________
5.	Pendulum Length	________	________
6.	Ball #1	________	________
7.	Squares and Diamonds #1	________	________
8.	Squares and Diamonds #2	________	________
9.	The Mice	________	________
10.	The Fish		
11.	The Dance	Record your answer below	

A-L

________ ________ ________ ________ ________

11. The Shopping Center Record your answer below

BDGC

___________ ___________ ___________ ___________ ___________

APPENDIX H

STUDENT PERCEPTIONS OF PREDICT-OBSERVE-EXPLAIN

LABORATORY ACTIVITIES QUESTIONNAIRE

STUDENT PERCEPTIONS OF POE LABORATORY ACTIVITIES QUESTIONNAIRE

1) How do you feel about Science? Why?

2) What is your most favorite science? What do you like about it?

3) What is your least favorite science? What do you not like about it?

4) How do you feel about Chemistry?

    A) If you have positive perceptions about chemistry, please explain what factors led to your positive perceptions.

    B) If you have negative perceptions about chemistry, please explain what factors led to your negative perceptions.

5) How do you feel about the POE lab activities? Why?

    A) If you have positive perceptions about POE lab activities, Please explain what factors led to your positive perceptions.

    B) If you have negative perceptions about POE lab activities, Please explain what factors led to your negative perceptions.

6) What can be done by the teacher to overcome these difficulties? (Please be more specific)

7) Since you have experienced both traditional and POE laboratory instructional styles, which one of these two do you prefer? Why? (Please be more specific)

8) Is there anything else that you would like to say about your perceptions of this class and the POE lab activities?

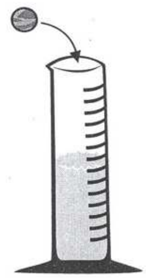
APPENDIX I

EXAMPLE OF PREDICT-OBSERVE-EXPLAIN

LABORATORY ACTIVITY

Don't Confuse Mass and Volume!

Two Riddles
Which weighs more, 10 kg of lead or 10 kg of feathers?
Which takes up more space, 10 L of gold or 10 L of wood?



An Experiment
Here are two metal objects that are the same size and shape, one brass and one aluminum. Pick one up in each hand and compare their weights.

Put the aluminum object in a graduated cylinder filled halfway with water. Make a note of how high the water rose.

Predict
What will happen to the water level if you put in the brass object instead? Check one [√].

Will the level be Higher [ ] Same [ ] Lower [ ]?

Try to explain your thinking.

____

____

____

Observe
Put in the brass object and see what happens.

____

____

Explain
Can you explain the change in water level when the brass object was put in the graduated cylinder?

____

____

____

Try This!
If you roll a clay ball into the shape of a sausage, will it still displace the same amount of water?

What do you think? ______________________________

____

____

APPENDIX J

PERMISSION TO USE PREDICT-OBSERVE-EXPLAIN ACTIVITIES

From: John Haysom [mailto:haysom@ns.sympatico.ca]
Sent: Wednesday, December 11, 2013 2:15 PM
To: Praveen Vadapally
Subject: RE: Permission to use POE activities in my dissertation study

Dear Praveen,

Good to hear from you again. Yes of course you have our permission to use POE activities from our book, to scan some of the activities and some of the student responses.

Naturally I am very interested in the results you have obtained and would be grateful is you would send me a brief summary of what you have found out.

With best wishes,

John Haysom, Ph.D., D.Phil.
Professor Emeritus, Saint Mary's University. Canada.

From: Praveen Vadapally [mailto:praveen.vadapally@gcccks.edu]
Sent: December-08-13 1:56 PM
To: haysom@ns.sympatico.ca
Subject: Permission to use POE activities in my dissertation study

Good morning Dr. Haysom,

My name is Praveen and I am a doctoral student in Chemistry Education Program at University of northern Colorado.
Last year in November, I emailed you to request your permission to use POE activities from your book (NSTA): *Activities enhancing scientific understanding*.
I received your email with your response saying "YES" to use POE activities. But I do not have access to that email anymore because I am teaching at a different school now.

- I would like to scan and paste a few activities from your book that I used in my study.
- Also, I would like to scan a few student responses to POE worksheets from you book.

I completely forgot to print that email and since I am no longer working there at that school, I lost your email. Could you PLEASE send me your email permitting me to use POE activities from your book in my dissertation? I will include a copy of your permission letter in my dissertation.

Thank you very much for your help! Happy Holidays!

Praveen Vadapally
Chemistry Instructor
Garden City Community College; 801 Campus Dr, Garden City, KS 67846
Email: Praveen.vadapally@gcccks.edu

APPENDIX K

PERMISSION TO USE SCIENCE LABORATORY

ENVIRONMENT INVENTORY (SLEI)

Permission to use Science Laboratory Environment Inventory (SLEI)

Barry Fraser <B.Fraser@curtin.edu.au>
Fri 1/10/2014 3:32 PM

Praveen

You have my permission to use the SLEI.

Barry Fraser

Dr Barry J Fraser
FIAE FTSE FASSA FAAAS FAERA FACE
John Curtin Distinguished Professor
Director | Science and Mathematics Education Centre
Associate Dean | Graduate Studies | Science and Engineering

Tel | +61 8 9266 7896
Fax | +61 8 9266 2503
Email | B.Fraser@curtin.edu.au
Web | http://smec.curtin.edu.au
Address | GPO Box U1987 Perth WA 6845

Vadapally, Praveen
Fri 1/10/2014 9:57 AM
Sent Items
To:
B.Fraser@curtin.edu.au;

Hello Dr. Fraser,

I am a doctoral student at the University of Northern Colorado, Greeley, USA.
May I please have your permission to use Science Laboratory Environment Inventory (SLEI) in my dissertation study with high school students?

Thank you very much for your help!

Regards,
Praveen

APPENDIX L

STUDENTS' PERFORMANCE ON PREDICT-OBSERVE-EXPLAIN LABORATORY TASKS

Performance scores in POE laboratory task 1

Category	Mean	Standard Deviation
Ff	2.27	1.01
Fc	1.71	0.99
Mf	1.64	1.02
Mc	1.31	0.95

Performance scores in POE laboratory task 2

Category	Mean	Standard Deviation
Ff	1.81	0.87
Fc	1.28	0.47
Mf	1.54	0.93
Mc	0.92	0.49

Performance scores in POE laboratory task 3

Category	Mean	Standard Deviation
Ff	1.64	1.12
Fc	1.14	0.66
Mf	1.36	0.80
Mc	0.85	0.80

Performance scores in POE laboratory task 4

Category	Mean	Standard Deviation
Ff	2.09	1.04
Fc	1.21	0.80
Mf	1.36	1.12
Mc	1.15	0.55

Performance scores in POE laboratory task 5

Category	Mean	Standard Deviation
Ff	1.91	1.13
Fc	1.43	0.85
Mf	1.91	0.94
Mc	1.31	0.75

Performance scores in POE laboratory task 6

Category	Mean	Standard Deviation
Ff	2.36	0.92
Fc	1.36	0.84
Mf	1.73	1.10
Mc	0.92	0.76