Phenomenological Investigation of the Effectiveness of a Cooperative Problem-Based Laboratory and a Metacognitive Problem-Solving Exercise

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PHENOMENOLOGICAL INVESTIGATION OF THE EFFECTIVENESS
OF A COOPERATIVE PROBLEM-BASED LABORATORY
AND A METACOGNITIVE COLLABORATIVE
PROBLEM-SOLVING EXERCISE

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Chemistry

by
Todd Adam Gatlin
August 2009

Accepted by:
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Dr. Jeffrey R. Appling
ABSTRACT

Problem-solving has been described by many as the most important goal of chemistry teaching and learning. Solving real problems requires not only cognitive abilities but also a regulation of those abilities—metacognition. In fact, metacognition is recognized as having considerable impact on problem-solving success and learning. Recent research focused on the development of interventions designed to enhance the use of metacognition. The main objective of this study was to determine “how” and “why” two interventions were effective in increasing students’ metacognitive use, and problem-solving abilities. Therefore, this study represents the qualitative portion of a sequential explanatory mixed-methods study; Qualitative evidence was collected in order to contribute to an explanation of prior quantitative findings. The two interventions at the heart of the study were a cooperative problem-based laboratory project, and a metacognitive collaborative problem-solving exercise. Nine general chemistry students were interviewed, and a phenomenological analysis was performed with the data. The outcome space of the phenomenological analysis revealed underlying similarities between each experience. Both experiences contained affective and skillfulness components. In the affective dimension students underwent moments of confusion and frustration that had to be overcome in order to be successful. The skillfulness dimension, in both experiences, involved the “skills” that students implemented while “figuring out” and solving problems. The skills were explicitly metacognitive. Interpretation of the outcome space led
to the conclusion that meaningful purposeful social interaction and reflective prompting acted as promoters for enhanced metacognition use and problem-solving abilities. The data collected in this study supported and contributed to an explanation of prior findings. Also, due to the nature of the phenomenological analysis, an accurate representation of the cooperative problem-based laboratory experience was gained. The laboratory experience provides a rich environment for the development of metacognitive strategies, and problem solving skills.
ACKNOWLEDGMENTS

I would like to acknowledge my research advisor, Dr. Melanie Cooper, for placing my interests at the forefront of decision making throughout my time at Clemson University. Dr. Cooper constantly encouraged me to pursue a research path that I would find meaningful and interesting. She even encouraged me to pursue my desire to teach high school chemistry, though I had yet to finish this research. I would like to thank my committee members Dr. Gautam Bhattacharyya, and Dr. Jeffrey Appling for their assistance and guidance during this process. I would also like to acknowledge Santiago Sandí-Ureña, with whom I worked so closely during this project, Beth Walls, and all other members of Dr. Cooper’s group and Dr. Bhattacharyya’s group for continuous support. Finally, I owe a great deal of gratitude to the students who graciously volunteered their time to participate in this research study.
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CHAPTER ONE

INTRODUCTION

Solving problems is arguably one of the most important aspects of chemistry. Therefore, it stands to reason that problem solving would be a leading focus in the chemistry classroom and laboratory. In 1996, Herron stated,

We begin with problem solving because it represents the ultimate goal of chemistry education. Individuals who can address novel situations and arrive at a suitable course of action are valued in society. Such behavior is what we mean by problem solving.” (Herron, 1996, p.63)

Even though chemists, researchers, and teachers recognize the need for problem-solving, students are rarely given a chance to solve authentic problems in the classroom setting. Real “problems” are ones in which students do not have an immediate solution pathway. Using this definition, problem-solving can be defined as “what you do when you do not know what to do” (Wheatley, 1984). Textbooks and online homework software are filled with repetitive algorithmic problems, and traditional lecture type formats do not provide enough opportunities for students to reflect, think critically, or evaluate, which are all important problem-solving processes. If students are expected to hone their problem-solving skills then they must be given the opportunity to put these skills to use.

Research on how students solve problems and how to teach problem-solving has often focused on algorithmic or routine exercises. However, a variety
of interventions and learning environments have been designed and tested with critical thinking skills and meaningful problem solving as focal goals (Bransford, & Stein, 1984; Cooper, Cox, Nammouz, Case, & Stevens, 2007; Farrel, Moog, & Spencer, 1999; Tien, Roth, Kamomeier, 2002; Tsai, 2001). Most of these environments and interventions are based on constructivist views and active learning techniques. However, the true potential of many of these environments remains unknown because traditional assessments fail to capture students’ problem-solving abilities. The correctness of a final answer is important, but how the students arrived at that solution is arguably more important. Furthermore, these assessment techniques fail to capture “why” or “how” these strategies work.

Our contention is that many of the designed learning environments and proposed interventions that draw on constructivism rely heavily on the use of metacognition. Others hold this contention, such as Gunstone (2004) who suggested that metacognition and conceptual change, a constructivist framework, are “totally intertwined.” Constructivism assumes “knowledge is constructed in the mind of the learner” (Bodner, 1986, p. 873), and metacognition is defined as “knowledge and regulation of one’s own cognitive system” (Brown, 1987). Based on these two definitions it stands to reason that metacognitive strategies play a large role in constructing knowledge and problem-solving.

Flavell first used the term *metacognition* in the 1970’s and stated, “Metacognition refers, among other things, to the active monitoring and
consequent regulation and orchestration of these processes in relation to the
cognitive objects or data on which they bear” (Flavell, 1979, p. 232). Although the
term metacognition is fairly new, the concept has existed for over two millennia
(Sandi-Urena, 2008). During the past three decades, effective metacognition use
has been linked with positive attributes such as, increased problem solving
abilities (Davidson, Deuser, & Sternberg, 1995; Mayer, 2001; Rozencwajg,
2003), learning transfer (Bransford & Schwartz, 1999; Georghiades, 2000) and
preparation for life-long learning (Cornford, 2002; Dunlap & Grabinger, 2003).

Because of this, recent work within the Cooper group has focused on the
use of metacognitive instruction and its effects on chemistry problem-solving (M.
M. Cooper, Sandi-Urena, Gatlin, Bhattacharyya, & Stevens, submitted; M. M.
Cooper, Sandi-Urena, & Stevens, 2008; M. M. Cooper & Sandi-Urena, 2009; S.
Sandi-Urena, Cooper, Gatlin, & Bhattacharyya, Submitted; S. Sandi-Urena,
(metacognitive assessment inventory) (Cooper, & Sandi-Urena 2009) and a
concurrent online ill-structured problem (HAZMAT, via IMMEX) (Cooper, Sandi-
Urena, 2008), was developed to assess the use of metacognition (Cooper et al.,
2008; Cooper & Sandi-Urena, 2009). Using this multi-method technique, the
impact of two metacognitive interventions on metacognition awareness and use
was measured. First, a collaborative paper and pencil problem solving exercise
was shown to increase students’ metacognitive awareness on the self-report
survey, and problem solving ability and solve rate on the online ill-structured
problem (Sandi-Urena et al., Submitted). Next, a cooperative problem-based laboratory project was shown to increase students’ metacognitive awareness, problem-solving ability, solve rate and efficient strategy use (Cooper et al., submitted). Quantitative results indicate that these interventions were effective in meeting their goals. Yet, this research approach did not facilitate access to the mechanisms that produced the changes observed in metacognition use and awareness.

The present study is a component of a larger sequential explanatory mixed methods (Creswell, 2003) research program and it intends to contribute evidence to explain previous quantitative findings (M. M. Cooper, Sandi-Urena, Gatlin, Bhattacharyya, & Stevens, submitted; M. M. Cooper, Sandi-Urena, & Stevens, 2008; M. M. Cooper & Sandi-Urena, 2009; S. Sandi-Urena, Cooper, Gatlin, & Bhattacharyya, Submitted; S. Sandi-Urena, 2008). A qualitative research approach was needed in order to determine “why” or “how” the observed changes took place. Qualitative research provides access to in depth and detailed analyses that would complement our knowledge of “what” happened with “how” it happened (Patton, 2002). Thus, the purpose of this research project is to explore the nature of general chemistry students’ experiences within each of the studied learning environments, using qualitative means. Since the focus of this qualitative study is on students’ lived experiences in a cooperative problem-based laboratory environment and a metacognitive problem-solving exercise, phenomenology was chosen as the ideal research process for determining the
nature of the experience. A phenomenological analysis, that focuses on the nature, or essence, of the experience should allow for a robust explanation of prior quantitative findings.

Research Goals

The overall goal of this research project is to determine:

What factors in the learning experiences under study (cooperative problem-based laboratory, metacognitive collaborative problem-solving exercise) are related to students' increase in metacognition awareness and use, and problem solving performance?

In order to accomplish this goal, a phenomenological investigation was undertaken with the leading questions:

1. What is the nature or essence of general chemistry students' experiences with a cooperative problem-based laboratory project, and a collaborative metacognitive problem-solving intervention?

2. What common features do these experiences share that may influence metacognition use and problem-solving performance?

Similar quantitative results were achieved with each metacognitive intervention (Sandi-Urena, 2008). Therefore, seeking the underlying connection of each learning environment may lead to a more thorough explanation of prior quantitative results.

This work seeks to contribute to the field of metacognition use in chemistry, and laboratory reform. Insights on the use, implementation, and
effectiveness of metacognitive interventions will be gained from a student’s point of view, which will be a valuable asset during the creation and implementation of future interventions. The phenomenological analysis will also give a “voice” to the participants in a cooperative problem-based laboratory. This project will enable us to determine if the curricular goals of the laboratory paradigm and the learned outcomes are aligned. This information can be used to guide future curricular laboratory reforms.

Chapter Two reviews relevant literature related to active learning. Chapter Three covers the methodological assumptions of phenomenology and methods used in this study to answer the aforementioned research questions. Chapter Four presents students’ experiences in the form of narrative descriptions. The phenomenological analysis is presented in Chapter Five. Finally, Chapter Six notes the contributions made by this research. The concluding chapter will also address future directions and teaching implications.
CHAPTER TWO
LITERATURE REVIEW

Introduction

The goal of this chapter is to review literature related to the current study. The three most important aspects of this study are, the learning environments being studied, the construct metacognition, and the current mode of study, phenomenology. A discussion of Phenomenology will be reserved for Chapter 3, and metacognition was reviewed during the quantitative phase of the mixed-methods study (Sandi-Urena, 2008). This chapter will focus on the learning environments relevant to the study. The cooperative problem-based laboratory and the metacognitive collaborative problem-solving intervention are forms of active learning strategies. Therefore, this literature review covers aspects of active learning environments.

National science reforms consistently call for the adaptation of teaching strategies that actively involve students in the learning process (Michael, 2006). This is in contrast to traditional methods of instruction, lecture in particular, that are viewed as placing students in a passive role. The “old” paradigm, was built on principles of “transferring knowledge from faculty to students” and is in line with the view that students are empty vessels awaiting knowledge (Johnson, Johnson, & Smith, 1991). According to Johnson, Johnson and Smith, the “new” paradigm assumes “knowledge is constructed, discovered, transformed, and
extended by students,” and “students actively construct their own knowledge” (Johnson et al., 1991).

**Defining Active Learning**

Active learning is a broad term that encompasses a large set of pedagogical strategies that place the learner in control of learning. Meyers stated that active learning is guided by two assumptions: “(1) that learning is by nature an active endeavor and (2) that different people learn in different ways” (Meyers & Jones, 1993). These two assumptions are simplifications of guidelines presented in other sources such as *How People Learn* (Bransford, Brown, & Cocking, 2000) and *How Students Learn* (Donovan & Bransford, 2005). More formal definitions of active learning are presented in the *Greenwood Dictionary of Education*,

1) The process of having students engage in some activity that forces them to reflect upon ideas and how they are using those ideas. Requiring students to regularly assess their own degree of understanding and skill at handling concepts or problems in a particular discipline. 2) The attainment of knowledge by participating or contributing. 3) The process of keeping students mentally, and often physically, active in their learning through activities that involve them in gathering information, thinking, and problem solving. (Collins, & O'Brien, 2003)

A variety of pedagogical strategies and learning environments fall under the definitions and framework of active learning. Michael listed cooperative learning, collaborative learning, problem-based learning, conceptual change strategies,
inquiry based learning, discovery learning, technology-enhanced learning, think-pair-share, and peer instruction as some samples of strategies that focus on active learning (Michael, 2006). Others consider active learning to be any activity added to a traditional lecture format in order to increase student engagement, adding to the abundant array of choices. According to Prince, the “core elements” of active learning are “introducing activities into the lecture format” and “engaging learning” (Prince, 2004). It should be noted that he separately defined active learning, cooperative learning, collaborative learning, and problem-based learning in a paper titled “Does active learning work? A review of the research.” In the article, the term active learning implied two different things, specific strategies added too the lecture setting, and the all-encompassing definition presented above, although he did not make it known to the reader (Prince, 2004).

Studies regarding active learning as a simple lecture enhancer are more prevalent in non-science related fields although some science educators do prescribe to these methods. One specific example is the use interactive lecture displays in chemistry (Zimrot & Ashkenazi, 2007) and physics (Laws, Sokoloff, & Thornton, 1999; Sokoloff & Thornton, 1997). Cooperative learning lecture strategies (M. M. Cooper, 1995; Kogut, 1997; Towns, Kreke, & Fields, 2000) also appear in chemistry, but these strategies fall under the broader view of active learning. Typically active learning methods in chemistry have involved total commitment to the design and a major overhaul of the traditional program, whether it is lecture (Hinde & Kovac, 2001; Lewis & Lewis, 2005; Moog & Farrell,
Research regarding the effectiveness of some active learning strategies is presented below, but first the theoretical basis for active learning is considered.

**Theoretical Basis for Active Learning**

Calls for pedagogical strategies that employ active learning are in direct correlation to the emergence of constructivist learning theories. Constructivism is an epistemological theory that is built around the principle, “knowledge is constructed in the mind of the learner” (Bodner, 1986). This theory moves away from traditional models of learning in which knowledge is seen as a transferable agent and viewed as “right” or “wrong.”

*Constructivism* has become a “buzzword” in the field of education. However, the term constructivism is often used to mean different things and leads some to argue that many of the uses hardly relate to constructivism’s true meaning (Duffy & Cunningham, 1996; Wilson, 1997). Some claim constructivism as instructional pedagogy (Matthews, 2002). However others argue that it is a philosophy rather than a set of instructional strategies (Wilson, 1997). At best it can be concluded that constructivism began as a learning or knowledge theory, but has begun to evolve into much more. Matthews (2002) provided eight dimensions that he suggested researchers separate and make clearly explicit during debates on constructivism. The eight proposed dimensions were: Constructivism as a: “1. Theory of learning, 2. Theory of teaching, 3. Theory of
education, 4. Theory of cognition, 5. Theory of personal knowledge, 6. Theory of scientific knowledge, 7. Theory of educational ethics and politics, and 8. World view” (Matthews, 2002, p.124). Possibly adding to the confusion regarding constructivism are the variations of the theory of cognition or knowledge (Bodner, Klobuchar, & Geelan, 2001; Duffy & Cunningham, 1996); personal constructivism, radical constructivism, social constructivism, and contextual constructivism are all representative forms of the variations of constructivism (Bodner et al., 2001).

The scope of the differences is beyond the review presented here. The importance for this discussion is that each variation shares two basic assumptions “(1) learning is an active process of constructing rather than acquiring knowledge, and (2) instruction is a process of supporting that construction rather than communicating knowledge” (Duffy & Cunningham, 1996).

The constructivist tenet—learning is an active process whereby learners construct meaning—is responsible for the development of active learning environments. Educators seek to provide students with the opportunity to foster this construction. Research abounds about the different types of active learning environments, and the next section will present a glimpse into that area. In the case of this review, constructivism was treated as the theory of learning, and active learning was viewed as the pedagogical strategies informed by the theory. It should be noted that some refer to active learning techniques as constructivist
techniques, however in the next section the term active learning is used exclusively.

**Researched Based Outcomes of Active Learning**

Active learning has been extensively reviewed and generally accepted to be beneficial for a wide range of audiences and a wider range of outcomes (Bowen, 2000; Johnson et al., 1991; Michael, 2006; Prince, 2004; Qin & Johnson, 1995; Slavin, 1996). Studies have been conducted at almost all levels and subjects of education. According to Slavin (1996), the most prevalent area of research is how active learning environments affect student achievement. There is an abundance of studies and reviews that suggested active learning can be used effectively to have positive outcomes on students achievement.

However, some cognitive psychologists argue against active learning environments and point towards a lack of controlled experiments (Kirschner, Sweller, & Clark, 2006). Kirschner, Sweller, and Clark (2006) make a claim for direct instruction over minimal guidance and cite multiple studies as evidence for this claim. A review of the cited articles revealed that each study compared direct-guided instruction to pure discovery learning. In each case, direct instruction was shown to be more effective, but this evidence hardly suggest that direct instruction is superior to all active learning techniques.

Perhaps the most widely adopted active learning techniques are forms of cooperative learning and collaborative learning. The terms collaborative and cooperative are often used interchangeably, but many researchers distinguish
between them. Smith and MacGregor (1992) present a view of collaborative learning that refers to any “joint intellectual effort.” This view would encompass all other group-designed experiences, including cooperative learning. Others oppose this view of collaborative learning stating that it is too simplistic, and they suggest a refined definition is in order (Dillenbourg, 1999). According to Johnson, Johnson and Smith (1991), “cooperative learning is the instructional use of small groups so that students work together to maximize their own learning and each others.” They present five elements of cooperative learning, which are positive interdependence, face-to-face promotive interaction, individual accountability, social skills, and group processing.

In chemistry education cooperative learning is typically viewed as a subset of collaborative learning, or the two are viewed as separate ends of a continuum. (M. M. Cooper, 2005) Cooperative learning groups usually involve specific student roles and are set up for long-term projects. Collaborative learning groups are typically used in less structured environments and can be set up for long-term or short-term use. Numerous studies and subsequent reviews, across the educational field, have focused on attributes of cooperative and collaborative learning. A sampling of these reviews is presented below followed by a discussion of a few promising recent developments in science education.

Qin, Johnson, and Johnson (1995) reviewed forty-six studies involving cooperative learning and concluded that it has a positive impact on students’ success solving complex ill-defined problems. They provided the following
reasons as possible explanations for the effects: “the exchange of information and insights among cooperators, the generation of a variety of strategies to solve the problem, increased ability to translate the problem statement into equations, and the development of a shared cognitive representation of the problem.” Only two of the studies reviewed by the researchers were science related. However, Bowen completed a meta-analysis on studies involving cooperative learning in high school and college chemistry. He reviewed fifteen studies that presented data relevant to cooperative learning in chemistry and concluded, “it is strongly recommended that chemistry instructors continue incorporating cooperative learning practices into their classroom” (Bowen, 2000).

Some chemistry educators have indeed taken to the call for cooperative learning. A quick search revealed hundreds of articles related to cooperative learning and collaborative learning articles filling the pages of chemistry education journals. However, many of these articles only detail the implementation of the strategies. The next section is a review of some of the recent relevant research studies that involved collaborative or cooperative learning. The focus is on articles that presented relevant findings rather than articles that discuss the implementation of strategies.

Recent Evidence for Active Learning in Science Education

An increasingly popular active learning strategy that puts cooperative learning to use is SCALE-UP (Student Centered Active Learning Environment for Undergraduate Programs) (Beichner & Saul, 2003, Beichner, et al., 2008). This
design requires a complete overhaul of the traditional lecture format, including the room. In this learning environment, the design of the classroom plays as large of a role as the materials. In fact its creators say that the layout of the classroom is a “vital” aspect. This model originated in physics, but it has spread into mathematics, chemistry, and engineering. Beichner et al. (2008) made use of conceptual tests to assess SCALE-UP’s effectiveness. The control groups in their study were made up of students in traditional lecture classes across multiple universities. Two different conceptual tests were used to assess the program at each university. Although no information is presented about the similarities of these universities programs or the number of students involved in the study, certain trends were shown via a graph. The graphs presented indicated that the students in a SCALE-UP classroom out-performed those students in the traditional setting at each university tested. Another promoted aspect of SCALE-UP was increased retention rates, especially in women and minorities. Also, Beichner et al. found that the top third of students in the SCALE-UP classroom improved their conceptual understanding more so than their traditional lecture counterparts. This effect was suggested to be due to the fact that these top students are “teaching their peers” in the scale up environment (Beichner et al., 2008).

The postulated effects of teaching proposed by Beichner et al. (2008) are consistent with findings from Cooper et al. (M. M. Cooper, Cox Jr, Nammouz, Case, & Stevens, 2007). The recent study addressed the effects of collaborative
grouping on students’ problem solving abilities. Students were categorized as concrete, preformal or formal using the Group Assessment of Logical Thinking (GALT) test. Students were then paired based on these categories making sure that each possible combination was represented. Students problem-solving abilities were tested using an online ill-structured problem. Evidence showed that all students could benefit from working collaboratively. Students working in pairs were more efficient problem solvers, and their enhanced problem-solving abilities transferred to independent work. Students that saw the largest improvement in problem-solving skills were preformal students paired with a concrete student. It was concluded that this pairing forced the preformal students into the “role of decision maker and teacher” (M. M. Cooper, Cox Jr, Nammouz, Case, & Stevens, 2007).

Peer-Led Team learning (PLTL) is another nationally recognized active learning environment that has made its way into general chemistry (Gosser, Strozak, & Cracolice, 2006) and organic chemistry (Kampmeier, Varma-Nelson, & Wedegaertner, 2006) programs. According to Gosser, Strozak, and Cracolice (2006), the underlying theme of peer-led team learning is “active learning in peer-led groups engages students in the process of learning chemistry. This engagement results in improved understanding of chemistry concepts and of the process of science.”

Quitadamo, Brahler, and Crouch (2009) recently conducted a study to determine if peer-led team learning could enhance students’ critical thinking
skills. They used a quasi-experimental pre-post test design. The treatment group was comprised of students who attended weekly peer-led team-learning meetings, and the control group was comprised of students in traditional lecture based environments. The weekly peer-led team learning sessions consisted of four to eight students working with a peer—a student who had previously taken the course—to solve problem sets. Both math and chemistry courses were used in this study. Results showed a small but measurable increase in students’ critical thinking skills in the chemistry peer-led team learning environment. The authors also claim the peer-led team learning environment reduced gender-biased grading, as females earned higher grades and dropped less frequently in the peer-led team learning environment. This result was contributed to the collaborative nature of the learning environment, suggesting that collaborative grouping has a larger impact on female students (Quitadamo, Brahler, & Crouch, 2009).

Lewis and Lewis (2005) studied an adaptation of a peer-led team learning environment. In their research design, peer-led team learning was combined with guided inquiry, to form what was called peer-led guided inquiry (PLGI). In this study, a control section met three traditional 50-minute lectures per week. The experimental section met two 50-minute lecture sections a week and a third meeting that was a peer-led guided inquiry session. During these sessions, students worked in peer-led groups to complete problems from a published guided inquiry book (Moog & Farrell, 2002). To assess students’ understanding,
four instructor created exams, and an ACS national exam were used. Data analysis revealed that students who partook in PLGI sessions performed better than students at the same SAT level in the traditional lecture course (Lewis & Lewis, 2005).

As stated earlier, Qin, Johnson, and Johnson (1995) completed a review of literature and determined among other things that cooperative learning produces higher achievement gains. Towns, Kreke, and Fields (2000) used that conclusion as a premise for an action research study of cooperative learning strategies. They worked under the assumption that the same effects were present in their learning environment and wanted to determine “how” the effects come about. The cooperative activities in this study consisted of weekly cooperative learning problem solving sessions, and ten to fifteen minutes of each class period devoted to small group learning. An open coding analysis of field notes, observations, and a written questionnaire resulted in two findings: 1) small group learning activities provided a mechanism for students to develop a feeling of community, and 2) collegial relationships were viewed as a positive force of learning (Towns et al., 2000). One of the drawbacks of this study is that quantitative data was not collected to ensure their students were meeting the assumed conditions. However, this study is unique in its attempt to better understand how or why cooperative learning affects students in science.
Conclusion

As constructivism continues to spread its roots in education, active learning strategies will continue to the rise in the college classroom. The review presented here is only small portion of the evidence supporting active learning strategies. Cognitive scientists deserve credit for holding the education community in check and reminding all that constructivism does not imply “hands-on” or “discovery.” Rather, the intent is for students to be “cognitively active” (Mayer, 2004) in the learning process.

A suggestive trend from the reviewed recent articles was the positive effects cooperative and collaborative learning have on female students in the science classroom. This is an avenue that should continue to be explored to fully understand what active learning environments provide for students. Multiple outcomes are attributed to these environments, but it remains unclear what actually occurs that causes the positive effects (Slavin, 1996).

In order to fully understand the benefits of these environments, student input is needed. A mixed-methods study would be ideal for this type of research. The lack of explanatory power in much of the present research was an influential factor in the design of this current research project. The design used in the current project will be discussed in the next chapter.
CHAPTER THREE

METHODOLOGY

Introduction

This chapter introduces the methods employed in gathering qualitative data to address the main research questions of this study. As stated before, this work is the complementary qualitative component of a larger mixed methods sequential explanatory project. Therefore, it is guided by a number of qualitative principles that stem from the working definition of qualitative research used in this study as described by Creswell:

Qualitative research is an inquiry process of understanding based on distinct methodological traditions of inquiry that explore a social or human problem. The researcher builds a complex, holistic picture, analyzes words, reports detailed views of informants, and conducts the study in a natural setting. (Creswell, 1998, p.15)

Many different theoretical frameworks fall under the term “qualitative research” (see Bodner & Orgill (2007) for specific examples in chemistry education). Factors such as philosophical beliefs and the focus of the study play major roles in determining the appropriate theoretical framework. The philosophical assumptions that guide this study are common to most qualitative research. From an ontological standpoint, reality is subjective. Participants’ prior knowledge and beliefs affect the way they “see” an experience. The possibility of determining the essence of the experience exists but can only be achieved by
studying the subjective realities of participants. Because of the subjective nature of reality, the epistemological assumption is that researchers should be close to the participants since the participants are the ones who hold the knowledge.

In the introduction, I discussed the need for this study and how the research questions dictate the use of a particular theoretical framework—phenomenology. It is important to remember that this work is part of a larger mixed-methods study. Two interventions (cooperative problem-based laboratory work, metacognitive collaborative problem-solving exercise) were being used to promote the use of metacognition and thus became the focus of this study. Therefore, the instructional goals and description of each intervention are discussed first. Then I will further discuss the theoretical aspects and implications of phenomenology, and the specific methods used to study students’ lived experiences within each learning environment.

**Metacognitive Interventions**

**Cooperative Problem-Based Laboratory**

The cooperative laboratory format was first implemented at Clemson University in 1992. The goal of this laboratory format is to give the students a “more realistic experience in the laboratory” (Cooper, 2008, p. 6). The laboratory format is created around positive interdependence, social skills, and individual accountability, which are tenets of cooperative learning. In the “To the Student” section of the laboratory manual the students are told that the instructors are concerned with teaching them to “learn how to think” (p.6). Teaching assistants
(TAs) are to act as an “advisor and coach, rather than a person who is going to tell them what to do” (Cooper, 2006, p. 11). The grading in this format is not based on right or wrong answers, but rather how well the students plan, evaluate, and report their projects. The focus of these labs lay squarely on the shoulders of “problem solving, data analysis, experimental design, and both oral and written communication skills” (Cooper, 2008).

At the beginning of the semester students are assigned to groups of four with each member of the team having a specific role: leader, communicator, record keeper, or counselor. Students maintain their roles throughout the first project before the students are allowed to switch. Typically, each project lasts three to four weeks, and students complete between three and six projects a semester. Each project starts by providing the students with a problem-based scenario. From the scenario and a few guiding questions, each group must create a laboratory procedure to meet the goals. Assessment techniques such as lab reports, poster presentations, oral presentations, notebook checks, summary questions, and peer evaluations are used throughout the semester.

All projects follow the same basic layout, but Project 11—“Identification, properties, and synthesis of an unknown compound,”—is especially relevant to this research and can be viewed in Appendix A. This project was treated as a metacognitive intervention in the prior quantitative study (Sandi-Urena, 2008). The following passage sets the stage for the laboratory project:
Your group is employed by the Environmental Protection Agency as analytical chemists. An unidentified compound has been discovered in a landfill in your hometown, and your group has been given the task of investigating it. Obviously you will want to identify the compound, but this is not the only thing you will need to do. It will be very important to the people of the area to know the properties of the compound, both chemical and physical, so that you can make predictions as to how it might behave. For example, if you know the solubility of the compound, you will be able to give some indication of whether the compound will leach out of the landfill during heavy rain. If you know what kind of reactivity the compound has, you could make some prediction on the same disposal and the longevity of the compound. If the compound is not very reactive, it may not be as long lived, but it may react to produce something more toxic or difficult to dispose of. Therefore, it is very important that you amass as much information as you can (Cooper, 2008).

Each group is given one unknown inorganic compound and has four to weeks to complete their analysis. During this time the “team analyzes the problem, sets intermediate goals, plans strategies, designs and implements experiments, learns necessary lab techniques, discusses and evaluates process and outcomes, answers guiding and planning questions and so forth” (Sandi-Urena, 2008). Since this is the first project of the semester, students turn in individual preliminary reports during week four in order to gain valuable feedback from the
TA. These preliminary reports are graded and returned to the students the next week. In the fifth week each group is required to give an oral presentation with the use of a poster as a visual aid. Finally, the students use feedback from the preliminary report and the oral presentation to complete their final written report to turn in, in week six.

In previous quantitative studies, this laboratory project was used as a metacognitive-promoting intervention. By assessing control and treatment groups with the multi-method technique, this laboratory project was shown to increase student’s metacognitive awareness, strategy use, problem solving ability, and solve rate. Students' increase in metacognitive skillfulness is attributed to the contextual characteristics that are present in the laboratory experience.

**Metacognitive Collaborative Problem-Solving Exercise**

The metacognitive collaborative problem solving exercise (Appendix B) is designed to "provide an opportunity for students to engage in small group collaboration and individual work that promoted reflection about processes and products in a problem-solving situation" (Sandi-Urena, 2008). The purpose of creating this problem-solving exercise was to "promote general metacognitive skillfulness" (Sandi-Urena, 2008). Details of the design of the instrument are reported elsewhere (Sandi-Urena et al., Submitted; Sandi-Urena, 2008). This section will focus on what the students are required to do to complete the exercise. The problem-solving exercise is completed in three different yet related
phases. Each phase is specifically designed to minimize instructor interaction and allow the students to actively reflect on their problem solving skills.

The first phase, which is completed collaboratively in class, presents the students with one non-chemistry related problem, the correct answer, and twenty-six metacognitive prompts. The students work the problem in teams of two or three and are then given the answer in hopes of creating cognitive discourse. Then, the student pairs respond to the twenty-six prompts that are designed to specifically address aspects of metacognition use. These prompts vary from yes or no questions, explanations, to selecting from a list. The question and representative prompts used in phase one are as follows:

Barbara asked me to bring her a pair of stockings from her bedroom. Unfortunately the bedroom is dark and the light is not working. I know there are black socks and brown socks in the drawer, mixed in the ratio of 4 to 5. What is the minimum number of stockings I will have to take out to make sure that I have two stockings of the same color?

1. “Do you think your group started working on the solution having a clear understanding of the problem? (yes) (no)”
2. “Do you think that using a representation did improve/would have improved your performance? Explain briefly.”
3. “Read the following statements and mark yes, no or n.a. (not applicable):
   The team answered the problem inappropriately fast."
The team used some sort of representation (drawing, diagram, flow chart, etc.)

The team devised a plan.

Was the plan complex?

Was the plan purely mental?

Was planning sufficient?

The team thinks planning is not indispensable."

Phase two of the problem solving exercise is an individual homework task. The students are presented with two problems, and choose one problem to complete. The students then answer 13 prompts. Again, both of the questions are non-chemistry related and the prompts are focused on aspects of metacognition. In this phase, the students work their chosen problem and answer nine prompts before receiving the correct answer. After being presented with the answer, the students are asked if they can explain the solution.

Phase three is an exercise in which the students “reflect about the activity as a learning experience stressing awareness and meaningfulness” (Sandi-Urena, 2008, p.79). Students receive feedback in the form of a handout that summarizes the findings from the previous phases. Samples of students work were compiled to create this handout. Students are once again presented with the problem from phase two, but this time the answer is in the form of a figure. Then, the handout provides...
students with the reasons prior students gave for the poor solution and students are asked to check all that apply for their case.

In a recent study (Sandi-Urena et al., submitted) the problem solving exercise was shown to be effective in promoting the use of metacognition. When control and treatment groups were assessed via the multi-method technique the treatments group increased their metacognitive awareness, problem solving ability, and solve rate. These effects were attributed to the collaborative nature of the intervention and the prompting of metacognitive processes.

**Theoretical Framework**

This study is framed within the perspective of phenomenology. “Phenomenology attempts to disclose the essential meaning of human endeavors” (Bishop & Schudder, 1991, p 5). This method is based on the belief that “truth can be found in lived experiences” (LeVasseur, 2003, p 409). Phenomenologist ask for the very nature of a phenomenon, for that which makes a some-“thing” what it is—and without which it could not be what it is” (van Manen, 1990, p. 10) By doing so, researchers are able to “grasp the very nature of the thing” (van Manen, 1990, p.177). It is the purpose of this research to “grasp the nature” of students’ conscious experiences in a cooperative problem-based laboratory and with a metacognitive collaborative problem solving intervention.
The phenomenological approaches, used today, are based on the philosophical work of two authors: Edmund Husserl and his student Martin Heidegger. Husserl’s phenomenological philosophy is built around the components of *intentionality, essence, and phenomenological reduction (also known as bracketing or epoche)*. Intentionality refers to the belief “that consciousness is always directed towards an object” (Creswell, 2003, p. 59). The second component of Husserl’s work is that lived experiences can be reduced to essential meanings—the essence of a phenomenon. The way of studying one’s intentionality to determine the essence of a phenomenon brings about the third component, the process of phenomenological reduction. Stewart and Mickunas, as cited by LeVasseur, suggest that Husserl used the terms phenomenological reduction, bracketing, and epoche synonymously. (LeVasseur, 2003) Phenomenologist use this process to “suspend one’s natural assumptions about the world…so that what is essential in the phenomena of consciousness can be understood without prejudice” (LeVasseur, 2003, p. 411). Followers of Husserl have taken his philosophical beliefs and created the methodological framework of transcendental or descriptive phenomenology (Moustakas, 1994).

Despite Heidegger’s alignment with Husserl on the principal of intentionality and phenomenological reduction, Heidegger’s beliefs of bracketing differ dramatically. Heidegger places focus on the *lifeworld* and its relation to the participant. According to Heidegger, “humans cannot abstract themselves from
the world” (Lopez & Willis, 2004, p. 729). Our thoughts and beliefs are situated by our background and prior experiences. According to Lopez, “Heidegger (1962) asserted that humans are embedded in their world to such an extent that subjective experiences are inextricably linked with social, cultural, and political contexts” (Lopez & Willis, 2004, p.729). In Heideggerian philosophy these components are known as being-in-the-world, and situated freedom, and because of them it is impossible for researchers to completely bracket our prior understandings. However, making our assumptions “explicit and explaining how they are being used” is considered useful (Lopez & Willis, 2004, p.730). This component of pre-understanding, in which expert knowledge is valuable and can even guide inquiry, is in stark contrast to the seemingly mythical removal of oneself described as the process of epoche. Those that followed the path of Heidegger are attributed with developing the methodological framework of interpretive or hermeneutic phenomenology.

This study seeks to determine the nature of students’ experiences. Therefore, the philosophical underpinnings of this work are more closely related to the beliefs of Heidegger. While many researchers have taken the work of Husserl and Heidegger and created research methods, this study follows the phenomenological framework put forth by van Manen (1990). Cohen and Omery (1994) describe these methods as being from the “Dutch School,” combining both descriptive and interpretive aspects in phenomenological research. Van Manen (1990) recognizes that a single stepwise plan cannot possibly fit all
phenomenological situations. Therefore the methods discussed in the next section do not follow a strict plan put forth by van Manen, rather they were deemed appropriate based on the guidelines presented above.

**Methods**

The methods for this phenomenological study are drawn from the aforementioned theoretical framework. The methods presented in this section were used to collect and analyze data for this research. In this section, participant recruitment, data collection, and data analysis will be covered.

**Participant Recruitment**

Purposeful sampling was used in this research project for participant recruitment. Purposeful, in this sense, means that each participant had experienced the phenomenon in question. An email was sent to every section of General Chemistry Laboratory (CH101L). Thus, every student received the same email and had an opportunity to participate. All contact between the participants, prior to the interview process, and myself was conducted via email. I was not a TA for CH101L during that semester. On occasion, I walked through the CH101 labs to assist TAs in implementing assignments that would later be relevant to research purposes. However, I did not have direct contact with the students during those visits.

Thirty-three students responded to the original interview to say that they were interested in participating. Of the thirty-three, eleven students found times that were suitable to our schedules. Of the eleven students who agreed to
participate, nine actually attended their scheduled interview. Therefore, the sample for this study is nine first semester, general chemistry laboratory students. The number of participants is in accordance considering the in-depth nature of a phenomenological study (Creswell, 2007). There were a total of five female participants and four male participants in this study. Eight of the nine participants were Caucasian and one was African-American. Two of the female participants would be considered “non-traditional” students and were not in their first year of college study.

**Data Collection**

Semi-structured open-ended interviews lasting between forty-five to eighty minutes were conducted with the participants. Semi-structured open-ended interviews were used due to the theoretical assumptions of phenomenology. Since the participants are the ones who “hold” the information, they had to be given the freedom to discuss their experience. Using open-ended interviews allowed the nature of students’ experiences to emerge during the interview process.

Although the participants had previously signed IRB consent forms, (Appendix C), I reminded the participants that their identity would be kept confidential. The students were also reminded they were free to end the interview at anytime, and that participating or not participating had no effect on their course grade. I started each interview by letting the students know I would
ask some background questions (Appendix D) before we started talking about their lab experience.

The background questions served two purposes. First, they were used to make the interview comfortable for the participants. Secondly, they were used to gather information that may have impacted students’ current experiences. While, it was impossible to garner all the background knowledge the participants brought with them to the college chemistry lab, answers to these questions gave a reference point to refer back to for comparison purposes.

After addressing relevant background information, we proceeded to discuss students’ experiences with the cooperative problem-based laboratory and the collaborative problem-solving intervention. The interviews followed a semi-structured process. Each student was asked the questions on the interview protocol, (Appendix D). However, a conversational manner was maintained in order to increase flexibility and further elicit information that arose during the interview process.

To address students’ experiences in the chemistry laboratory, they were asked: how has your experience been in the chemistry laboratory this semester?, how is it similar or different to the other labs you are taking? What effects, if any, has the work in lab had on your overall general chemistry experience, including the lecture course?, and finally Do you think the experiences in the lab course had any impact on the way you think of chemistry problems now?
Next, students were asked to respond to questions relevant to their experience with the collaborative problem-solving intervention: What was your experience with this activity?, Did it have any effect on your work with the Hazmat problems, why, why not?, and finally, We observed an increase in the correctness of the answers from students who participated in this exercise. What do you think could have caused this change?

Finally, students were thanked for participating and given a final opportunity to discuss anything else they had on their mind.

All interviews were tape-recorded and transcribed verbatim by myself. Each interview participant was given a pseudonym in order to conceal his or her identity. The transcribed data was then uploaded into NVivo7, a qualitative analysis software program used to assist in data analysis.

Data Analysis

Two graduate level researchers, a group member and I, performed the majority of the data analysis. During this process, we independently analyzed the data, and then held meetings to discuss our analyses and potential thematic aspects. Van Manen’s phenomenological methods were used in guiding the analysis of the participants’ transcripts. First, each transcript was read several times. Within this approach, each transcript was read several times while asking, “what statements seem essential or revealing about the phenomenon or experience being described?” (van Manen, 1990, p.107). A selective highlighting approach was used to uncover thematic aspects within the
interview transcripts. The essential statements were grouped together in relevant themes, and further scrutinized during collaborative meetings. The purpose of these meetings was to triangulate the analysis and determine if we were interpreting the same thing. It was clear that we were interpreting the same experience only using different terminology for explanations; therefore we discussed and agreed upon a consistent terminology. During the meetings, figures were created and adapted to help model the overall outcome space of the analysis. We used these figures to reanalyze the interview transcripts for confirming and disconfirming evidence, and adapted the thematic units and figures when necessary. This process is considered constant comparative analysis, which started in grounded theory methodology (Strauss & Corbin, 1990) but has since spread to other areas of qualitative research. The figures were also presented to a qualitative research specialist who had access to the transcripts. The process of peer debriefing along with constant comparative analysis and triangulation between researchers helped ensure the validity of our interpretations.

Conclusion

Phenomenology was chosen as the research method in order to shed light on the true nature of students’ experiences in each learning environment. This chapter presented information relevant to the research design. Methods presented in this chapter led to the collection and analysis of data, which will be discussed in the next two chapters. Chapter Four contains narrative descriptions
of each participant's experience in each of the learning environments. Chapter Five provides the phenomenological analysis of the participants' experiences.
CHAPTER FOUR
NARRATIVE DESCRIPTIONS

Introduction

This chapter includes narrative descriptions of each participant’s experience. Students cooperative problem-based laboratory experience will be presented first, followed by the metacognitive collaborative problem-solving exercise experience. Each participant’s story is told without reference to the other participants’ experience. The narrative descriptions are attempts of letting the participants “voice” come through.

Interpretations and analyses of these experiences are withheld until the next chapter. Note that the narrative descriptions do not have to be read in order to understand the phenomenological analysis that is presented in Chapter Five. However, the information presented here provides the reader a chance to become situated in the experiences of the students before being presented with the phenomenological analysis. The reader may use these narrative descriptions to begin forming his or her own analysis, or he or she may use this information as a form of validity checking after reading the phenomenological analysis presented in Chapter Five. Direct quotations are used throughout this chapter. Grammatical errors were not corrected, except for repetitive wording. Brackets were used to denote research input, and ellipses were use to indicate research omissions.
Cooperative Problem-Based Laboratory Experience

Anna

Anna had very strong feelings for the cooperative problem-based laboratory setup. In her words, “Um, honestly, I hate chemistry lab. Uh, I really like my lab group and I like my TA a lot, but the chemistry lab sucks and I don’t like to complain a lot but [I] do think it sucks.” Anna’s hatred of the chemistry lab originated from comparing chemistry lab to her biology lab.

Um I guess I compare [chemistry lab] to biology lab because I have biology on Monday and chemistry on Tuesday and [in] biology your TA walks you through what to do, kinda, and you at least have like a foundation of what you’re doing and [biology TA’s] kinda help you out. There’s like guidelines for what you’re supposed to do, as opposed to chemistry lab where they’re like oh, here go find a compound and you’re like what do I do and they’re like oh well use your lab manual and we’re like ok it has no directions. So I just kinda feel like I have no idea what to do.

Anna liked that fact that, in biology lab, she had a plan and knew what to expect. Anna goes on to say that the biology lab setup was “more chill,” because, as she stated, “[in biology] you’re sitting down. You have all your stuff right in front of you, what you need, and it’s just a lot more organized, as opposed to kind of go find what you’re supposed to do.” Anna favored the organization of the biology lab, and felt that she understood what she had done and why when she left the lab each week.
I just know what I’ve done, and I know why I’ve done it. I think that’s the biggest thing. Like we did electrophoresis and I know what I was doing, what I was looking for, and what like this graph represents and what like these segments represent and so and our TA explained it to us when we got the final results.

Chemistry lab, on the other hand, was full of mistakes, confusing moments, and a sense of the unknown for Anna’s group. Anna stated, “[in] chemistry [lab]…we do it wrong at least once, and then I think every group does it wrong at least once, and then you don’t really know if you’re ever doing it right.” Anna found lab work very difficult to handle when the procedure was not given to her. She felt more comfortable when she received correct information from a trusted source.

So, I mean I don’t like to put something in my head that I’m not sure if its right and I like to know its right, and then I’ll, you know, go with it, but we just, I, you never know what you’re doing exactly and its kinda like well I think it’s this and then if we do know what we’re doing I don’t know why we’re doing it and so I just, it’s just so confusing. I guess.

Anna turned to her TA to overcome confusion and frustration; “I rely on my TA so much, I go up and ask her so many questions.” According to Anna her TA provided the students with an overview of what they should do each day, including a procedure to follow. Her class was usually not required to create their own procedures. In Anna’s lab, it was the students’ job to “fill in the cracks” using their lab manuals and other resources to “figure out how to do certain
procedures.” Anna sated “[once we determined how to do the procedure], we go ask our TA, is this what we’re supposed to be doing?”

Anna declared, “I haven’t really taken much from chemistry lab.” Upon further questioning Anna explained, “I don’t really, when I take stuff from [the lab] and apply it I just like I don’t think that I’ll ever need to know the color of sodium under heat or whatever.” Anna did not see a connection between the content of chemistry lab and her future. However, Anna revealed that she was “learning how to use her resources to create procedures.” When asked what process her group goes through to create procedures Anna stated,

we [use] the lab manual and we read it and we figure that stuff out and we see as much information as we can gather from that, and then the information the TA gives us and then we kinda like devise a plan to go by and then when that starts either not working you know we do something wrong, miscalculation, um you know we go to the TA or we just keep looking in our lab manual so it kinda…gives you that kind of, you don’t really know what to do just use your resources kind of thing. So it teaches you that you’re not, I guess it’s out of your comfort zone because you want. I mean for me like I’d rather be given a list of instructions and follow them and learn from it that way as opposed to doing my own thing and just kind of I don’t know doing it by myself and not really know what to expect.

Although Anna found this process confusing and frustrating at times, she credited the laboratory process with helping her prepare for upcoming challenges and
problems. Anna had a better understanding of how to go about finding answers to the problems by the end of the semester. She reflected on the overall process by saying,

coming from high school where everything is pretty much given to you anyway, I didn’t really know what to do. But at least now going into the different labs, like when we start a new project, I kind of know what to expect. And I kinda know that it’s our responsibility to make a plan, and figure it out. So, I’m more prepared coming in for these labs then I was at the very beginning when it was, when it was very bad.

Gina

Gina described her laboratory experience as “hectic” in a sense that “nobody knows what’s going on.” According to Gina, her TA told the class which project to begin with a minimal amount of instructions, but Gina felt her group remained "lost on what steps you actually need to be taking. Gina stated,

[it was] really hard to determine what you’re supposed to do for lab…’cause it’s like you have ten pages of what you’re supposed to do for this lab but there’s never one clear cut thing that you’re supposed to find and then here’s the steps that you can do them. I mean I know they don’t want to give you ok here’s this step and then this step but it would be nice to like have it clear this is the goal no a five paragraph like section that says this is what you’re trying to find.”
In fact, Gina thought the hardest part of lab was determining what their end result should look like—“what the final goal is.” She understood the format of the cooperative problem-based projects was designed so that students had to create their own procedures; however, Gina wished the problem had given to them in a sentence rather than a case scenario.

In order to overcome the lost feeling, Gina’s group would often turn to the Internet in search of information.

We use the internet a lot because the lab manual is like well you need to determine ‘this’ and we’re like, well, we don’t even know like what ‘this’ is. ‘Cause a lot of times the lab comes before we do it in chemistry class. So, we don’t even know what the process [the manual is] talking about is.

After gathering relevant background information, Gina’s group attempted to “figure out, ok we need to do this so we need to do these like seven steps and then break it down past that and say well to find the pH of something we need to do these four things and then start doing it.” Gina descried herself as having a “lead personality” and often started her group’s planning process. She felt working with her group in the chemistry lab was a good experience but had frustrating moments, “just as any group [would].”

Jane

Jane was “not incredibly fond of the laboratory”, but it was clear these feelings were directed towards the actions of her TA. Jane stated that from the beginning she and her classmates had a hard time understanding their TA when
he spoke. However, Jane said as the semester progressed her group was able to ask him questions, “even if it takes a couple of times explaining what we’re asking for, he is able to figure it out eventually.” Jane was also unhappy with her TA’s grading and felt that he tried to act “authoritative” at certain times while he was very lax and unprofessional at others. For example, Jane discussed her frustrations with her TA taking two points off of her lab report for grammatical issues but not requiring them to make up a required oral presentation. At the time of the interview, Jane said she had only seen two of her grades. Jane wanted to be better informed and felt her TA was not doing a great job. Jane said her ideal TA would be “somebody who lets us experiment like [lab is] supposed to be, [a] problem solving environment, but is willing to help, willing and able to help us to some extent [without] leading us through everything. So, if we ask a question, ‘how are we supposed to get to the answer?’, he’s going to be like well I can’t tell you that but here’s a hint and just guide us like any teacher would.

Even with Jane’s indifferent feelings towards her TA, she credited his actions, or lack there of, with leading to a positive outcome. While talking about her TA, Jane stated, “the one thing I can say good about [my TA] that I think is very strong is the fact that because we don’t get any instruction we really do have to learn the material to um be able to complete the lab stuff so.” Later Jane stated,

I’ve gotten so frustrated with my TA, but at the same time, I do see the way
that the whole open-ended you figure out the problem format of the lab is helpful….I even said I think it does help you learn it the fact that you have to go about it that way

In order to “learn the material,” Jane stated,

we have to have our laptops and normally we go online and research whatever the background is or um our chem. Lab manual actually explains a good amount of stuff in there too, so if you just kinda look through it to find exactly what we’re researching then it makes it a little bit easier.

When asked how this lab experience was similar or different from her previous high school labs Jane said;

[In high school] we were told exactly what to do and how to do it, with what supplies to use, etc. In this [cooperative chemistry] lab we have to figure out what we need figure out. How to use it, figure out what’s going on in the process and come to conclusions all on our own. Its not as guided, which can be a good or a bad thing. So, I can understand why they would want that in the aspect we’re learning it more thoroughly but it does get frustrating at times.

For Jane, group work allowed her to transition from very guided high school lab instruction into cooperative problem-based lab instruction.

[With] four people it tends to be a little bit easier to figure things out, because we have four brains working on the same thing and also, the group that normally works next to us, when either one of us has a problem we can
go ask the other group. So I mean its just problems, like you just have to work it out, you just have to go about something, if it doesn’t work, try something else and eventually, normally, we can come to the right conclusion. It does get frustrating though.

Mark

Mark began college with more laboratory experience than the other interview participants. Mark attended a specialized science and mathematics high school, and he also participated in a summer research program before starting college. Previous experience led Mark to be disappointed with the equipment in his freshman labs, and at times he did not feel comfortable using the equipment he was given. Mark felt his science background gave him a better understanding of the aspects of lab. When comparing the cooperative college chemistry labs to the labs he experienced in high school, Mark stated,

I guess a main difference is instead of spending like three days for a lab [in college], a [high school] lab would be like one day of concentration and the class would be pretty much in sink with the lab…[In college] I guess the approach is not to really enhance what you’re learning in class, but to think logically.

Later, Mark was asked to compare his college lab experience to previous research experience. He felt that both the laboratory projects and his research project started with a feeling of not knowing. However, Mark felt the laboratory projects were a “bit more predictable” because his prior background knowledge
gave him a “general consensus of what will happen at the end.” Research involved more “mystery.” Mark went on to say,

for the research, I think the courses will give you a background of generally what you’re supposed to know and then when you go into the [research] lab you’ll be able to imply like, use what you know to try to figure out something that is unknown or I guess something known that you’re trying to pretty much get to that result.

Mark felt the cooperative chemistry lab was trying to get to the level of research, but he does not view the freshman chemistry lab as research; “mainly because, I expect the result to be already known, and since it’s already known that means it’s something, like I’m assuming I should know how to figure out the result already.” Some procedures were given in his cooperative chemistry lab, and he felt, “in research there really isn’t much a procedure to follow.

Mark believed the lab experience had not had an impact on his other classes mainly due to his familiarity with those subjects. Mark mentioned that his first semester classes were very similar to ones he took in high school so he was “riding in” the semester. However, he felt if he took something from his lab experience into future classes, it would be how to “understand the problem.” Mark felt that he had received an extant of what he should have from the lab experience, which in his words was “problem-solving skills.” However, he wished the program were more explicit with the overall goals, and felt it could help others avoid confusion. “I guess if they told us initially that we’re trying to see if you can
figure out how to do this or that, they’d probably be able to pull it off that way. Like you know, try to use what I know…” Mark’s chemical background was far superior to his group members. However he felt working in his group taught him “about getting things done.”

Mary

Mary had an overall enjoyable lab experience, but the enjoyment was not without troubles or setbacks. Mary mentioned the difficulties of trying to navigate the expectations or “big picture” of each project as well as trying to figure out the exact “road to take.” To her, the difficulties had to do with the nature of the lab and the freedom that was given to the students in creating their own procedures. Although, Mary stated it was difficult for her group to create their own procedures, she actually enjoyed that aspect of the program. Mary compared her biology lab to the cooperative chemistry lab by stating,

It was kinda helpful to have both because I got to see some of the differences in ways that I like to learn. It was kind of constricting to have all those certain steps, [in biology lab], that I have to do, and I don’t necessarily know why I’m doing them. With the chemistry labs, I don’t have the steps, but I understand what I’m supposed to do and what I’m doing. So therefore I understand the reasoning behind it. Um, so its nice to have that freedom [in chemistry lab], but, like I said, it was just a little bit difficult sometimes to figure out I guess the exact road I’m supposed to take, in the respect of, you know, what’s the end result supposed to look like.
In order to determine the path to take, Mary relied on an array of different resources. The lab manual, group members, other groups, textbook, and TA became valuable resources for Mary when creating procedures. Mary felt her TA was a weak link in the lab process. Although Mary realized her TA was trying to get her to do the work, Mary would have liked more guidance. She stated that she wanted “the freedom to figure things out and still have a support system so when I’m going downhill somebody can redirect me.”

When Mary was asked if things were easier during the latter portion of the semester, she claimed she began to adapt to the format. Mary contributed her familiarity with the expectations, “I knew what I had to do,” and the knowledge gained during lecture with helping her “figure out what to do [for each project]—big picture wise.” Mary left the chemistry lab with a feeling that she was now more prepared to “figure out” problems on her own.

**Pedro**

For Pedro, the cooperative chemistry laboratory was an interesting experience in which he had to learn to overcome group conflicts in order to work together to solve problems.

Group problems aside, Pedro felt it was difficult to begin each project. He stated,

It’s kinda difficult to get started on labs but...actually doing them, once you get like a jump start to it, it get easier as it goes, ‘cause you kinda know what you’re doing by that point. You understand what’s going on, but, like, when you first hand in the lab and you’re like ok this is what you’ve gotta do,
it’s always like, um, we don’t really know where to start, but once we find that starting point it’s alright.

In order to find the starting point, Pedro’s group turned to research in their chemistry books to better “understand the question.” Their TA was also available for assistance. Pedro stated,

[Our TA] doesn’t like outright give us the answer ‘cause I guess he’s not allowed to do that, but he can kinda guide us in the right direction of like this is what you need to look for, this is what you need to kinda set up, and then once we do that we understand what we’re doing.

Even with the help, it was still a hard process to find that beginning point. Pedro expressed his wishes that the lab more closely paralleled lecture,

I think that would help to kinda gain a better starting point when you’re confused, when you start. I think it would help. You would have ideas of how to start and you can see like if you don’t have an idea you can go back and oh well we learned this in the last two weeks in lecture, so lets read through this and just kinda summarize what we were going through and then try to see if that helps us apply it.

When comparing the cooperative chemistry labs to his other labs, Pedro stated one difference was the group environment. In chemistry, two of his group members had poor relations that led to a verbal argument, but after the argument the group began to function normally. Pedro felt that even though his engineering lab was set up similarly, with groups, the students in engineering
were more motivated because they had a purpose for taking that class.

Saul

For Saul, the laboratory experience was a “lot of new things.” Saul felt the cooperative chemistry laboratory experience was similar to his other labs in that it helped him ‘understand [lecture] material better’ because the lab experience gave him visuals to put with the information he received in lecture. Saul stated that he usually had an idea of what was going to happen in his other labs, but that was not always the case during the cooperative chemistry lab. He felt as if his background in chemistry was not as good as some of his group members, and often had to refer back to his lab manual for a better explanation of the tests his group decided to run. Throughout this process, Saul gained an appreciation for visualizing concepts and stated his approach to lecture classes has changed. Saul credits the laboratory experience with turning him into an “active participant” in his lecture class. Before the lab experience, Saul would sit idly listening in lecture class, but he noticed that when he went back to study he had a hard time understanding any of the material. Saul felt the laboratory work with opened his eyes to the power of visualization, and he started to try to “visualize” and “conceptualize” the information he heard during lecture.

For Saul the laboratory experience also offered him a chance to overcome a ‘bullheaded’ attitude in which he always wanted to be in charge. Saul realized ‘his peers really do know quite a bit’ and had to step back to let them take the lead on many projects. Admittedly this was not easy for Saul, however, he felt it
was a valuable lesson and gained a ‘different perspective on how to [lead].’ Saul also credited interactions with his group members with helping him understand what was happening in lab.

[my group members] understand what’s happening and…they know what they’re doing, but they’re on the same level as I’m on. So they can work better to relate it to me, where a graduate student, like my TA, he kinda forgot what its like to be right there and…he skips over some of the basic concepts…and the students down at my level can be like oh well I know what you’re missing, you don’t understand this part. And then they can go back and understand it and explain that to me so I can understand it.

But more than anything, Saul states the cooperative laboratory experience was about learning the “concepts behind the things”; “It’s learning why you do this, I mean we can sit there and analyze chemicals all day but if you don’t know why you’re doing it then there’s no reason to it.”

**Ted**

Ted came to the interview with hopes of making the chemistry lab better for those who came after him. Ted was a man of few words and described his laboratory experience as “eh, well, difficult.” Ted admitted being confused from day one, when he was unclear about which book to take to class. From there, it only got worse as he was unable to understand his TA’s accent. According to Ted, his first day troubles led to a few months of not knowing what was going on. As the semester progressed some things changed for Ted,
at first I was doing none of the work because I had no idea of what I was
supposed to be doing and I was kinda worried about my safety because I
didn’t really know how dangerous the chemicals were. But, uh, like, for the
past several weeks, now that I know what’s going on, I have been a more
active participant in [lab].  

When asked to compare his chemistry lab to other labs, Ted claimed that
there were not many similarities because,

“In, um, the other labs I’m a part of there they give us directions on what
we’re supposed to be doing. But, um, in this chem. Lab, um, they don’t
really give us concise spoken directions. They’re primarily expecting us to
understand what is in the lab manual so its, um , we're pretty much going
on our own.”

Even with the difficulties Ted faced during the chemistry lab, he did favor some of
the freedom offered with the cooperative style. He admitted his ideal lab would
be a combination of his different labs. Ted felt a larger overview at the beginning
of a project would have helped him know where to look when problems arose.

Zoey

Zoey described herself as a “hands on type of person” and stated, “I loved
the labs, I think labs are great.” However, the loving moments were few and far
between during Zoey’s first lab project. In fact, Zoey described the first project as
an intimidating experience:

I was very intimidated the first uh, project that we had, just because, I felt
like we were kind of thrown in, and we had to try to swim to the surface to try to figure out what to do. …I’d never done a chemistry lab. So I was a little intimidated by it, but after, about, the halfway through the first project, I started to get in my groove and did pretty good after that.

Zoey overcame her beginning apprehension with the help of her TA. She was very fond of the way her TA handled the class and treated her.

The first two labs were so frustrating, and I thought, oh my God there is no way I’m going to make it through this, this entire semester….[but] my TA did help because when he could tell that I was like beyond frustration, he was like ok lets, lets think about this for a minute. You know, look, look at this. You know, go back to your solubility rules, and its like, Oh! He kinda helped me connect the dots, but um, just, sitting down and calmly trying to figure out a logical way to go about what I had to do. Ok, what we, what’s the first thing that I should do, and in the lab manual you know when I figure out, oh, it’s in the lab manual you know. You know, doing the flame test and everything, you know, narrowing it down. I kind of, kind of got a plan of action….then I was like, wait a minute, we’re doing this, and then it kinda clicked and then I could connect the dots. But just sitting down and calmly trying to figure out a logical way to approach the problem and then working on steps to do it.

When Zoey was asked how her chemistry lab compared to her biology lab she said, “I guess for a lack of a better term there’s more structure to [biology
lab], Because you know what you’re doing before you get in there, and its written up on the board.” Zoey continued to discuss the differences between her biology, chemistry, and microbiology lab.

My micro lab at tech was setup the same way [as biology], where when you walked in, everything was written on the board what you were going to do that day, and you had more guidance with it. Now granted stuff is written on the board in the Chemistry lab but you kinda flounder around to try to figure out exactly what you’re supposed to do. We have, like, in the Bio. lab here, they’ll give you the pages of what you need to cover before you come to lab. Um, you take a quiz on that stuff that you’re covering before you even cover it, but it makes you study and prepare for that lab, Um, sometimes I felt like I didn’t exactly know what to study for in the chemistry lab. Um, but then like I said about…when I go to the second lab, which was the analyzing the colas, I kinda understood a little bit more, but you had to figure it out on your own, it wasn’t handed to you [in chemistry], like it is in biology.

Zoey felt that her chemistry lab experience had a positive impact on her overall chemistry experience. She wished the lab had been more coordinated to the lecture, because she felt had she done some of the projects earlier in the year, she would have done better on the lecture exams. When asked to elaborate, she discussed how a calorimetry project helped her understand the concept of enthalpy, saying,
doing the math in lab and having the hands on and understanding. Like the whole enthalpy thing, understanding what you were doing with that math, it made it a whole lot easier to understand that just, in lecture looking at a board and saying, ok this is the formula for that, and this is how you figure this out, and this is what you’re figuring it out. You know it was easier to see it in lab, do the experiment, and then sit, I understood why I was doing that.

Zoey also contributed her laboratory experience with having a positive impact on her other courses due to the problem-solving aspects of the lab:

the process of learning helped me, the whole process of you know, of having to figure out some of this stuff yourself and my TA is wonderful…at first, he was very, you know, you gotta figure it out. I'm like, ok, but how do I figure it out? Look at it; figure it out. Look at what, what do you want me to look at! ‘Cause I was really afraid I was going to blow something up, you know. I don't want to mix something up, and blow this lab up, you know,…but him being insistent and not handing me the answer did help me with my thought process. Ok, lets work smarter and not harder. Which, which is the best way to look at this problem and figure out how to do it. And that has helped me in my other classes.
Metacognitive Collaborative Problem-Solving Experience

Anna

Anna and her partner began the problem solving exercise by answering the first question correctly. When asked how they solved the problem, Anna stated:

Well, um, well, we just, I mean we wrote out the 4 to 5 [ratio] but, um, I guess, we had a bunch of different things going through our head and she was saying numbers that were probably, I thought were too big, and then, um, and then we just kinda thought it through and, and so, and then I said three, and…she didn’t agree with that at first. So we kinda talked it through, and then we, and then we came to the conclusion….well if you have two color socks then, you can’t take out more than three.

Anna claimed the most important aspect for correctly solving the problem was “understanding what it’s asking.” Anna and her partner also identified “reading the problem, reading it through carefully…understanding what it’s asking and kind of getting all of your information, sorting out what you need and what you don’t need” as being beneficial to problem solving.

When asked how she would explain the prior quantitative findings, Anna said,

[The problem solving exercise], it’s just kind of reinforcing how to go about solving a problem, and telling you do this do this you know kinda saying read it close, read it carefully, understand it, before you start guessing and stuff. So it kind of tells you to work hard at it.
After being asked to expand upon what she meant by “it tells you to” Anna stated,

…that’s how I interpreted this assignment, was, um, figuring out ways to become better problem solvers. So, I guess I told it too [do those things (read it close, etc)]. I wrote [answers] down and told it too…. [So the exercise is] making you think about it, [problem-solving], and figure out how to do it.

Gina’s lab section completed the problem solving exercise the same day as her interview. When asked about the first problem, Gina stated,

I remember to start with we looked at it and we were like ok its going to take 6 because you gotta have—actually it was me another guy working on it—I started making a chart and that kinda helped. Because I was like, well if you start with brown and black—if you have 6 then you have 0 of that. And then that would be 5 and one, and four and two. And then we realized ok that’s way too many we were like, we have too many socks. So then we ended up getting it down to where you had brown and black and you had—what was it—4 and 0 and like 3 and 1 and 2 and 2. So no matter what, you were going to get a pair.

Gina later discussed that she felt they understood the problem but went about solving it the wrong way.

The experience caused Gina to think, however she did not sense that she
received a lot of benefit from it. She correctly answered each problem presented in the exercise and felt that the exercise did not have a large effect on her because she already “thinks outside the box.” However, she felt like the exercise would be beneficial to those students who were not accustomed to thinking that way.

Gina attempted to explain prior quantitative findings by saying,
I think also just because like when you were filling out all the things, [prompts], it made you think about—Like when it said what were some of the…obstacles that somebody would face like solving a problem—reading all the directions and making sure you look at all the information…So like later on, two weeks from now, if you’re doing hazmat you’d think about those, and also like the things with like the cars and the eggs. It makes you think about it a little harder it’s not just clearly obvious, the right answer.

When asked what she meant by “think about it” she described her original thought process for solving the egg problem, then said, “you have to say ok well you know that might be an answer, but is there another possible way that it could work or is there another combination I could do or could I split it up somehow?”

Jane

Jane was one of the two students who had not completed the problem solving exercise before coming to the interview. Jane was asked to read the first problem and think aloud while solving. Jane stated:

This is the kind of question that if we were given in lab, our group would,
one of us would suggest something, the other one would figure out what was wrong with what the first person said and that’s why our group works well together because we all think differently. I would probably start that one out by being like, well you don’t know that you have all stockings of the same color. Well first of all you don’t know how many stockings are in there total so you can’t say maybe there’s only ten pairs so then you know that there’s two socks in there that are um brown, no black. So then I would say you needed all but two, all but one of them that means, no you need all of them. I don’t know, I would be thinking out loud and one of them would chime in. I honestly have no idea how to solve that problem.

Jane discussed how collaboration would have been helpful, however she could not solve the problem individually. When presented with the correct answer Jane responded:

So the answer is three, that’s what they’re saying. [pause]. Yeah it’s really obvious now that I think about it. I would say for number three [of the prompts] I would say other, and I would say that I’m overanalyzing the question, because I think simple math tells you that if you have three, you have to have two of the same thing if there’s only two choices.

Jane’s first thought after seeing the correct answer was “that three seems far too low”, but she “started thinking about it, and…realized that if you have three of something, and there’s only two different choices that means two of them have to be the same.” Jane went on to say that it would have been helpful to model the
situation rather than trying to solve it in her heard. Her model was a replica of the problem space:

Like having 4 of something to 5 of something, and then if you were to like pretend this was a situation and pick stuff randomly I think you would eventually realize that that’s the answer. Its I mean its pretty straightforward.

When Jane was asked how this problem solving exercise affected students’ performance on HAZMAT, she stated:

When I originally looked at this first problem I was thinking that it was kind of a abstract thing that we do in chem. lab. But when you look back over it everything that you need to know is given to you and that’s the same thing with HAZMAT. At first it appears that [HAZMAT is] really all over the place, it’s a bunch of things that you can click on, a bunch of different ways that you can go about it, but you have to formulate the way to go about it. So maybe this shows you that everything is there you just have to you know, work it out.

Mark

Mark was frustrated with the problem solving exercise. Mark correctly answered each problem and did not see the need to answer all of the prompts that followed. He described the experience by saying,

To be honest, I was kinda frustrated with it. Like the first problem…we figured it out…and then like it was like 50 million questions off of something
that seemed so fundamental to us, like, if you have two different socks, I mean if you pull out three, there’s gotta be two that’d be the same, based off of the information…and a lot of these questions are like did your group do this? did your group do this? did your group do this? We didn’t really analyze it to that extent because, I mean, we only worked it for like 20 to 30 seconds, for that one problem…We felt like we were forcing answers out of ourselves just to, to answer this.

The next problem was a similar experience for Mark:

we went through that one too…the answer was like given to us. I think it was on this page, they gave us like a problem, and then said, when they meet. When I got to that point I was like, ok if they meet they must be at the same distance so we were like ok, and then [the prompts] were like identify the, we didn’t really plan this we just read it and then, look for the key, when the meet kinda yelled at me, and like so, I mean I guess, I didn’t know like how, what to write as the planning for that problem or anything like that, and, and I mean we didn’t do a drawing, and, I, I don’t know I, these questions they seem very like, they’re expecting us to work for like a long time, I guess maybe a minute or thirty seconds on like a problem.

When asked how this experience could affect students’ performance on HAZMAT, Mark stated,

Um, lets see, I guess an immediate, like correlation doesn’t come to mind, but I guess, I guess they were trying to get to the same approach or logic.
That was the first thing I looked at when I was reading these questions. I guess they’re trying to get logical skills going, to try to deduce things. Mainly that was a logical question—try to figure out what you need and what you don’t…When I was working on this I was kinda thinking…[this] sounds similar to HAZMAT. I guess they’re trying to get this whole approach going, but then like these questions seem unnecessary at trying to do that. I think this would have been better for our group if the questions were a little bit more involved. . . . Not necessarily like an hour working on it, but like at least like a minute, like a little more like thinking involved. And, but I guess the correlation would be that, they’re trying to get the logic going, maybe, like connections going.

Mark believed the experience could have a positive impact, but felt as if the intended outcomes should be more clearly stated. He also felt the problems should be more involved. Mark found the actual problems too easy. Finally Mark described a good problem solver by stating,

A good problem solver is, you’d be able to figure out what you need and what you don’t need, and also you have to have a good background of like information….So I think that communication is…the second part, and then the third was um, I guess it would be the overall connection...’cause once you understand like why are you doing this and this...the chain will pretty much connect. You understand the big picture, um, I guess that’s what it is.
Mary

Mary felt the problem solving experience was a very beneficial endeavor that “helped review what good problem solving skills requires.” Her partner got the first question right, and wanted to skim through the prompts, but in the end, they worked together to answer the prompts. During the interview, Mary recalled what she and her partner determined made a good problem solver:

Um, first of all to figure out what the problem is, and then to kind of gain an understanding of, to organize it, you know in your mind what you need to do, and then if you need to write down any steps to, to show your work, and then from there, you know, you’d hopefully get the right answer.

Later, Mary contributed many of these attributes with increasing students’ success on the online assessment problem, HAZMAT.

. . . with HAZMAT you have to seek out why you got the problem wrong. This one, [the problem solving exercise], forces you to look at, did you get it right, did you get it wrong, why did you get it right or wrong, and it helps you, you know it ask you, how can you be better, so then you start thinking, ok well I need to do this, and this, and this, and this, and that helps you improve, just being able to identify what you need to do. . . .So then, using this information you can say, ok well first I need to figure out, what is the problem, and then say ok, you know, you plan out your steps and then, from those steps evaluate what you have, where as some people might just start clicking stuff [in HAZMAT], and not understand what they’re trying to figure
Mary also thought the problem solving exercise was helpful for other matters. She felt the experience had a place in the lab setting, because problems are a main part of the lab. Although she stated, “you need more problem solving skills in chemistry versus biology, because in biology you have steps. Mary went on to say,

…This would help you just in general in life, too. Not just with a lab per se, but also figuring out say any test problem, because you have to look, you have to identify first what your…what it’s asking of you, to be able to go through it, and that’s applicable in any problem.

Mary was asked if she could think of any problems she faced outside of school. She recalled an experience of deciding whether or not to buy a house. When asked about the similarities between that problem and the ones presented in chemistry lab she stated, “you still have to figure out what, what you want the end result to be. And then figure out, you know, ok, what’s the best way to get there.” Problem solving was about finding the best way to solve a problem, and the problem solving experience helped Mary review the skills needed.

Pedro

Pedro thought that the overall assignment was pretty straightforward. However he recalled having difficulties on each problem.

The questions were pretty difficult I would say. Like the first one, I was definitely [lost], didn’t really know where to start with that one. As for as like
the other back here, [the prompts], um I would say these are a lot a like based on what you think questions…I did problem number two and my first guess was 8 minutes but um like I understood when I actually got the answer and they said it was 6 minutes I understood like how they were going about doing that, frying the eggs and stuff like that, but I would say it kind of, I don’t know, applies to problem solving skills, that you, someone develops in hazmat.

In this instance, Pedro made a connection between the problem-solving exercise, problem-solving skills, and HAZMAT. According to Pedro, the exercise itself applied to problem solving skills, the same skills that were being developed in HAZMAT.

Pedro and his partner missed the first question. He admitted,

Um we didn’t really know where to start with this problem, because it didn’t really give you a specific number, it just gave you a ratio. So I would have thought theoretically that you could keep pulling socks out and never get a brown pair of socks. Or two socks of the same color. That was my initial thinking about that. As for as going in and actually being like solving the problem, no I didn’t know how to do that.

Pedro and his partner answered the prompts and agreed they were on the wrong path. Pedro stated,

[A] misunderstanding, I would say we didn’t analyze the question well enough, um lack of preparation maybe, would be a good one. Um that’s
about it though I think its all based on . . . we just we didn’t take the time to look at it.

Even though Pedro and his partner missed all the problems, he believed it was a valuable experience because it caused him to “think outside the box.” Pedro’s experience also showed him “how peoples’ minds work, [how] different peoples’ minds work.”

Saul

Saul was one of the two students who had not completed the problem-solving exercise before the interview. However, he gained a brief view of the experience during the interview. Saul was asked to complete the first problem. After he worked the answer, he turned the page to reveal the correct answer. After reading the correct, answer Saul stated,

Well I was kinda like, three? . . . What? Why would it be three? And, um, I thought about the problem for a second and I thought about what I read and I was like, did I just I think I read pairs instead of socks? ‘Cause you think about socks and you think about them in pairs, and um that’s a problem I have is when I skim over things I read them too fast. And I see words that aren’t there, um, so I was like well if the answer is three that means that you got out one sock of one color and two socks of the other, so you have to get, statistically you would get um a pair. Um but I don’t know…at first I was like, I didn’t understand. . . . Then I had to think about it for a second and I realized what I did.
Saul completed a couple of prompts related to the first problem. He stated that he did not understand the question and he assumed he knew the correct process. When asked about this, he related the same difficulties with test taking.

Even though Saul only had a brief experience with the exercise, he was able to provide a hypothesis as to why the experience is helpful for future problems, such as HAZMAT. Saul said,

[The problem-solving exercise] makes you pay attention to detail. A lot! . . . So I mean it, [the problem solving exercise], really makes you pay attention to detail and just read the results you get [on HAZMAT] because just about everything you get from that is going to be important to you in some way or another. So, just work. You gotta look at everything you have and just pay attention to detail.

Saul even believed this exercise would be helpful for other classes because,

it makes me begin to think . . . this gets me thinking ok well I might need to start uh applying what I’ve learned a little bit, wake my brain up. . . . But um these kinda simple problems like this will make you think a little bit and get you started going. So once you get into class you’re thinking about things more uh more critically.

**Ted**

Ted’s partner answered the first question, however Ted didn’t fully understand how his partner came about the answer. Ted stated that he continually referred back to the first problem while he and his partner were
responding to the prompts. Although the solution initially eluded Ted, he “eventually figured it out” while working on the prompts. Ted’s initial mistake was placing too much importance on the ratio of 4 to 5. He felt this was his error because “they had a big clue right there that I missed.” The clue he mentioned was the fact that there were only two colors of socks. Ted, did not completely understand the question before he began working. He felt the experience taught him not to “jump to conclusions, and . . . look at all the data first.”

Ted defined a good problem solver as,

one who um reads through the problem fully and is able to separate the relevant information from the stuff has no use or is not help to solving the actually problem itself. Like here, they gave us the specific colors for the socks but really it doesn’t really matter what color socks there are, just there are just two different colors.

Ted’s definition of a good problem solver is in direct correspondence to the difficulties he had while attempting the first problem. In the original problem, Ted did not separate the relevant and non-relevant information. This experience helped Ted reflect on what he was doing wrong.

When Ted was asked how this experience could impact HAZMAT performance, he stated, “well maybe this exercise got them, [students], to practice using their problem solving skills and um like help[ed] train them better at it so they would be better prepared to view the problems presented by hazmat.” Again he discusses “viewing” the problems to determine what is really
being asked. Also, Ted felt this experience was beneficial to lab because “it would, um, sorta give us like a clear perspective. Like it clearly explains to us what we’re really doing in chemistry lab, ‘cause the whole thing, all of our projects, we’re given a problem we’re supposed to solve” Even though the lab and problem-solving exercise were completely different in their setup, Ted reduced both experiences to problem-solving.

**Zoey**

Zoey’s initial response to discussing her problem solving experience was to laugh. She relieved her experience with the first problem by saying,

Is this the sock one? . . . Well I’ve done it before in the dark, I think we all have had to find socks in the dark, and um, I really didn’t, this is going to sound really bad, but I really didn’t use any major problem solving skills to, to do this particular one. Because I have had to do it before, so you’re like, ok so you pick three.

The initial question was not a “problem” to Zoey because she already had a clearly defined solution. Her solution came from prior experience. However, Zoey later discussed the possibilities of using problem solving skills in that she realized she did not need the ratio or other information in the problem. She described this process by saying,

Calmly looking at it and say, where do I start? One thing I always do with word problems is, what’s fluff and what’s real? And I knew immediately with the ratio thing, I’m like, you don’t need that. If there’s only two colors of
socks in the drawer, pick three. You’re going to get the same color, you may not get the same type, but you’re gonna get the same color sock. Um, when we did it together we just kind of—because she came up with the same [answer]—I mean we both said it at the same time...The other members of our group—because we did it in pairs—were having a really hard time trying to figure this out, and they had another piece of paper, a scrap paper, and they’re working it out . . . First thing I did was doubted what we said. I’m like wait a minute, should we be doing that? And I’m like, no, there’s only two color socks, you pull out three, you’re going to get, you know. So we kinda went through this real quickly, because we realized real quick from life experience, and also realizing what’s fluff and what’s fact in your word problem to, to figure out the answer.

Zoey had also completed the rest of the take home assignment. Zoey chose to work the question that dealt with frying eggs, because, in her words, “I’ve cooked a lot of eggs.” She went on to say,

I drew pictures for this one. One of the things I’ve learned is whenever you have a word problem the best thing to do is draw a picture, because it really does help visualize what you’re trying to solve. So, I drew a picture of you know the best case scenario for him to try to do this, and it was probably wrong, but it seemed logical to me that this would be the easier practical way to do it.

Zoey attempted to explain prior quantitative findings by stating,
Well maybe because [the problem-solving exercise is], taking you through the steps of figuring out the problem. You know, here’s the problem, number one, identify and define the problem. State the problems and the goals, I mean it’s taking you through the problem solving skills. Where in HAZMAT, [you have to] figure it out, you know, kinda the same thing with the labs, [a] similar way. Here it’s taking you through you know each one, you know sort through the fluff, according to the goal what information given is not relevant and might not be used. You know . . . that’s the fluff, here’s the facts, now plan it out—how you’re going to solve it. So it’s teaching you how to solve the problem, so that’s probably why when they got to the HAZMAT they already had that skill imbedded and they could go through it step by step.

Zoey also felt this process was beneficial to her, and wished professors would allow students to complete these types of exercises. She emphasized the importance of problem solving across the spectrum of education and life. She felt she was learning the skills to be successful by “identifying the true problem, realizing what resources you have available to you, and knowing how to effectively utilize the resources in an efficient manner to solve the problem.” Zoey continued by giving a very specific example of how learning problem solving skills had helped her:

It has helped me figure out a financial future for my husband and I and our family. Um, you know, when you look at something and you’re
overwhelmed with it, you have a tendency to do knee jerk reaction with things. Um, we just did our budget for, um, the next year, and we hate sitting down and doing the budget because it’s torturous, and nobody wants to talk about it, but this time it was a lot easier and I think its just because, ok, I troubleshoot. Ok, what problems did we have last time? How did we figure those out? And I kinda went through these same steps, ok this was a problem, what about it made it a problem, what can we do to you know resolve it and to make it better, you know, what, what aspects could we add to it, or take away from it that, would solve it? I mean it did [help], and it made it a lot easier this time, so I see how it works when I sit down next year to do our budget . . . I did use these things, I didn’t draw a picture, but I did use these things, skills, to do that.

**Conclusion**

This chapter contained narrative descriptions of each students lived experience in each learning environment under study. The information presented provided valuable information to help answer the initial research questions. The phenomenological analysis that this information served as the basis for is presented in the upcoming chapter along with explanations of the prior quantitative findings.
CHAPTER FIVE

PHENOMENOLOGICAL INTERPertation

Introduction

In this chapter, results from the phenomenological study of both pedagogical interventions are presented. This chapter includes three main sections. The first two sections address the nature of students’ experiences with the cooperative problem-based lab, and the cooperative metacognitive problem-solving intervention, respectively. The third section, in this chapter, will compare the analyses of both experiences.

The first two sections of this chapter will present our interpretative findings from the data analysis. In the following sections, quotes from each participant are not used, however, all participants’ experiences were used to identify the nature of the laboratory experience.

Cooperative Problem-Based Laboratory Experience

The outcome space shown in Figure 5.1 emerged from phenomenological analysis of the interview transcripts. The model presented represents students’ cooperative problem-based laboratory experience using three dimensions. The interconnecting factor, or singular essence, of the experience, was the students’ need to take charge of the learning process.
Figure 5.1: Outcome space of emergent dimensions in the cooperative problem-based laboratory experience.

Affective Dimension

For most participants, the first semester of college was their first experience in a lab-based curriculum. Many students took multiple labs during their first semester, but had little, if any, previous experience in cooperative based labs. The cooperative problem-based paradigm was new, and students felt “out of their comfort zone.” In a sense, the laboratory paradigm created a cognitive and affective imbalance that the students had to overcome in order to take control of the laboratory experience.

The initial project left students with a feeling of confusion, shock and frustration. Students expected to find directions and procedures in the lab manual but instead were faced with the reality that they had to create their own
procedures. This became unsettling for many and led some down a frustrating path. However, whether students had an initial positive or negative response all came to accept the nature of the laboratory.

As the semester progressed, shock due to the laboratory paradigm faded, yet confusion and not knowing remained an integral part of the experience. Each new project presented students with a problem in which they did not have an immediate answer or solution pathway. Affective conflicts remained a normal part of the laboratory process, but, as the semester progressed, students were better apt to handle the situation.

Zoey’s comments provided direct evidence of the affective conflicts:

I was very intimidated the first uh, project that we had, just because, I felt like we were kind of thrown in, and we had to try to swim to the surface to try to figure out what to do. . . . I’d never done a chemistry lab. So I was a little intimidated by it, but after, about, the halfway through the first project, I started to get in my groove and did pretty good after that.

The cooperative laboratory format was new to Zoey, and she was not sure how to handle the situation. Obviously, the first project caused confusion and frustration for Zoey; however, she goes on to say, “once I figured out the way it (the chemistry lab) worked, I guess the way it was gonna progress, um, it did help me.” Other participants contributed to this dimension by discussing the difficulties faced at the beginning of each project. Pedro stated,

It’s kinda difficult to get started on labs but as for as like actually doing
them, once you get like a jump start to it, it gets easier as it goes, ‘cause you kinda know what you’re doing by that point. You understand what’s going on, but, like, when you first hand in the lab and you’re like, ok this is what you’ve gotta do, it’s always like, um, we don’t really know where to start, but once we find that starting point, it’s alright.

Both Zoey and Pedro, discussed the laboratory experience becoming easier to handle once they “understood” how it worked. These comments about understanding were representative of all participants and comprised the second dimension in our model.

**Understanding Dimension**

In this dimension, students began to understand the laboratory paradigm. Students came to an understanding of the nature of cooperative education and accurately expressed the goals and expectations of the laboratory format. Students described the workings of a cooperative based laboratory format versus more traditional structured formats. The students communicated these expectations and goals, by comparing the laboratory format to others that they have experienced, such as high school, biology, and engineering labs. This understanding of how the laboratory format works came from the students being immersed in the environment rather than from being informed by the TA. Therefore, this understanding was developed and formed over time through experience; a greater understanding by the students led to greater ease of taking control of the laboratory. Once students understood how the format worked, and
what was expected of them, they were better able to perform and succeed in the laboratory.

As noted in the quotes above, students contributed an “understanding” with helping them progress through the lab. It became clear that students understood the setup and tenets of cooperative education when they compared their chemistry lab experience to their other lab experiences. Mary compared her chemistry lab to biology lab by saying,

The biology lab is, you have pre-described steps and you follow them and you have little tables and stuff for you to fill out… what, what your answers are that you get from the test. Um, chemistry lab, you have a concept and you’re supposed to read through [the lab manual] before you go into it and know kinda what you’re supposed to do and get some directions from the TA and then just go from there. There isn’t, you know, step one do this, step two do this, step three do this… With the chemistry labs, I don’t have the steps but I understand what I’m supposed to do and what I’m doing, so therefore, I understand the reasoning behind it.

Ted was another participant who accurately depicted the expectations of the laboratory when he compared his different labs:

In, um, the other labs I’m a part of, there they give us directions on what we’re supposed to be doing. But in this chem. lab., um, they don’t really give us concise spoken directions. They’re primarily expecting us to
understand what is in the lab manual so it’s, um, we’re pretty much going on our own.

For Ted, his other labs consisted of following directions. However, chemistry lab involved understanding and being able to function as a group.

Another aspect of the lab that students accurately described was the role of the TA. These depictions of the TA’s role were further evidence of an understanding of the workings of a cooperative format. Pedro looked to his TA for information, not answers:

He [the TA] doesn’t like, outright give us the answer ‘cause I guess he’s not allowed to do that, but he kinda guides us in the right direction of, like, this is what you need to look for, this is what you need to kinda set up and then once we do that, we understand what we’re doing.

Zoey, who was cited earlier as being intimidated by the first project, praised her TA for helping her overcome her affective conflicts. Through her description of her interactions with her TA, it was clear that Zoey saw him as a resource rather than a provider of answers:

My TA did help because when he could tell that I was like beyond frustration, he was like ok let’s, let’s think about this for a minute. You know, look, look at this. You know, go back to your solubility rules, and its like, Oh! He kinda helped me connect the dots

Other students mentioned having a rather difficult TA. However, even those participants, such as Jane, were able to identify the ideal role for the TA:
Somebody who lets us experiment like it’s supposed to be, like um problem solving environment, but is willing to help, willing and able to help us to some extent that doesn’t lead us through everything. So if we ask a question . . . he’s going to be like well I can’t tell you that but here’s a hint and just guide us like any teacher would.

Mary was another student who wished her TA had been more “resourceful,” but identified appropriate TA interactions:

I think it was great having the extra freedom to be able to figure it out . . . I didn’t have a very resourceful TA . . . just having a support, for when you do have a question would be good. Because even in real life, you can ask a question and you’ll get some support. You can go to an expert or, to, wherever, or somebody in the company, or a textbook, or something and be able to ask a question and get some information out of it.

Mary and Jane both understood the role of a TA even though they both claimed to have difficult TAs—who did not appear to understand their role. In some instances, it seemed as if the students had a better understanding of the appropriate role of the TA, than did their actual TA.

Finally, included in this dimension was students understanding of an overall goal of the chemistry lab: that is - problem solving. Perhaps no student said it more clearly than when Mark stated, “[In Chemistry Lab] I guess the approach is not to really enhance what you’re learning in class, but to think logically.” Other students commented on the “open-ended, you figure out the problem format of
the lab.” By the time of the interview, it was clear that students understood the expectations of the lab and realized they would have to solve problems on their own. What the students actually did to “figure out” the problems comprises the third dimension.

Skillfulness Dimension

The skillfulness dimension involved the things that students must do in order to be successful in the laboratory. This dimension was the most relevant for determining how the laboratory experience impacted students’ use of metacognition. The main tenet of this dimension is the process of “figuring out,” a phrase used frequently by the interview participants. Students depict an array of processes that they use to “figure out” the questions and problems that arise during laboratory activity. Many of these processes were a result of the nature of the lab, the fact that students were required to plan their experiments. Students manage their time by working independently and as a group and use a variety of sources such as the lab manual, textbook, Internet, TA, and other groups to gather information. This process also involved a lot of individual reading, group discussion, and questioning. Students used the information they had gathered to plan and carry out procedures in hopes of achieving the projects overall goal. Results from their experiments were analyzed and the students decided how useful their results were before determining the next logical step. Figure 5.2 provides a detailed description of this model. It should be noted that the processes that students considered beneficial to “figuring out” their problems
could be classified as components of regulatory metacognition: planning, monitoring and evaluating.

Figure 5.2: Detailed description of the skillfulness dimension.

Mary discussed some of the difficulties she faced when presented with a new project:

I’ve enjoyed actually doing them. Um, I’ve had some trouble trying to navigate what’s expected of me, not because I need prescribed steps. I’ve actually enjoyed not having the prescribed steps that I have in my biology lab. But uh, there’s some, just some difficulty trying to figure out the direction that I’m supposed to go….I said it was just a little bit difficult sometimes to figure out I guess the exact road I’m supposed to take, in the
respect of, you know, what’s the end result supposed to look like.

In the previous passage, Mary not only discussed her group’s need to plan, but she also discussed the difficulties that came with evaluating their end result. Like Mary, Zoey enjoyed the lab experience. In fact Zoey “loved the labs.” Zoey also tells a similar story to Mary:

The process of learning helped me, the whole process of, you know, of having to figure out some of this stuff yourself . . . he (my TA) was very, you know, you gotta figure it out. I’m like, ok, but how do I figure it out? Look at it, figure it out. Look at what, what do you want me to look at! . . . but, him being insistent and not handing me the answer did help me with my thought process. Ok, let’s work smarter and not harder. Which, which is the best way to look at this problem and figure out how to do it. And that has helped me in my other classes.

Zoey had to turn to planning, monitoring, and evaluating strategies in order to overcome her cognitive conflicts and “figure it out.” Zoey’s TA helped her by modeling the correct behaviors in lab. Zoey even contributed her learning process in the laboratory experience with helping her in the other classes.

Another participant, Anna, had a different view of the laboratory experience. Anna stated, “Um honestly I hate chemistry lab. Uh, I really like my lab group and I like my TA a lot, but the chemistry lab sucks and I don’t like to complain a lot but do think it sucks.” Anna hated the chemistry lab because its style contradicted with her viewpoint of learning. For example, Anna stated,
I mean, I don’t like to put something in my head that I’m not sure if it’s right . . . I like to know it’s right and then I’ll, you know, go with it . . . And so, I like to be taught something and learn it, and be like, well this is why [that] happens, ok, now go do it.

Anna viewed information as either right or wrong, and felt that knowledge could be “put in her head.” The objectives of cooperative learning, and this specific chemistry lab went against Anna’s viewpoint. Therefore, it is not a surprise that Anna did not enjoy the lab experience. However, it may be surprising to some that Anna’s thoughts on what she took away from the lab experience were very similar to the other participants. When asked what she was getting out of the experience, Anna stated, “It kinda shows you the chemist’s perspective of chemistry. You know, like you have, when you think of like a scientist, you know, exploring stuff.” Later she stated, “I’m learning how to use my resources to find out like how to do a procedure,” and when asked what that process was she added:

we kinda like devise a plan to go by and then when that starts either not working, you know, we do something wrong, miscalculation, um, you know, we go to the TA or we just keep looking in our lab manual so it kinda, [it] gives you that to, just kind of you don’t really know what to do just use your resources kind of thing.

Here, Anna clearly defined that her group must plan, monitor, and evaluate during the lab in order to “explore” or solve problems. It turns out, no matter how
much students liked or disliked the lab, they all described it as an environment in which they were learning to solve problems.

**Interconnecting Factor: Taking Charge**

The three dimensions in Figure 5.1 may be viewed as progressing in a sequential order revolving around *taking charge*. For example, students were confronted with a problem-based scenario on the first day of lab, thus beginning their cognitive and *affective* imbalance. Following this, they began forming an *understanding* of the expectations and how the lab environment works. Finally students had to employ the *skills* necessary to *figure out* the problems. However, the sequential order began to fade as the semester progressed and the dimensions overlapped. As stated, students began the first project the first day class met, so it stands to reason that students must begin implementing certain skills before they have a complete understanding of the lab. It can also be said that even after students have a firm understanding of the laboratory environment, they still have affective conflicts each time they were presented with a new project.

In Figure 5.1 the connecting edges between each dimension represent the possibility of students transferring from one dimension to the next. An interconnecting feature of the model is *taking charge*. From a phenomenological standpoint, *taking charge* is the essence of the students’ laboratory experience. Students are forced to accept the environment for what it is, and must overcome any affective conflicts the environment may cause. Students come to the
realization that they are the ones in control of their learning process and must find a way to develop and implement the needed skills in order to be successful. By taking charge of the laboratory experience, students are continually moving in and out of the three dimensions described in this model.

**Metacognitive Collaborative Problem-Solving Experience**

The outcome space shown in Figure 5.3 emerged from phenomenological analysis of the interview transcripts. The model presented represents students’ metacognitive collaborative problem-solving experience using two dimensions. The interconnecting factor, or singular essence, of the experience was “reflection”

![Figure 5.3: Outcome space representing the emergent dimensions of the metacognitive collaborative problem-solving experience.](image)
Affective Dimension

An affective dimension emerged as a relevant theme of the students’ experiences. Evidence for this dimension, resulted from both students who experienced cognitive unrest, and those who did not. Affective conflicts were a normal part of the students’ experiences. Some students’ conflicts began when they first read the problem and did not have an immediate solution. Other students experienced a conflict after they “solved” the first problem and were then presented with the correct answer. This presented a moment of cognitive imbalance as students realized their solution was incorrect. Students described feelings of not understanding how to solve the problem and confusion as to why they incorrectly answered the question. These conflicts situated students into the right mindset to complete the rest of the activity and gave them a reason to reflect. A couple of students immediately knew how to solve the problems, and did not experience a conflict. The lack of conflict led these students to a different impression of the intervention. Descriptions of their experiences helped solidify the importance of the affective dimension.

Jane was one of the two students who saw the problem-solving exercise for the first time during the interview. She was asked to read the first question and think aloud while solving. Jane gave a great description of how her group members could help her solve it, but since she was alone in the interview, resorted to the statement, “I honestly have no idea how to solve that problem so.”
Jane, could not grasp how to work the problem, however when she flipped the page she was presented with an obvious answer:

So the answer is three, that's what they're saying. Yeah it's really obvious now that I think about it. . . . I would say that I'm overanalyzing the question, because I think simple math tells you that if you have three, you have to have two of the same thing if there’s only two choices.

Pedro and his partner also had difficulties understanding the initial “sock” question:

Um we didn’t really know where to start with this problem, because it didn’t really give you a specific number, it just gave you a ratio. So I would have thought theoretically that you could keep pulling socks out and never get a brown pair of socks. Or two socks of the same color. That was my initial thinking about that. As far as going in and actually being like solving the problem, no I didn’t know how to do that.

When Pedro was asked about his first thought after reading the correct answer, he simply responded, “I didn’t understand it at all.” This thought process was common amongst the students who answered the first question incorrectly.

After answering the first question, Mark was actually frustrated with having to answer all of the prompts:

I was kinda frustrated with it. Like the first problem, it was, we figured it out, like oh ok, and then like it was like 50 million questions off of some thing like, that seemed so fundamental to us, like, if you have two different socks,
I mean if you pull out three, there’s gotta be two that’d be the same, based off of the information. And then like, and a lot of these questions are like did your group do this, did your group do this, did your group do this, we, we didn’t really analyze it to that extent because I mean we only worked it for like 20 or 30 seconds, for that one problem.

Mark differed from Jane and Pedro, in that he immediately knew how to solve the first question. In a sense, he was not presented with a true problem. Mark did not experience an affective conflict and therefore felt no enhanced reason for focusing on the prompts. While it may be true that the intervention did not have as great of an impact on Mark as it did others, his statements helped solidify the evidence of an affective dimension. In fact Mark felt this assignment could have met its goal of increasing logical skills if the problems were “more involved.” This was interpreted as challenging or causing cognitive conflicts.

From the information above, it is clear the collaborative metacognitive problem-solving experience contained an affective component. Two of the students discussed not seeing a direct impact on themselves after completing the assignment, however those were also the students who immediately knew the solution. Hence, they did not experience a cognitive imbalance. From the students’ point of view, this intervention was more effective if they experienced cognitive unrest at the beginning.
**Skillfulness Dimension**

The skillfulness dimension involves the things that students must do in order to correctly solve problems. In this experience, “skills” were represented in two ways. First, students had to complete three problems by putting their skills into use. Students depicted the process they used to solve these problems, again, relating problem-solving to “figuring out.” After each problem, students addressed a series of prompts that asked them to provide specific skills needed to be a good problem solver, among other things. In this case, students were not directly using the skills, but rather reflecting upon them. During the interview process, students shed light on how they worked together to solve problems, and they articulated the perceived usefulness of this assignment. Many students claimed that this type of problem-solving exercise provided them with skills conducive to success in multiple areas. Students also stated this intervention impacted the way they think—a big compliment for a relatively small assignment.

Gina recalled a vivid description of how she and her partner went about solving the first problem:

I remember to start with, we looked at it and we were like, ok, it’s going to take 6 because you gotta have—we took the highest number—well you’re gonna have to have two, so you need six, but then I didn’t--actually it was me another guy working on it. I started making a chart and that kinda helped. Because I was like, well if you start . . . brown and black, if you have 6 then you have 0 of that. And then that would be 5 and one, and
four and two. And then we realized, ok that’s way too many. We were like
we have too many socks. So then we ended up getting it down to where
you had brown and black and you had . . . 4 and 0 and like 3 and 1 and 2
and 2. So no matter what you were going to get a pair.

Gina felt that this process did not directly impact her problem solving skills
because she already “think[s] outside the box.” However she felt it would impact
anyone who had not experienced this type of thought process. When Gina was
asked why she thought students who completed this assignment did better on
Hazmat, she responded, “I think, also just because like when you were filling out
all the things, [the prompts], it made you think about [it].” When asked exactly
what she was thinking about, she described the following process:

  I guess you’re thinking, like, ok, to start with, like, the eggs you think, ok,
its going to take them 8 minutes cause you’re gonna put two in a pan and
then put one in a pan. But then you have to say ok well you know that
might be an answer but is there another possible way that it could work or
is there another combination I could do or could I split it up somehow

Gina credited this intervention with compelling students to question their work
and reflect on their solutions to evaluate their efficiency. Efficiency was also an
important aspect for Anna. She explained her view of the intervention by saying,

  [It is] reinforcing how to go about solving a problem, and telling you do
this, you know, kinda saying read it close, read it carefully, understand it,
before you start guessing and stuff. So it kind of tells you to work hard at it.

It was interesting that Anna stated that the problem-solving intervention “told” her what to do. When asked about that, Anna stated, “that’s how I interpreted this assignment, was, um, figuring out ways to become better problem solvers. So, I guess I told it too [do those things, read carefully, etc.]. I wrote [answers] down and told it too.” Therefore, the problem-solving experience was a chance for students to reflect on what they do, and how they could do it better. It is also important to note that Gina touched on the interaction between her and her partner. These interactions were a key aspect in both solving the problems and discussing the prompts, as every participant referred to collaborative interaction.

Ted felt the problem solving exercise was very relevant to the laboratory experience because, it gave him “a clear perspective, like it clearly explains to us what we’re really doing in the chemistry lab. ‘Cause the whole thing, [for] all of our projects, we’re given a problem we’re supposed to solve.” Saul, had a similar opinion to Ted, in that he felt this experience would be beneficial for other classes. Saul stated,

. . . this would actually really help me at the start of any class because it makes me begin to think…this gets me up on my toes. Um, this gets me thinking . . . So once you get into class you’re thinking about things more, uh, more critically.
Here, Saul added to the idea of “thinking outside the box” that he and others mentioned while discussing the problem solving experience.

Other students saw benefit in this activity not only for other classes but life in general. Mary told a story of how this experience related to buying a house, and Zoey concluded, “people are faced everyday with problems and sometimes overwhelming problems all at the same time. And you literally need these steps to sit down and calmly, logically work through the problem.”

These representative comments were evidence of a skillfulness dimension in the students’ experiences. Again, these skills were used and discussed between the group members. It is important to note that the skills used, and those discussed are components of regulation of metacognition: planning, monitoring, and evaluating. During the interview it was clear that students associated this intervention as a helpful one in which they were made aware of their problem solving strategies and forced to “think outside the box.”

**Interconnecting Factor: Reflection**

The designed focus and students’ perceived focus of the metacognitive problem-solving intervention were related to problem solving. The essential underlying theme that emerged was one of “reflection.” Without reflection, we can strongly say this experience would not have been the same. Students were engaged in active reflection throughout the experience. From the moment students were presented with the correct solution, they began a reflective process; students were forced to reflect on how and why they came to the wrong
solution. The additional prompts that followed each question provided students with yet another chance to reflect on the work they had just done and problem solving in general. Students even reflected on their own learning process and some began to change the way they thought about learning and problem solving. Therefore the essence of this experience is reflecting upon the skills needed in order to “figure out” and solve problems.

**Explanation of Prior Quantitative Findings**

Students’ experiences of the two interventions have some striking similarities. This section will discuss those similarities. This information is scaffolded by literature and used to answer the question posed as the overall goal of this research project: What factors in the learning experiences under study (cooperative problem-based laboratory, metacognitive collaborative problem-solving exercise) are related to students’ increase in metacognition awareness and use, and problem solving performance?

The cooperative problem-based laboratory experience and the collaborative metacognitive problem-solving experience both contained an affective and skillfulness dimension. Both of these dimensions were valuable for explaining why students who participated in these environments increased in metacognitive awareness and skillfulness.

The conflicts students faced in the affective dimension in both experiences are very reminiscent of the “conflicts” described as necessary in conceptual change research (Limón, 2001). Therefore, this discussion will be viewed in light
of Conceptual Change Research. Which, as its first tenet, states that before students change naïve conceptions, their original belief must be challenged (Posner, Strike, Hewson, & Gertzog, 1982). Researchers still debate what should be considered a “concept” under this theory (diSessa & Sherin, 1998), but for the purposes of this discussion, problem-solving will be considered the “concept”. Problem-solving is not a traditional “concept,” but for the purposes of this discussion it proves quite useful.

The collaborative metacognitive problem-solving intervention challenged students’ problem solving skills. After students worked the first problem, they were presented with the correct answer. For many, this caused a cognitive imbalance, and forced them to reflect on where they went wrong. Students began the exercise with a set of problem-solving skills. These skills were challenged, and due to the metacognitive prompts, students were forced to face that challenge. By working through the included prompts, students were presented with an intelligible, and plausible alternative, the second and third tenets of conceptual change theory (Posner, Strike, Hewson, & Gertzog, 1982), to their original problem-solving skills. These prompts provided students with an immediate opportunity to evaluate their stance on problem-solving. Directly after finishing the in-class portion of the assignment, students were able to apply problem-solving skills to a less structured assignment, a lab project. During that week, students completed the take home portion of the assignment, a structured word problem, and answered more prompts. The following week in lab, students
had yet another opportunity to apply these “skills.” Therefore, these “new” skills were found to be *fruitful*, the fourth tenet of conceptual change research. This was also evident by the students’ discussions of the practical applications of the problem-solving assignment. Students developed problem-solving skills that they felt were relevant not only to chemistry, but other classes and life.

Based on this critique, we can conclude that the problem solving exercise is designed in such a way that can bring about a change in students’ problem-solving skills. Since problem-solving relies so heavily on the use of metacognition, it is concluded that meaningful social interactions and reflective prompting contributed to the measurable increase in students’ awareness and use of metacognitive strategies.

The design of the laboratory setting was less structured than the problem-solving exercise. Because of that, it is harder to detail the laboratory experiences total impact on students. Some students had their views of learning challenged, and all students found themselves out of their “comfort zone” at some point during the experience. During this time, the laboratory environment was constantly challenging students’ problem-solving abilities.

Arguably, for the first time, students were given the chance to take control of their own learning, and they had an admittedly difficult time. Students were accustomed to having information given too them, but were faced with the realization that they had to eventually take control of their learning process. Students were confused and shocked. This satisfied the first tenet of Conceptual
Change Research. Students relied on the interactions with group members, classmates, and their TA in order to overcome the conflicts and “figure out” the problems. As stated earlier, the processes that students used were explicitly metacognitive.

However, the question remained, how were these metacognitive skills developed? We know from prior research that repetition alone is not the key to successful problem-solving. A prior study, using the same concurrent online assessment tool, (IMMEX-Interactive Multi-Media Exercises), found that students stabilized on a strategy after five attempts whether or not it was advantageous (Stevens, Soller, Cooper, & Sprang, 2004). Because students had to use metacognitive strategies during the lab, does not immediately imply they were becoming better problem-solvers. Students may have been very inefficient in their use of strategies. But in the case of this laboratory experience, quantitative evidence said they did improve their problem-solving abilities. Two aspects of the lab are of upmost importance explaining “how” this change came about: reflection and social interactions. The experience provided students with an opportunity to discuss and analyze problems in real time and make provisions to their problem-solving strategies. In fact, students had to do this in order to be successful. Over and over, students turned to others for advice and help. Students observed others “leading” the group and modeling desired skills, and each week students were prompted to reflect on what was being done and what
steps should be next. The TAs had potential to make a big impact on students by modeling the correct behavior.

The lab was less structured than the problem-solving intervention, and it is harder to classify when the students began to see the intelligibility or plausibility of adapting their problem-solving approaches. However, it is reasonable to conclude that social interactions played a large role in students recognizing the intelligibility and plausibility of metacognitive strategies. The students that understood these two aspects also began to recognize the fruitfulness of metacognitive strategies. Students mentioned the helpfulness of being able to plan and monitor while problem solving and felt this would impact other areas of their life besides chemistry.

Returning to the original goal of this research project, we concluded that the answer is the same for both experiences: Meaningful, purposeful social interactions and reflective prompting acted as promoters for metacognition use.

Beeth stated, “any instruction based on principles of conceptual change must assume the ability of the learner to reflect on the consequences of his or her thinking, to be metacognitive” (Beeth, 1998, p. 58). The cooperative problem-based laboratory environment, and the metacognitive problem solving intervention provided this opportunity for the students.
Conclusion

This chapter presented the qualitative findings of the phenomenological study. Interpretations were made based on the evidence presented, and an explanation of prior quantitative results was given. This completes the sequential explanatory mixed-methods study of the enhancement and use of metacognition in the chemistry laboratory.

Quantitative evidence showed that the two interventions at the heart of this study impacted students' use of metacognition. The results presented in this study confirmed those prior findings, as well as shed light on “how” it happens. Both the laboratory program, and the problem solving exercise are effective means to increase students' use of metacognitive strategies in chemistry problem solving. The final chapter will discuss the relevance of these findings.
CHAPTER SIX

CONCLUSIONS

The completion of this qualitative research project marked the end of the aforementioned sequential explanatory mixed-methods study on the enhancement and use of metacognition in chemistry problem-solving. The goal and guiding questions of this research project were introduced in Chapter One, and Chapter Five presented results relevant to meeting that goal. The intent of this chapter is to elaborate on the significance of the findings, make connections with current literature and discuss possible future directions.

In the Phenomenological Analysis chapter, conceptual change theory was used to discuss the changes in students’ metacognition use and problem-solving skills. Typically the concepts of interest in conceptual change research in chemistry education have been topics such as bonding, energy, and chemical reactions. Yet, problem solving is a main goal of chemistry teaching and learning. Viewing problem solving under the lens of conceptual change research may prove useful, as some students are in need of drastic alterations to their problem solving strategies. Both interventions used in this collective study sought to enhance students’ use of metacognition and promote changes in chemistry problem solving. Quantitative evidence and qualitative evidence collected during the sequential explanatory mixed-methods study point towards students’ enhanced use of metacognitive strategies and chemistry problem solving abilities after partaking in each intervention.
This result is especially interesting when the design of each intervention is taken into account. The goal of each was the same—enhance the use of metacognition—but the design and implementation differed drastically. The metacognitive collaborative problem-solving intervention was implemented via paper and pencil and required a relatively short period of time to complete. Its focus was very direct and pointed towards metacognitive strategies using non-chemistry specific problems. The cooperative problem-based laboratory was much less structured, and each project extended over several weeks. Metacognition use was interspersed throughout the lab experience, rather than being the focus of the students’ work.

After studying problem-solving in mathematics, Mayer stated, “the most successful instructional technique for teaching students how to control their mathematical problem-solving strategies is cognitive modeling of problem-solving in context…having a competent problem solver describe her thinking process as she solves a real problem in an academic setting” (Mayer, 2001, p. 56). Both interventions studied were effective means of meeting this goal. Even though the outward appearance of the two studied learning environments was different, students’ experiences within those environments were intrinsically similar. Both experiences involved affective and skillfulness components and utilized prompting and meaningful social interactions to increase students use of metacognition.
A cognitive imbalance and metacognitive prompts were specifically designed into the problem-solving exercise and were the starting point for students’ reflective processes. The reflective dialogue amongst partners led to a more robust metacognitive experience. This finding is in accord with Okita, Bailenson, and Schwartz (2008), who found that the mere belief of social interaction led to more fruitful learning. The data collected on the collaborative problem-solving intervention also suggested students’ ability to transfer metacognitive strategies across domains. This is a very relevant addition to the overall importance of metacognition use. These results add to the growing body of research that suggests metacognition should be a focal point in curricular design (Bransford, Brown, & Cocking, 2000; Donovan & Bransford, 2005).

In the cooperative problem-based laboratory, reflective prompting came from other students, the TA, or data collected during experimentation. Many of the laboratory projects were too demanding for a student to tackle alone. Students were placed into a position where in order to take control of their own learning, they had to rely on others. Interactions were not just social, but rather meaningful and purposeful. It is important to make that distinction as some argue that many active learning environments focus on “behavioral activity” rather than “conceptual activity” (Mayer, 2004).

Another important aspect of this study is that it is one of the first focus on the true nature of the cooperative problem-based laboratory experience. Many suggested that a need existed to focus on what students were actually “doing” in
the laboratory (Hodson, 1990; A. Hofstein & Lunetta, 2004; A. Hofstein & Mamlok-Naaman, 2007), and Casey (2007) suggested, “a phenomenological study of the laboratory experience that gives voice to the meaning of the student’s (and the researcher’s) experience might be a push that helps reform take hold.” The qualitative nature of this study provided rich descriptions of what a cooperative problem-based lab experience is really like. This finding, coupled with the quantitative evidence that expressed the impact on students’ metacognition use and problem-solving abilities (Sandi-Urena, 2008), gives a louder “voice” to supporters of cooperative problem-based education.

However, it should be noted that the execution of the lab program was not without problems. Frustration, due to cognitive conflicts, was a normal part of the experience, but frustration could certainly be lowered, if not eliminated, in other areas. The leading cause of frustration, other than the unavoidable, was interactions with TAs. Students presented clear descriptions of what was and was not helpful in regard to student-TA interactions. This information may prove useful in future TA training. For example, at times, TAs resorted to giving the students partial procedures in hopes of helping them overcome their affective conflicts. It should be noted that our evidence does not support this strategy; in fact, it seemed to cause even more frustration for the students. On the other hand, TAs that modeled metacognitive behaviors had more success helping their students overcome the difficulties of planning experiments.
In the ideal role, as noted by students, the TA was constantly modeling metacognitive strategies. It would be interesting to determine if the experience has similar effects on the TAs as it does on students. TA gains from guiding or teaching a chemistry laboratory is an understudied area. In fact, in three major reviews of science laboratories, there was no mention of the teaching assistant (Hofstein & Lunetta, 1982; Hofstein & Lunetta, 2004; Hofstein & Mamlok-Naaman, 2007). After reviewing literature regarding active learning, Michael (2006, p.164) states, “one of the critical issues is faculty development, helping teachers to become familiar with new approaches to teaching and helping them gain experience actually implementing them.” This statement surely resonates over the laboratory setting and teaching assistants. Information regarding the TAs experiences in the laboratory setting coupled with information of students’ experiences may make for more useful and productive TA development program. A phenomenological analysis of teachings assistants’ experiences may prove useful in this endeavor.

Critics of constructivist inspired pedagogies often claim that evidence does not support the use of active learning techniques (Kirschner et al., 2006). While their claim has some merit, most existing assessments are not based on constructivist views and cannot truly assess the effects of such environments (Schwartz, Lindgren, & Lewis, In Press ). The mixed-methods study and the collective body of research that preceded it are a prime example of the power of new assessment techniques. Without the metacognitive assessment, the true
power of these two experiences would be lost. As research promoting constructivist assessments emerges, we will continue to develop a better understanding of when and where to use certain instructional techniques.

After the quantitative portion of this study, Sandi-Urena (2008) stated, “The convergence between the two independent pedagogical protocols presented in this study clearly supports the assertion that it is the thoughtful practice of metacognitive skills that benefits students.” This assertion was further credited by the qualitative work presented in this paper. Furthermore, the mixed-methods study is a collection of sound evidence for the use of metacognitive interventions and active learning techniques in the field of chemistry. Hopefully the collection of this data and its results will be enough to convince some teachers to begin implementing tested and proven learning techniques in the classroom. Maybe this is the evidence needed to help some teachers move away from the passive impersonal ways of lecture and expository laboratories and into the evidenced-based realm of active learning, constructivist theories, and metacognition.
Appendix A

Cooperative Problem-Based Laboratory Project

Project 11: Identification, Properties and Synthesis of an Unknown Ionic Compound.

Your group is employed by the EPA (Environmental Protection Agency) as analytical chemists. An unidentified compound has been discovered in a land-fill in your home town, and your group has been given the task of investigating it. Obviously you will want to identify the compound, but this is not the only thing you will need to do. It will be very important to the people of the area to know the properties of the compound, both chemical and physical, so that you can make predictions as to how it might behave. For example, if you know the solubility of the compound you will be able to give some indication of whether the compound will leach out of the landfill during heavy rain. If you know what kind of reactivity the compound has you could make some predictions on the safe disposal and the longevity of the compound. If the compound is not very reactive it might sit in a landfill for a long time. If the compound is very reactive it may not be as long lived, but it may react to produce something more toxic or difficult to dispose of. Therefore, it is very important that you amass as much information about the compound as you can.

GOALS

1. Identify the unknown compound.
2. Discover as many chemical and physical properties of the compound as you can.
3. Devise two syntheses of the compound, and compare them for cost effectiveness, safety and potential yield of compound.

You will be given five grams (no more) of the compound; you will not know the identity of the compound, nor will you be given any other information about it.

Safety Notes:
- Be sure to consult the MSDS for any compound that you work with.
- All of the compounds that you will work with in this project are Generally Recognized As Safe, but normal safety precautions should be observed.
- Any excess reagents solutions or waste materials may be disposed of by diluting the solutions and pouring down the drain unless otherwise instructed by your laboratory teacher.
In order to help you identify your unknown compound, samples of known compounds will be available in the laboratory. Use only what you need to compare with your unknown sample in tests. The following are some hints and ideas of possible lines of investigation for your project, however, the list is not all inclusive and you may have other possibilities which are equally valid.

1. What solvents is your compound soluble in? What are the relative solubilities in different solvents? How will you measure solubilities? What kind of information do your results reveal about the nature of your compound? What generalities can you make about the solubility of your compound and that of other known compounds available in the lab?

2. What ions are present in your compound? How will you find out? What resources are available to you to find and learn the techniques you will need?

3. Is your compound an electrolyte? How will you find out? How does it compare to other compounds available in the lab?

4. Does your compound have acidic or basic properties? How will you find out? Will you make quantitative measurements of the acidity/basicity?

5. What compounds does your unknown react with? How did you know a reaction took place? What did you observe?

6. How will you prepare your compound? (Do not forget about stoichiometry, theoretical yield and percent yield.) Is there more than one way to make your compound? What are the relative merits of the different methods? Do not forget safety and cost effectiveness in your deliberations.

In order to make your task feasible within a reasonable time frame, we will restrict the identity of your unknown compound to one of the following:

<table>
<thead>
<tr>
<th>NaCl</th>
<th>KCl</th>
<th>Na₂SO₄</th>
<th>CaCl₂</th>
<th>MgSO₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na₂CO₃</td>
<td>K₂SO₄</td>
<td>KNO₃</td>
<td>Ca(NO₃)₂</td>
<td>MgCl₂</td>
</tr>
<tr>
<td>NH₄Cl</td>
<td>(NH₄)₂SO₄</td>
<td>CaCO₃</td>
<td>MgCO₃</td>
<td>CH₃CO₂Na</td>
</tr>
</tbody>
</table>

Samples of these compounds will be available in the lab for you to test your hypotheses and compare with your unknown.

*When using a technique for the first time, use samples of known compounds from those available to practice before you use up a sample of your unknown.*
Techniques you may need to learn or review
- Preparing a solution (qualitative)
- Preparing a solution (quantitative)
- Measuring solution conductivity
- Analysis of ions (qualitative)
- Analysis of ions (quantitative)
- Filtration of solid
- Titration

Analysis of an Unknown Compound

Pre-Lab Organizational Questions:

1. Outline a procedure for finding the solubility of your compound. What solvents will you use?

2. Outline a procedure for finding the quantitative solubility of your compound in water.

3. Outline a procedure for determining the conductivity of your compound. What solvent should you use for this test? If your solution conducts electricity what does that tell you about the compound?

4. What tests will you perform to find out what anions are present in your compound?

5. What tests will you perform to find out what cations are present in your compound?

6. How will you use the known compounds that are out in the lab to help you find the identity of your unknown compounds.

7. Write a preliminary plan for your experimental procedure. Indicate what each person in your group will do next week. Remember that all tests should be run in duplicate (at least).

Post lab questions week 1

1. What is the identity of your unknown? (if you have not yet identified it – give the possibilities)

2. Describe the experiments you carried out to determine the identity of your compound. How did each experiment lead to your identification?
3. Look up the MSDS for your compound and record the LD50 and the safety precautions that should be used when handling the compound. What does an LD50 tell you?

4. Next week you need to make sure that your identification is correct. There are authentic samples of all the possible compounds available. You need to make a solution of your compound and a solution of an authentic sample and compare their reactivity. What kind of reactivity do you expect for your compound? (Is it acidic or basic? Will it react to give a precipitate? etc.)

5. Give five examples of reactions (neutralization, double displacement, etc.) that you can carry out next week with your compound (both your sample and the authentic sample) to investigate its reactivity and confirm its identity. Write out the expected reactions and the products you expect to see, if any. (Remember that a negative result can still give you information)

6. One of the techniques you will need to learn is vacuum filtration – check out the technique in your lab manual or other resource and then give a brief description below.

7. Write a preliminary plan for your experimental procedure. Indicate what each person in your group will do to solve the problem, and what data they will record.

**Post-Lab questions week 2**

1. Give the results of the five (or more) reactions that you carried out to confirm the identity of your compound. Give a brief summary of the reactivity shown by your compound. How did these reactions serve to confirm the identity of your compound?

2. In order to be sure that your identification of the compound is correct you will need to devise a method that will give a quantitative analysis of the compound. How would a quantitative identification differ from a qualitative identification?

3. Using today’s results, what features of the compound could you use to give rise to a quantitative analysis? For example: can you react your compound with something that would give an insoluble salt, does your compound have acidic or basic properties? (Review quantitative analysis in your lab manual or other resource)

4. Remember that quantitative analyses should be run in triplicate to give accurate results. Outline the procedure you will use to do this.
Appendix B

Metacognitive Collaborative Problem-Solving Exercise

Department of Chemistry
Chemistry Education
Research
Problem Solving Exercise

This activity is part of your lab assignments.

Instructions:

1. You must work in teams of two students unless your instructor tells you otherwise.
2. Discuss each step with your partner. Grading is based on the completeness of the answers.
3. The team must complete all the items in this exercise.
4. Part VI “Final Problem” must be turned in individually. There are two copies of this section attached to this document.
5. This is a timed exercise, use your time wisely.

Team members: ___________________________________ Lab section: _________

__________________________________________
Part I
INITIAL PROBLEM

Read the following problem carefully and try to solve it the best you can.

“Barbara asked me to bring her a pair of stockings form her bedroom. Unfortunately, the bedroom is dark and the light is not working. I know there are black socks and brown socks in the drawer, mixed in a ratio of 4 to 5. What is the minimum number of stockings I will have to take out to make sure that I have two stockings of the same color?”

If needed, you may use the space given below to solve the problem.

Please, enter your answer here, and then move on to the next page: __________________
Please, answer the following questions. Be concise but observe that in some cases, an explanation is expected and yes or no will not necessarily suffice.

1. The commonly accepted answer to this problem is “three”. Did your group succeed in solving the problem correctly?  
   
   (Yes) (No)

2. Do you think that your group identified the problem correctly?  
   
   (Yes) (No)

3. If your group did not identify the problem correctly, what do you think was the cause? (Check all that apply):

<table>
<thead>
<tr>
<th>Lack of ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>We assumed we knew what was being asked.</td>
</tr>
<tr>
<td>Lack of necessary knowledge</td>
</tr>
<tr>
<td>Unknown or difficult vocabulary</td>
</tr>
<tr>
<td>Lack of capacity to reason</td>
</tr>
<tr>
<td>Misunderstanding, the team understood something different</td>
</tr>
<tr>
<td>Lack of attention</td>
</tr>
<tr>
<td>The question is confusing</td>
</tr>
<tr>
<td>The problem is too difficult</td>
</tr>
<tr>
<td>Inadequate amount of time put in identifying the exact problem</td>
</tr>
<tr>
<td>The group approached the problem mechanically, without much reasoning</td>
</tr>
<tr>
<td>This is a tricky problem, the question is misleading</td>
</tr>
<tr>
<td>The statement is not well-written</td>
</tr>
<tr>
<td>The group is not good with math</td>
</tr>
<tr>
<td>The group did not make a real effort to understand</td>
</tr>
<tr>
<td>The question seemed similar to previously encountered problems, we did not analyze the question well enough</td>
</tr>
<tr>
<td>Other (specify):</td>
</tr>
</tbody>
</table>

4. Approximately, how many times did your group read the problem statement before actually starting work on the solution?

   0 1 2 3 4 more than 4 times.

5. Do you think your group started working on the solution having a clear understanding of the problem?  
   (Yes) (No)
6. If you answered “no” to question (5), what could be the reason(s)?

7. How many times did you change your answer? Circle as appropriate;
0 1 2 3 4 more than 4 times.

8. What were the reasons for changing your answer? (Check all that apply):

<table>
<thead>
<tr>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initially, the team was just guessing</td>
</tr>
<tr>
<td>The number was clearly too large!</td>
</tr>
<tr>
<td>The result was right the first time, no change was needed</td>
</tr>
<tr>
<td>The members of the team did not agree on the right answer</td>
</tr>
<tr>
<td>The result was too small!</td>
</tr>
<tr>
<td>The team was very uncertain about the result</td>
</tr>
<tr>
<td>A mistake in one of the calculations was found</td>
</tr>
<tr>
<td>The team realized the problem had not been understood properly.</td>
</tr>
<tr>
<td>Members of the team reviewed the result to see if it made sense.</td>
</tr>
<tr>
<td>The result seemed strange</td>
</tr>
<tr>
<td>Members of the team could not agree on a single result</td>
</tr>
<tr>
<td>No change made, the team was sure the result was right, although later it was found to be wrong</td>
</tr>
<tr>
<td>We reviewed the solution and came up with a different result</td>
</tr>
<tr>
<td>Other (specify):</td>
</tr>
</tbody>
</table>

9. List three aspects your group could change to be more effective and efficient solving problems like the one given.
1)  
2)  
3)  

10. In a scale from 0 to 10, what grade would you give to the solution provided by your group?
0 1 2 3 4 5 6 7 8 9 10
Extremely bad Extremely good

11. Why would you assign your group that grade?
Answer:
Part II
Can any student become a better problem solver?

There are different ways to characterize problems. One way is to assume a problem contains: givens, goal, and obstacles.

A. The givens are the elements, their relationships and the conditions known initially. Everything that helps describing the initial state or condition.
B. The goal is the desired solution or outcome of the problem; it can be seen as the desired final state.
C. The obstacles are the properties of the problem and the characteristics of the problem solver that make it difficult to reach a solution.

12. Which one of the above mentioned aspects can be changed by the student? **Why?**

13. Do you, as a team, believe that any student can become a better problem solver? **Why?**

14. For the problem your team solved, list two characteristics of the problem solvers that can be considered as obstacles:

1) 
2) 

15. List three things that would help *anyone* becoming a better problem solver:

1) 
2) 
3)
Part III
IDENTIFYING THE PROBLEM

As obvious as it may sound, one must recognize there is a problem before one can start solving it! One must also identify the right problem and identify it correctly, too. Sometimes, there are givens that are not necessary for the efficient solution of a problem. A good problem solver sorts out the information and makes a mental or written record of those elements critical or relevant.

16. State the “goal” for the previous problem?

17. List one piece of information that was not necessary to solve the problem and one that was relevant?

Information not necessary:

Information relevant:

18. Did your team try to use any piece of information which was not really necessary to solve the problem? Which piece of information was it?
Part IV
PLANNING

Ineffective problem solvers jump prematurely to a solution. No matter how complicate or simple a problem, it is always necessary to do some planning. The depth and complexity of planning depend in part on the problem itself. Sometimes, one needs to write a sequence of steps or several equations to be used, intermediate goals and calculations. Sometimes the plan is completely mental, brief and simple.

Though always necessary, planning does not only depend on the problem but on the problem solver, too. The amount and the form of planning vary from individual to individual and it is imperative to find the best planning type one can use.

19. Read the following statements and mark yes, no or n.a. (not applicable):

<table>
<thead>
<tr>
<th>Statement</th>
<th>Yes</th>
<th>No</th>
<th>N.A.</th>
</tr>
</thead>
<tbody>
<tr>
<td>The team answered the problem inappropriately fast</td>
<td>(yes)</td>
<td>(no)</td>
<td></td>
</tr>
<tr>
<td>The team used some sort of representation (drawing, diagram, flow chart, etc)</td>
<td>(yes)</td>
<td>(no)</td>
<td></td>
</tr>
<tr>
<td>The team devised a plan</td>
<td>(yes)</td>
<td>(no)</td>
<td></td>
</tr>
<tr>
<td>Was the plan complex?</td>
<td>(yes)</td>
<td>(n.a.)</td>
<td>(no)</td>
</tr>
<tr>
<td>Was the plan purely mental?</td>
<td>(yes)</td>
<td>(n.a.)</td>
<td>(no)</td>
</tr>
<tr>
<td>Was planning sufficient?</td>
<td>(yes)</td>
<td>(no)</td>
<td></td>
</tr>
<tr>
<td>The team thinks planning is not indispensable.</td>
<td>(yes)</td>
<td>(no)</td>
<td></td>
</tr>
</tbody>
</table>

20. Do you think that having been more reflective would have helped your group find the correct solution? Explain briefly.

21. Do you think that using a representation did improve/would have improved your performance? Explain briefly.

22. In the teaching profession there is a frequently used principle called “The Five P’s”: Proper Planning Prevents Poor Performance. What do you think of this expression?
Part V
EVALUATING

Evaluating the process one uses to reach a solution is important. By doing so, one knows one is not off track and it makes the whole process more efficient. Let’s pretend you are going to a job interview. You are using a map to get to this place to which you have never been before. Your directions read “after the gas station, go straight for two miles and turn right at the Courthouse”. If you pass the gas station and after driving straight for 5 miles you find no Courthouse, wouldn’t you know there is something wrong with your driving plan? Most probably, you would stop, re-consider the situation, make adjustments to your plan, execute the changes and see if it works this time! Or would you keep driving just because that is what the plan is?

Evaluate the outcome, if it makes no sense, it cannot be good! For example, if the goal of a problem is finding the weight of a car, and one arrives at the answer: “the car weighs one million pounds”… most certainly something is not correct with the solution.

Let’s say a group produced the following answer to the problem given initially: “The minimum number of stockings needed to take out to be sure one has two stockings of the same color is 8”.

23. Does this answer make sense? Why/why not?

24. Would your solution for this problem have been different if the room had not been dark?

25. Do you, as a team, believe that any student can become a better problem solver? Why?

26. List the best three things that you think could help anyone becoming a better problem solver:

1)
2)
3)
Part VI
FINAL PROBLEM YOU MAY DISCUSS AS A GROUP, BUT EACH INDIVIDUAL MUST TURN IN HER OR HIS ANSWER SEPARATELY
(THERE ARE TWO COPIES OF THIS PAGE ATTACHED)

Name: ____________________________________________ Lab Section: ___________

Choose and solve only one of the following problems. Practice any new skill you may have learnt from the previous pages, for example, identifying the goal, sorting out relevant information, using graphical representations, planning and evaluating, etc.

Problem #1 “A car in Philadelphia starts toward New York at 40 miles an hour. Fifteen minutes later a car in New York starts toward Philadelphia – 90 miles away – at 55 miles an hour. Which car is nearest Philadelphia when they meet?”

Problem #2 “George wants to fry 3 eggs as quickly as possible. Unfortunately, his pan only holds two eggs and each egg takes 2 minutes a side to cook. What is the shortest amount of time in which George can fry his 3 eggs?” (Yes, George wants both sides of his eggs cooked!)

1) Identify and define the problem: state the problem and the goal in your own words.

2) According to the goal, what information given is not relevant and might not be used?

3) What information is relevant and will be used?

4) Planning: devise a brief plan to solve the problem.
5) Make a drawing or scheme that represents the initial conditions and the final conditions for this problem.

6) Can you see the answer from your drawing?

7) What is your answer to this problem?

8) Does your answer make sense? Why?

9) Was the solution to this problem obvious from the beginning or did your representing and planning help you in understanding and solving the problem? Explain.

10) Things are not always what they seem, and too often one is so very over-confident that does not check the process and answers. The correct answer for problem #1 is “neither one, both cars are at the same distance from Philadelphia”. The correct answer for problem #2 is “The shortest amount of time George needs to fry his 3 eggs is 6 minutes”. Knowing the answer, can you explain the solution? (yes) (no)

11) From the previous experience, how would you rate yourself as a problem solver?

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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<td>Extremely bad</td>
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<td>Extremely good</td>
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</tbody>
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12) Do you think you can transfer these problem solving skills and practice to Chemistry problems? Explain briefly.

13) Please, write any comments your may have about this problem solving exercise.
Appendix C

Informed Consent Form

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

DEVELOPMENT OF TECHNOLOGY BASED ASSESSMENTS IN CHEMISTRY

Study to be conducted at: Clemson University, Chemistry Department

Principal Investigators: Melanie M. Cooper  656 2573  
Charles T. Cox  
Terry L. McAlister  
Guillermo S. Sandi-Urena  
Todd A. Gatlin

INFORMATION:

You are invited to participate in a research study. The Institutional Review Board (IRB) of Clemson University has reviewed this study for the protection of the rights of human subjects in research studies, in accordance with federal and state regulations. However, before you choose to be a research participant, it is important that you read the following information and ask as many questions as necessary to be sure that you understand what your participation will involve. Your signature on this consent form will acknowledge that you received all of the following information and explanations from the principal investigator (or his/her designated representative), and have been given an opportunity to discuss your questions and concerns with the principal investigator or a co-investigator. Additionally, should you have any questions regarding your rights as a human participant, please do not hesitate to contact a member of the IRB at 864-656-0636.

PURPOSE:

This study involves research into how students learn to solve problems. Approximately 1300 students per semester will be involved in this research.

PROCEDURES:

You will work a series of web based chemistry problems approximately four times during the semester. The program you will be using keeps track of the information you use to solve the problems and allows us to compare your strategies with those of your peers. Part of the information collected will be in the form of surveys and/or scales administered before or after your working on the web based problems. Random short interviews may be used to collect additional information. Your approximate time commitment will be four (4) hours per semester.

POSSIBLE RISKS:

This project is minimal risk research. Any statements or actions on your part will not be identified by your name or any other identifier to anyone outside the project, and your participation in this project will be held in confidence, however results of the project may be published. Any results from this project will not contain information by which you may be identified.
EXCLUSION REQUIREMENTS:

Students under 18 years of age will not participate in this research study.

POTENTIAL BENEFITS:

The potential benefits from this research include: improved problem solving skills and improved content mastery. It is not possible to predict whether or not any personal benefit will result from your participation in this study. You understand that the information that is obtained from this study may be used scientifically and may be helpful to others.

VOLUNTARY PARTICIPATION:

Participation in this study is voluntary. You may refuse to participate or withdraw from the study at any time. If you do not wish to participate, you may still be asked to complete the problems as part of the assignments in the lab. Data will not be collected on students who elect not to participate. If you refuse to participate or withdraw from the study at any time, you will not be penalized or lose any benefits and your decision will not affect your relationship with this institution. The investigator may withdraw you from the study at any time. If this is done it will not affect your grade. You will be informed of any significant new information regarding this study that may affect your willingness to continue in this study.

CONFIDENTIALITY:

The records of your participation are confidential. The investigator will maintain your information, and this information may be kept on a computer. Study information or data may be examined by the Institutional Review Board of Clemson University and various federal regulatory agencies. This study may result in scientific presentations and publications, but steps will be taken to ensure you are not identified by name.

QUESTIONS:

For more information concerning this study and research-related risks or injuries, you may contact the Principal Investigator (see first page for identifying information). You may also contact a representative of the Institutional Review Board of Clemson University for information regarding rights of participants involved in a research study.

CONSENT

I have been given an opportunity to ask questions about this study; answers to such questions (if any) have been satisfactory. In consideration of all of the above, I give my consent to participate in this research study. I acknowledge receipt of a copy of this informed consent statement.

PARTICIPANT'S SIGNATURE: ______________________ DATE: __________

PARTICIPANT’S PRINTED NAME: ________________________________

Please sign here if you choose NOT to participate: _________________
Appendix D

Interview Protocol

Department of Chemistry
Chemistry Education
Research

Effect of the lab experience, IMMEX and the intervention on students’ problem solving

Interview protocol
Interview protocol

Effect of the lab experience, IMMEX and the intervention on students’ problem solving

1. Introductory aspects

We consider that it is very important for instructors to understand the way students learn in the lab and the ways in which they solve problems. The best way to accomplish this goal is to listen to students and give them the chance to tell us about their opinions. We want to learn from students, to be educated by students. This is not part of the assessment of the course; we are not evaluating the students, we are simply listening. The conversations will be audio taped just as a means for us to go back and review what was said. During the conversation, I may take notes which most probably will be reminders to myself of something I want to inquire about later, or something especially interesting you said. I will not jot down things about you, you are not under observation.

Please feel free to spend as much time as you need or want on any given topic. You do not have to reply to a question if for any reason you do not feel comfortable. We may stop the conversation at any time you wish or need to. Do not feel like I am being too insistent if I ask some follow up questions to your comments. It is our interest to clearly understand what you mean; we are trying to get to a deeper level of understanding.

Once again, this interview does not have any effect on your grades. There are no correct answers; we just want to listen to your comments. We very much appreciate your taking the time for this conversation. We will start with some general background information and then we will move on to aspects related to your thoughts about the 101 lab experience, the projects and IMMEX.
2. Background

a) How many years have you been at Clemson?
b) Where do you come from?
c) Roughly, what is the size of your high school? Is it rural, urban or suburban?
d) What kind of science courses did you take in high school? Follow up: what courses in chemistry did you take? What kind of Math courses did you take?
e) What other courses are you taking now?
f) Other than your chemistry courses, what other lab courses did you take in high school? What other lab courses did you take this term?
g) Have you decided on a major yet?

3. Effect of lab experience, IMMEX and intervention on students’ problem solving

Thoughts about the chemistry lab:

a) How has your experience been in the chemistry lab this semester?
b) How is it similar or different to the other labs you are taking?
c) What effects, if any, has the work in lab had on your overall general Chemistry experience, including the lecture course?.
d) Do you think the experiences in the lab course had any impact on the way you think of chemistry problems now?
Thoughts about Hazmat:

One of the online problems on which you worked last semester was called Hazmat, and it was very similar to the first lab project. Make the problem set available to the students.

a) How was your experience working on Hazmat?

b) What was your reaction to this problem?

c) In what ways is hazmat similar to or different from other problems you have seen in chemistry or other classes? Follow up: how would you describe this problem?

d) What made it (easier or more difficult) to work on these problems?

e) What effects, if any, has working on Hazmat had on your problem solving skills? Did you take anything more away from that problem than just the answer, anything applicable to other problems or classes?

Thoughts about the intervention:

We often try to create opportunities for students to improve their problem solving skills. As part of this effort, you worked on a problem solving exercise. Hand in copy of intervention to the student; tell them they can write on it.

a) What was your experience with this activity?

b) Did it have any effect on your work with the Hazmat problems, why, why not?

c) We observed an increase in the correctness of the answers from students who participated in this exercise. What do you think could have caused this change?

What was it that led you to volunteer to participate in this interview?

4. Wrap up (here I thank students again for their valuable collaboration and remind them this is not part of the evaluation)
REFERENCES


Smith, B. L., MacGregor, J. T., (1992). What is collaborative learning? In A. Goodsell, M. Maher, V. Tinto, B. Smith, & J. MacGregor (Eds.), Collaborative learning: A sourcebook for higher education.


