EXPLORING STUDENTS' INTERACTIONS, ARGUMENTS, AND REFLECTIONS IN GENERAL CHEMISTRY LABORATORIES WITH DIFFERENT LEVELS OF INQUIRY

by

Haozhi Xu

A Dissertation Submitted to the Faculty of the

DEPARTMENT OF CHEMISTRY AND BIOCHEMISTRY

In Partial Fulfillment of the Requirements

For the Degree of

DOCTOR OF PHILOSOPHY

WITH A MAJOR IN CHEMISTRY

In the Graduate College

THE UNIVERSITY OF ARIZONA

2012

THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

As members of the Dissertation Committee, we certify that we have read the dissertation prepared by Haozhi Xu entitled "Exploring Students' Interactions, Arguments, and Reflections in General Chemistry Laboratories with Different Levels of Inquiry" and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy

____ Date: 04/19/12

Vicente Talanquer

____ Date: 04/19/12

Hamish Christie

____ Date: 04/19/12

Jon Njardarson

____ Date: 04/19/12

Ingrid Novodvorsky

____ Date: 04/19/12

Debra Tomanek

Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copies of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

____ Date: 04/19/12

Dissertation Director: Vicente Talanquer

STATEMENT BY AUTHOR

SIGNED: Haozhi Xu

ACKNOWLEDGMENTS

I would like to first give my deepest gratitude and love to my parents who have always been supportive all these years. They provide me with opportunities to be where I am. Without them, none of this would be even possible. They are my biggest fans and I can always find strength from them. To them, I dedicate this dissertation.

And I especially want to thank my advisor, Vicente Talanquer, who has made this possible for me. His excellent mentoring, extreme understanding and support are so appreciated to make my Ph.D. study productive and meaningful. Vicente has been very patient and supportive throughout the process. He encouraged and guided me when I was lost. Thank you, Vicente, for everything.

TABLE OF CONTENTS

TABLE OF CONTENTS - *Continued*

LIST OF TABLES

LIST OF TABLES-*Continued*

LIST OF FIGURES

LIST OF FIGURES –*Continued*

ABSTRACT

Students' learning in inquiry-based investigations has drawn considerable attention of the science education community. The central goal of inquiry-based learning is to engage students in hypothesis testing, planning and monitoring investigation activities. Furthermore, inquiry activities can be viewed as knowledge construction processes in which students are expected to develop conceptual understanding and critical thinking abilities. Our study aimed to explore the effect of experiments with different levels of inquiry on students' interactions in the laboratory setting, as well as on students' written arguments and reflections. Our results are based on direct observations of group work in college general chemistry laboratories and analysis of associated written lab reports.

The analysis of students' interactions in the laboratory was approached from three major analytic dimensions: Functional analysis, to characterize the communicative strategies used by the study participants; cognitive processing, to examine the ways in which students processed the experimental tasks; and social processing, to determine the nature of the social relationships developed through participation in peer groups. According to our results, higher levels of inquiry were associated with an increase in the relative frequency of episodes where students were engaged in proposing ideas versus asking and answering each others' questions. Higher levels of inquiry also favored episodes in which experimental work was approached in a more exploratory (versus procedural) manner. However, no major changes were observed in the extent to which students were engaged in either interpretive modes of cognitive processing or discussions of central scientific concepts and ideas. Increased levels of inquiry were also associated

with more frequent episodes of domination in which a few students in a group made most decisions and directed the actions of others.

As part of our study we were also interested in characterizing the effects of experiments involving different levels of inquiry on the structure and adequacy of university general chemistry students' written arguments, as well as on the nature of their reflections about laboratory work. Our findings indicate that the level of inquiry of the observed experiments had no significant impact on the structure or adequacy of arguments generated by students. However, the level of inquiry of the experiments seemed to have a major impact on several areas of students' written reflections about laboratory work. These effects were most noticeable in the areas of Learning, Evaluation, Improvements, and New Questions. In the case of Learning, our findings were particularly interesting as higher levels of inquiry led to a smaller proportion of reflections in this area. However, these reflections shifted from mostly focusing on factual knowledge to largely concentrating on procedural knowledge and metacognitive knowledge.

In general, our results elicit trends and highlight issues that can help instructors and curriculum developers identify strategies to better support and scaffold productive engagement in the laboratory. Our results suggest that careful design and implementation of instructional interventions may be needed to maximize the learning effects of the more open-ended inquiry activities at the college level.

CHAPTER 1: INTRODUCTION

Laboratory work has a well recognized central and distinctive role in the science curriculum. It is critical to bridge the gap between scientific concepts and experimental observations (Russell & Weaver, 2011). Learning goals of laboratory work include understanding the nature of science, improving scientific reasoning and critical thinking abilities, and appreciating how science works (Johnstone A. , 1982). Laboratory work also provides a learning environment where students can develop their operational skills including equipment manipulation, experiment design, observation and interpretation, data collection and analysis, problem-solving abilities, decision-making abilities, communication, and team work (Bennett & O'Neale, 1998).

However, the effectiveness of laboratory work has been seriously questioned by educators (Bates, 1978; Hofstein & Lunetta, 1982). All too often students are involved in verification laboratory activities that engage them very little in conducting the experiment and put too much emphasis on confirming concepts. This traditional confirmatory type of laboratory is the oldest yet most well established approach used in a majority of academic institutions (Russell & Weaver, 2011). Students are taught about a certain concept or idea before experiments and then asked to verify what they have learned by executing a pre-determined procedure. This deductive process may help students to develop practical skills such as operating equipment, but contributes little to students' conceptual understanding (Tweedy & Hoese, 2005). This approach to laboratory work has been critiqued as "*carrying out an exercise*" instead of "*doing an experiment*" (Bennett & O'Neale, 1998).

Over the past forty years, a variety of researchers have investigated laboratory's educational effectiveness. (Domin, 1999) Tobin (1990) provided recommendations for meaningful learning in laboratory settings. To be specific, he pointed out that meaningful learning can be achieved if students are provided with opportunities to generate research questions, design experiments, reflect on what they find, and communicate concepts and ideas with peers. These types of results have prompted efforts to transform laboratory instruction to open opportunities for students to more meaningfully and productively participate in scientific practices and discourse (Osborne & Dillon, 2008). In particular, the major efforts have been on creating opportunities for learning science through active exploration, data acquisition and analysis, and argumentation; in other words, an approach centered on learning through inquiry (Tweedy & Hoese, 2005).

Scientific inquiry is defined by The National Research Council (1996) as follows: "*Inquiry is a multifaceted activity that involves posing questions; examining books and other sources of information to see what is already known; planning investigations; making observations; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; reviewing what is already known in light of experimental evidence; and communicating the results to others*."(National Research Council, 1996, p.23.) The inquiry approach to teach laboratory has risen to the top among different models for laboratory instruction, supported and recommended by numerous studies and organizations (NRC, 1996). Sadi's (2011) work on hands-on instruction intervention indicates that the involvement of students in more inquiry-based activities enhances student achievement and interest toward science (Sadi & Cakiroglu, 2011).

Barneaa, Doria, and Hofstein (2010) explored the effectiveness of incorporating inquiry-based laboratory in a high school chemistry class. They found that students who participated in this type of lab had a significantly better understanding of chemistry concepts and that such an experience prepared students better for advanced chemistry courses (Barneaa, Doria, & Hofstein, 2010).

Although the larger proportion of the reform efforts to transform science laboratory instruction in the past twenty years have focused on the secondary school level, there have been important initiatives to reform lab work in the different science disciplines at the college level (Leonard, 1994; McNeal, 1997). In the particular case of chemistry, changes to traditional conceptualizations of practical work have been suggested by several authors (Johnstone & Al-Shuaili, 2001; Reid & Shah, 2007). In particular, research-based models of reform, such as those that follow the science writing heuristic framework (Burke, Greenbowe, & Hand, 2006) or process-oriented guided inquiry learning approach (Lamba & Creegan, 2008), have been developed and enacted in different college settings. However, little educational research has been done focused on the analysis of what these new models of instruction afford in terms of student learning, reflective engagement in experimental work, productive interactions, or writing literacy in the college laboratory setting (Krystyniak & Heikkinen, 2007; Poock, Burke, Greenbowe, & Hand, 2007).

In recent years, reform efforts at the general chemistry level at our own university have led to the development and implementation of a set of lab experiments that engage students in different levels of inquiry, from highly structured lab activities to guided-inquiry investigations to open-inquiry projects (NRC, 2000). The primary goal of this educational reform has been to create a more student-centered learning environment by gradually embedding the inquiry-based approach in the general chemistry laboratory. The present study was conducted in the first year of this reform process. We were interested in analyzing and gaining insights into the challenges of incorporating inquiry-based activities in the college general chemistry laboratory. In particular, we wanted to develop a better understanding of the learning opportunities created by laboratories with different levels of inquiry during the transition process. Research has shown that there are many challenges associated with the shift from traditional "follow-the-recipe" instruction to open-inquiry strategies. For example, Trumbull, Bonney, and Grudens-Schuck (2005) have found that students may not gain conceptual understanding or inquiry skills as expected by merely participating in inquiry activities. Practices that actually mimic the work of scientists in the discipline are required to promote meaningful learning gains in an inquiry setting. Additionally, integrating learning of content knowledge with learning about inquiry seems to be critical to foster students' understanding (Trumbull, Bonney, & Grudens-Schuck, 2005)

The research work presented in this Thesis is aimed to explore how engagement in laboratory experiments with different levels of inquiry affects a) students' interactions while working in collaborative small groups, and b) students' written arguments and reflections about laboratory work as expressed through laboratory reports. Specifically, our research was guided by the following research questions:

- How does the level of inquiry of experimental activities affect interactional patterns in small groups in the general chemistry laboratory?

- How does the level of inquiry of experimental activities affect students' written arguments and reflections in their laboratory reports?

In order to fulfill these goals, two related studies based on mixed methods research design were conducted. The two studies shared the same target participants yet used two separated sets of data. In the first study, we investigated the impact of experiments involving different levels of inquiry on students' interactions by direct observation of small groups engaged in experimental activities in a general chemistry laboratory. In the second study we characterized the way students formulated lab reports making use of the Science Writing Heuristic, as well as the effect of level or degree of inquiry on students' arguments and reflections.

As this study was conducted in a unique phase of a general chemistry laboratory in which there were efforts to incorporate different levels of inquiry, observation and analysis of students' work may provide instructors strategies to scaffold students' learning in inquiry-based investigations. The analysis of students' writing is expected to enrich the criteria that can be used to assess its quality. Findings from this study are expected to have implications for science instructors at both K-12 and college levels and assessment of students' writing.

The dissertation has been organized in the following way: the theoretical framework that guided the design and implementation of this project is presented in Chapter two. The description of the setting, methodology, results, conclusions and limitations specific to each of the two studies is presented in two different chapters: Chapter three focuses on the study on students' interaction in the laboratory, and Chapter four presents the major results for the study on students' written lab reports. Chapter five includes the overall conclusions, and future research directions.

CHAPTER 2: THEORETICAL FRAMEWORK

Meaningful Learning in the Laboratory

Research has shown that the laboratory is a unique teaching and learning environment which allows students to construct knowledge by doing science (Tobin, 1990). However, in a traditional expository laboratory, instructors define the topics, outline the procedure and direct students' actions. Students merely follow instructions presented by the teachers or lab manual to confirm results that are predetermined and already known by the students. This traditional instructional approach has been criticized as hindering meaningful learning (Johnstone & Al-Shuaili, 2001). On the contrary, learning can be meaningful if students are given opportunities to manipulate instruments and make meaning of practical work. To promote meaningful learning in the laboratory, inquiry-based instruction has emerged as an alternative to traditional laboratory instruction. In this approach, students are responsible for designing experiments and generating procedures, and results are induced from the investigation rather than predetermined by instructors. Inquiry labs are designed to promote critical thinking among students to achieve better conceptual understanding.

When students are actively involved in learning in the laboratory, they interact with the environment, manipulate tools that are helpful during the process, make observations of what they encounter, formulate explanations and communicate their ideas and results to peers. To be specific, students are engaged in making meanings on a continuous basis. Questions may be evoked by students such as what happens when I do this? How can I interpret the phenomena? Meanings are constructed by actively manipulating the ideas and information (Jonassen, 2003). Meaningful learning, in this case, refers to the acquisition of knowledge that allows you to do something with it. Michael (2001) gave a vivid explanation of what meaningful learning was. He saw meaningful learning as knowledge that was well integrated with something else, and that could be stored with connections to existing knowledge. Rote learning, by contrast, was defined as memorization of simple facts and information. In order to promote meaningful learning, according to Ausubel's theory, several conditions must be met. "*(a) the concepts presented to the learner must be potentially meaningful and hence must provide opportunity for the learner to form non-arbitrary relationships with existing conceptual frameworks (meaningful learning tasks), (b) the learner must have a conceptual framework to which the new concepts can be linked (relevant prior knowledge), and (c) the learner must manifest the meaningful learning Set*" (Ausubel, 1968).

The prerequisite for meaningful learning implies that prior knowledge or content knowledge is essential for meaningful learning to occur. If students lack sufficient content-related knowledge, they will not be able to conduct efficient investigations or provide correct interpretations. For instance, students may notice a precipitate or a color change during an experiment, but they will not be able to suggest an explanation if they do not have adequate relevant knowledge. Several research studies have shown that prior knowledge is one of the most significant factors in determining students' performance (Seery, 2009). As links between prior knowledge and new knowledge are formed, meaningful learning is believed to take place (Ausubel, 1968). Students construct their knowledge effectively in a way that integrates new knowledge with their prior knowledge.

Furthermore, to construct knowledge, students' mental efforts are needed. Knowledge cannot be taught to students by teachers. Students' cognitive involvement is needed to trigger meaningful learning.

The meaning-making process has also been characterized by some researchers as collaborative. It has been suggested that students must be engaged in some form of dialogic activity if the goal is to foster students' understanding (Jimenez-Aleixandre & Reigosa, 2006). Given a task or a problem, students naturally seek other's help and elaborate the ideas as a group. Benefits of collaborative learning include more positive attitudes toward science courses and enhanced learning achievement Shibley's study (2002) on an introductory chemistry laboratory showed that students in the collaborative learning sections were more willing to work effectively during class time and voiced positive perceptions about the collaborative experience. McCreary, Golde & Koeske (2006) explained that higher levels of satisfaction with the learning experiences in collaborative laboratory setting may have influenced students' performance in the study (McCreary, Golde & Koeske, 2006).

Some researchers have highlighted the common imbalance of opportunities for students to operate instruments and to engage in scientific dialogue in traditional laboratory settings (Jimenez-Aleixandre & Reigosa, 2006). Students generally are not provided with enough time in the laboratory to make sense of what is happening or to reflect on what is learned; they are usually required to execute certain tasks or manipulate instruments within a time frame. Thus, Gunstone (1991) suggested that having students construct their knowledge in a laboratory is a reasonable but naive idea, since learning from practice is a very complex process that requires close analysis and in-depth study.

Levels of Inquiry

Given that students are not provided with sufficient opportunities to be engaged in meaningful learning in traditional laboratory settings, educators have tried to incorporate the inquiry approach into the curriculum. Inquiry-based laboratories have been promoted because they are expected to improve students' critical thinking abilities and understanding of chemistry concepts. However, although the term "inquiry" has been widely used in the chemistry and science education community, there are difficulties to differentiate different levels of inquiry in the science classroom. Schwab (1962) and Herron (1971) were among the first to develop a rubric to better characterize science inquiry in the secondary science curriculum. In particular, they used a continuum of openness in the design and implementation of experiments to characterize levels of inquiry (Schwab, 1962; Herron, 1971).

In general, three main features have been identified as critical in the determination of the level of inquiry of an activity. Typically, experimental work starts with a "problem", the question that needs to be investigated. Then the activity is conducted via "ways and means", the procedure followed in the task. Finally, "answers" are generated in the form of findings and conclusions. Each of these three features can be coded as open to the students to provide or as provided by the teacher or the curriculum materials. For example, Schwab (1962) classified inquiry into three levels:

> *At the simplest level, the manual can pose problems and describe ways and means by which the student can discover relations he does not already know from his books. At a second level, problems are posed by the manual but methods as well as answers are left open. At a third level, problem, as well as answer and method, are left open: the student is confronted with the raw phenomenon-let it be even as apparently simple a thing as a pendulum.*

Later Herron (1971) added a lower level of inquiry in which problems, methods and interpretations are given in the lab manual. Based on Schwab and Herron's work, other rubrics such as the Biological Science Curriculum Study (BSCS) have been generated to describe inquiry in secondary laboratories (Tamir & Lunetta, 1978). Buck, Bretz and Towns (2008) have extended this line of work to undergraduate labs by developing rubrics to characterize inquiry in undergraduate laboratory activities. In particular, they collected 22 laboratory manuals across science disciplines to characterize inquiry levels. Six characteristics were identified which correspond to areas in the analysis of activities where students can act independently. These characteristics include: 1) problem/question, referring to the topic for the investigation; 2) Theory/background, meaning the content knowledge for the investigation; 3) Procedure/design, referring to the experimental procedure that student follows in an investigation; 4) Results/analysis, reflect how data is analyzed and interpreted; 5) Communications, refer to how students communicate their ideas to others; and 6) Conclusions, the summary of the investigation. In each of these areas, five levels are used to indicate the extent to which external guidance is provided during laboratory work. The different levels describe degrees of openness from the least open in which all of the six characteristics are provided by the lab manual or the instructor, to the most open level in which students are make decisions about all the six components. (Table 2.1.)

Table 2. 1 A rubric to characterize inquiry in the undergraduate laboratory. (Buck, Bretz, & Towns, 2008)

Characteristic	**Level 0: Confirmation**	**Level ½: Structured inquiry**	**Level 1: Guided inquiry**	**Level 2: Open inquiry**	**Level 3: Authentic inquiry**
Problem/Question	Provided	Provided	Provided	Provided	Not provided
Theory/Background	Provided	Provided	Provided	Provided	Not provided
Procedures/Design	Provided	Provided	Provided	Not provided	Not provided
Results analysis	Provided	Provided	Not provided	Not provided	Not provided
Results communication	Provided	Not provided	Not provided	Not provided	Not provided
Conclusions	Provided	Not provided	Not provided	Not provided	Not provided

The openness of inquiry activities affords different levels of participation and dynamic interaction. Providing students opportunities to be actively engaged in inquiry requires designing activities that enable students to participate in scientific ways of thinking. The different levels of inquiry create the potential for changes in participant structure. In this case, participant structure refers to the social arrangement or social positioning of the students in a group, directly supporting and enabling discipline-specific learning. Research studies that are interested in how participant structure affects learning often focus on understanding how student interactions influence social regulation. (Cornelius & Herrenkohl, 2004).

Interactions in Lab Settings

Experimental work in college science laboratories traditionally involves students working in small collaborative groups. The identification and characterization of factors that facilitate or hinder the emergence of group processes that foster generative forms of collaboration is thus of critical importance to promote meaningful learning. Some research studies in this area have explored the effect of individual traits, such as gender, prior knowledge and achievement, and personality, on collaborative outcomes (Webb & Palinscar, 1996). Recent work framed from a situative perspective has focused on the role played by social process during collaboration, looking to characterize and understand the interdependence among practices, processes, and conditions leading to the social construction of knowledge in different learning situations (Barron, 2000, 2003; Kumpulainen & Mutanen, 1999; Oliveira & Sadler, 2008; Richmond & Striley, 1998; Volet, Summers, & Thurman, 2009; Stamovlasis, 2006) These types of studies tend to pay close attention to the content and function of classroom discourse as elicited through the analysis of student-student and student-teacher interactions.

Analysis of interactions during traditional laboratory work at the secondary and tertiary educational levels suggests that lab talk is very goal-oriented. On-task conversations and actions are largely focused on managing and completing lab work and tend to be characterized by brief, highly compressed or fragmented utterances (Carlsen, 1991; Gallagher & Tobin, 1987; Tapper, 1999). Student talk during experimental activities is mostly centered on procedural issues related to how to carry out specific experimental tasks or how to manage lab equipment (Aufschnaiter, 2003; Krystyniak &

Heikkinen, 2007). Considerably less time is invested on either analyzing and discussing experimental data or trying to understand scientific concepts and ideas, building connections between theory and practice, or reflecting on science practices. These interaction patterns seem to characterize how students interact among themselves and with their teacher during traditional labs. They constitute what can be described as the procedural display of “doing the lab:” The set of interactional procedures that count as the accomplishment of experimental activity in schools (Bloome, Puro, & Theodorou, 1989).

Krystyniak and Heikkinen (2007) compared the verbal interactions among students in a lab team, and those with their instructor, during non-inquiry college general chemistry labs and extended open-inquiry investigations. Their results revealed a decrease in student-instructor interactions concerning procedures and data recording and an increase of conversations related to lab safety and data analysis in the context of open inquiry. However, participants in this study also talked less about chemistry concepts while engaged in the more open investigations. These authors also observed that students sought less instructor guidance during the open-inquiry than the non-inquiry lab activities. These latter results are consistent with findings from other researchers that indicate that students gain independence from their instructor while involved in open-inquiry investigations (Roychoudhury & Roth, 1996).

Several authors have suggested that the types of *social processing* and of *cognitive processing* in collaborative groups may be used as indicators of productive engagement and participation (Kumpulainen & Mutanen, 1999; Volet et al., 2009). Social processing in collaborative groups needs to be understood as a dynamic process driven by one or more individuals. It may quickly vary from situations in which a single individual temporarily leads group work by providing information or asking questions to instances of co-regulation in which multiple members regulate and monitor joint activity. For example, Roychoudhury and Roth (1996) identified three major types of social interactional patterns during collaborative group work in open-inquiry labs: Symmetric, asymmetric, and shifting asymmetric. In symmetric interactions the participating students contributed similarly to the discourse while in asymmetric interactions one of the participants achieved a higher status by carrying the main bulk of the work. During shifting asymmetric interactions one student dominated the discourse for extended periods of time but this role shifted within members of a group. These authors also found that students engaged in open inquiry investigations seemed to negotiate meaning in different ways, primarily following a collaborative mode, and adversarial mode, or by following a majority rule.

The existence of different patterns of interaction during collaborative group work indicates that there might be uneven social status in groups. Some groups may promote coalitions, thus creating competition rather than collaboration. (Hythecker, Dansereau, & Rocklin, 2010) Different status within a group can affect students' learning opportunities and bias the evaluation of their performance and achievement (Chui, 2000). High-status students, often identified as group leaders, seem to learn more because they have greater access to group resources and feedback from others. On the other hand, low-status students interact much less with other members in the group and contribute less to the group learning. (Dembo & McAuliffe, 1987) The different levels of participation in group work may cause less cognitive involvement for some members, inducing a *free-rider effect* which hinders learning. The *free-rider effect* is present when one or more group members perceive their efforts as unimportant, assuming that the work will be done by the talented or highly active members of the group. (Salomon & Globerson, 1989) However, the *free-rider effect* is more likely to take place in some specific types of group activities. In particular, the effect is likely to be present when group work can be completed by a single individual and does not maximal effort from all group members. (Kerr, 1983)

In general, the particular nature of the social interactions among group members has been shown to be a fundamental source of variability in the actual accomplishments of collaborative groups (Barron, 2000, 2003). Symmetric collaborative interactions are expected to be more productive as they open spaces for the co-construction of shared understandings by refining partial meanings presented in the group space (Oliveira & Sadler, 2008; Reusser, 2001). However, co-construction of meaningful understandings requires more than instances of co-regulatory activity; it demands sustained engagement in high-level cognitive processing such as building explanations, developing models, drawing inferences, synthesizing ideas, or critically evaluating arguments (McNeill & Krajcik, 2008; Osborne, 2010; Volet et al., 2009). From this perspective, analyzing both social and cognitive processing during collaborative work in lab settings is critical in understanding how to promote productive learning interactions in such contexts.

Science Writing as a Learning Tool

Most educators recognize the difference between spoken and written language, as only writing can be “the carrier of ideas of precision and subtlety” (Kaplan, 1997). Writing is viewed as a fundamental factor for modern thought, as writing “facilitates a logical, linear presentation of ideas” (Langer & Applebee, 1987) In line with this, writing can be treated as a tool for learning. Improvement of students’ writing, particularly in the context of academic tasks, is believed to improve students’ learning and thinking. A pioneer study by Emig (1977) closely examined how writing can be a learning tool. “*What is striking about writing as a process is that, by its very nature, all three ways of dealing with actuality are simultaneously or almost simultaneously deployed. That is, the symbolic transformation of experience through the specific symbol system of verbal language is shaped into an icon (the graphic product) by the enactive hand. If the most efficacious learning occurs when learning is re -enforced, then writing through its inherent re-enforcing cycle involving hand, eye, and brain marks a uniquely powerful multi-representational mode for learning*”.(P 125) Diverse cognitive approaches to writing have emerged in the past thirty years based on these types of ideas (Flower & Hayes, 1980; Bereiter & Scardamalia, 1987; Klein, 1999)

Flower and Hayes’ approach saw writing as a problem-solving cognitive process, as the thinking required in writing involves many intellectual skills. Writing was argued to contribute to active problem solving by defining a rhetorical problem and satisfying a rhetorical goal. These authors collected protocols from both expert and novice writers and built a model of the rhetorical problem itself. They claimed that the rhetorical problem included two units: the rhetorical situation and the writer's own goals.The situation refered to the audience and also the assignment that was given to the writer. Four goals including the reader, voice, building a meaning, and producing a formal text were identified by the authors. The main contrast between a good writer and a poor writer was that a good writer elaborated on the goals that were set by themselves and generated ideas to fulfill these goals, while a poor writer simply relied on the ideas that were prompted by original topics without further elaboration. Bereiter and Scardamalia (1987) further explained this difference between experts and novices by establishing the knowledge-telling and knowledge-transforming models. In the knowledge-telling model, writers retrive ideas from memory that are related to the topic and the genre and then translate them into text. The deliberation or conscious application of knowledge is not required by this process as writers merely think about what to say next. By contrast, the knowledge-transforming model involves operation and recognition of both existing ideas and new ideas to satisfy rhetorical goals, hence a development of writer's understanding of the topic.

Although these models provide insights into the contrasting ways of writing of novices and experts, they seem to ignore the thinking process behind the text (Galbraith, 1999). In this regard, Galbraith (1999) suggested writing as a knowledge constructing process. The generation of ideas in writing was claimed to involve two distinct processes, "*One - rhetorical planning - did involve evaluating and modifying ideas to satisfy rhetorical goals, as claimed by problem-solving models, but was not associated with developments of the writer's understanding. Instead, it involved the reorganization of* *existing ideas. The other - which I called dispositional spelling out - involved spontaneously articulating thought, as it emerged during text production, and was associated with the development of the writer's personal understanding of the topic*." Galbraith argued that information was synthesized within the concepts network that was stored instead of simply retrived as the problem-solving model stated.

In Langer and Applebee's (1987) work about how writing shapes thinking, these authors claimed that activities involving writing better promoted learning than activities involving reading and studying only. Different kinds of writing activities lead to different cognitive and learning outcomes. Short-answer study questions, in which the information is listed or implied by the text, require little reconstructing of knowledge or ideas by students. Analytic writing, on the contrary, focuses more on complex manipulation and organization of concepts and ideas. This suggests that instructors need to be selective on which type of writing activity to assign to the students. The analytic writing leads to better understanding while short-answer questions can deal with more information yet superfically. Langer and Applebee also made recommendations for effective instruction based on their study. They found that the most effective instruction took place when the teacher and students had a shared understanding of the instructional goal and a shared sense of the importance of collaboration. Several key components are needed for effective instruction scaffolding: *Ownership implies that* students should be given room to write what they want to convey. This feature is often neglected by teachers as information recall is usually the primary goal of traditional school writing tasks. *Appropriateness* suggests that tasks should be designed in a way that students can accomplish the goal with appropriate help but they will not be able to finish the task without any help. *Support* suggests that a supportive dialogue must be provided to students so that they can internalize the language and thoughts. *Collaboration* implies that the relationship between teachers and students when engaging in learning new concepts should be collaborative. All too often, teachers become evaluative as they grade the writing and they direct the process instead of supporting it. These suggestions for effective instruction provide a basis for contriving methods of using writing-to-learn strategies in science contexts.

There is little disagreement on the importance of writing to learning science. Science Writing is a meaning-making process, since task-related information is internalized and related to prior knowledge (Grimberg & Hand, 2009). Several research studies have shown a postive effect of writing on learning in science and mathematics. Craig (2011), for example, applied a classification scheme to examine the effect of explanation writing strategies on college mathematic students' problem-solving behavior. The results of this study showed a higher level of students' engagement with the mathematical material and a more positive attitude toward science. In a study analyzing how one group of middle school students generating meaning from scientific data, Keys (1999) found that rich written elaborations based on the observed data were critical to students' understanding of the topic. These studies on the effect of writing to learning have prompted the development of various writing strategies to enhance learning. One approach that acts as a outcome of these studies has been the Science Writing Heuristic approach.

Science Writing Heuristic

Although science educators have emphasized the importance of incorporating inquiry activities in science classrooms and laboratories to promote conceptual understanding, inquiry activities alone have been argued as insufficient to achieve such a goal. Involvement in high-level cognitive tasks such as writing seems to be required in addition to engagement in hands-on activities (Hohenshell & Hand, 2006). The Science Writing Heuristic (SWH) is an educational approach that has been developed and used by educators in science classrooms and laboratories to facilitate meaningful learning through writing-to-learn techniques. To be specific, the purpose of the SWH approach is to promote thinking, negotiate scientific meaning and communicate ideas by writing. It is an inquiry-based argumentation approach, which scaffolds students' knowledge construction process by prompting students to generate questions, claims, evidence as an argument to support the claims, as well as writing a reflective script to clarify meanings and explanations to their classmates and teachers (Akkus, Gunel, & Hand, 2007). Thus, the Science Writing Heuristic serves two main functions. On the one hand, the approach can be used as an instructional model, since it helps teachers organize laboratory instruction to promote critical thinking and knowledge construction (Greenbowe, Poock, Burke, & Brian, 2007). On the other hand, it can be also used as a heuristic tool for constructing students' lab reports. Thus, two heuristic templates are often described. One assists teachers to design activities in order to scaffold students' reasoning and conceptual understanding, while the other template is a semi-structured protocol that guides students in understanding inquiry and scientific concepts through writing.

There are several key components of the SWH templates that are traditionally used to guide students' lab work and report writing. The first part of the template is referred to as *beginning questions*, where students are encouraged to formulate their own investigation questions. These questions are expected to be researchable and answerable by performing an experiment. In a second stage, students are asked to design practical procedure and make observations. Based upon reviewing the procedure and observations associated with beginning questions, students then need to generate knowledge *claims* and provide rational *evidence* to support such claims. Students are expected to "*note a pattern, demonstrate a generalization, articulate a relationship, or provide an explanation that they have uncovered by their work*" (Burke, Greenbowe & Hand, 2006). The last stage of the template fosters students to *reflect* on what their understanding of the concepts and experiments are and how their ideas have changed due to the investigation. The format is designed to promote the development of conceptual understanding instead of rote memorization.

Questioning plays a central role in inquiry type investigations as conceived in the SWH approach where such investigations are conceptualized as "an experimental study that requires first-hand participation and leads toward providing evidence that permits a question, posed at the outset, to be answered" (Lock, 1990). When generating questions, problems to be solved can be well-defined or ill-defined. Thus, question-generating is an important cognitive skill that fosters knowledge comprehension and self-regulation (Blonder, Mamlock-Naaman, & Hofstein, 2008). An investigation which is guided by beginning questions leads to making claims and presenting evidence to support the claims.

Although argumentation is fundamental to the nature of science and critical to science communication, studies demonstrate that students are not good at generating arguments (Zimmerman, 2000). Students often fail to see the connections across sets of data, ignore data or reinterpret data to match prior beliefs or existing knowledge. Another essential feature that is structured in the Science Writing Heuristic is metacognition. Metacognition is described as awareness of how one learns, involving self-regulation and management of one's own cognitive process related to the investigations (Kaberman & Dori, 2009). In the SWH approach, students are expected to reflect on what they learn, what they still do not know, and on the degree to which their ideas have changed after the experiment. These reflective tasks require students to monitor and self-check their learning progress by evaluating their understanding. In addition, Questioning also incorporate metacognitive activities. Question generating demands that students become aware of what they know and what they do not know.

The developers of the Science Writing Heuristic approach, Hand and Keys, have conducted a series studies to investigate the effect of implementing the SWH in secondary science. In one of Keys and Hand's (1999) studies, the authors implemented activities based on the Science Writing Heuristic in secondary classrooms. Their intent was to investigate core characteristics of students' report writing and understanding of the nature of science. The analysis of the reports and interviews provided evidence that "*use of the science writing heuristic facilitated students to generate meaning from data, make connections among procedures, data, evidence, and claims, and engage in metacognition*." Keys and Hand also examined the relationship between the Science

Writing Heuristic intervention and students' achievement, showing that students in the experimental sections outperformed those enrolled in the control sections. (Hand, Wallace, & Yang, 2004)

The Science Writing Heuristic approach has been implemented in college level science classrooms and laboratories as well. For example, Greenbowe et al (2001, 2007) gradually incorporated the SWH approach into their general chemistry laboratory curriculum. Their intent was to convert the verification laboratory activities to inquiry-oriented investigations in order to improve students' conceptual understanding of chemistry. In one of their early studies, Greenbowe et al (2001) explored the effect of laboratory work on students' understanding of the concept of physical equilibrium. In particular, they were interested in exploring whether students could build connections between questions, data, claims, and evidence. To accomplish this goal, the scores of the lecture exams on the topic of physical equilibrium for experimental and control groups were collected and compared. Their results showed that students in the experimental sections outperformed those in the control sections. Additionally, students that followed the SWH approach expressed better attitudes toward chemistry (Rudd J, Greenbowe T, Hand B, Legg M, 2001). In a later study focusing on investigating the effect of SWH labs on overall lecture performance, Greenbowe et al (2007) demonstrated that students involved in the Science Writing Heuristic approach achieved better than those in traditional lab sections (Greenbowe, Poock, Burke, & Brian, 2007).

Argumentation in the Science Laboratory

Science educators consider argumentation as a significant component in science learning. Students' use of evidence in written explanations reflects how they make sense of complex experimental data and how they support specific claims (Berland & Reiser, 2009). However, it has been stated by Sandoval and Millwood (2005) that students often fail to build connections between data and causal ideas or concepts. They tend to ignore abnormal data and observations during the experiment or distort it to match their prior knowledge. These authors attribute this behavior to the fact that students lack adequate contextual knowledge and that they have little experience designing and conducting scientific investigations. Other science educators (Kind, Kind, Hofstein, & Wilson, 2011) also mentioned that students had difficulty generating arguments in laboratories. They pointed out that students were often asked to follow a step-wise pathway from research problems to conclusions without thorough reflections. As a result, students were focused on 'correct' data which would lead to 'correct' conclusions. It has been suggested that inquiry-based laboratory can provide opportunity for students to facilitate argumentation skills. (Eijck, 2010; Glaesser, Gott, Roberts, & Cooper, 2009).

One of the studies conducted by Tien and Stacy (1996) indicated that students who participated in guided-inquiry laboratory activities performed significantly better than those who were enrolled in traditional verification laboratory in terms of finding evidence, making conclusions based on such evidence, and evaluating their results. Ozdem and his colleagues (2011) investigated the type of argumentation schemes generated by pre-service elementary science teachers in inquiry-based laboratories. They found that the designed inquiry activities, which were enriched with critical discussions, provided those teachers opportunities to apply varied premises to ground their claims or to argue for a case. As the Science Writing Heuristic strategy has the potential to promote better argumentation in laboratories, some researchers have examined the learning conditions needed to optimize its positive effects. (Yoon, Bennett, Mendez, & Hand, 2010) These authors claimed that students would not automatically participate in scientific dialogue. A non-threatening learning environment, in which students were confident that their voice would be listened to and respected, was believed to be optimal to promote argumentation. Other than learning environments, task types are also believed to have influence on the quality of argumentations. Kind et al (2011) compared the quality of arguments generated by middle school students in both laboratory-based activity and paper-based activity. They found that students generated more argumentation units when involved in paper-based tasks that did not require hands-on data collection. These authors claimed that student argumentation during experimental tasks was often brief, as collecting data was their primary interest.

A wide variety of studies in science education have applied Toulmin's (1958) argument structure to analyze students' written or spoken arguments. Toulmin's analytical framework is based on the identification of six core elements of an argument: Claims, data, warrants, backings, qualifiers, and rebuttals. *Claims* can be defined as statements not yet proven, *data* are facts that support the claim, and *warrants* are reasons or principles that connect the data to the claim. The *backings* are the theoretical assumptions behind a warrant, whereas the *qualifiers* establish the boundaries of a claim and *rebuttals* are arguments that refute elements of an argument. (Aufschnaiter, Erduran, Osborne, & Simon, 2008) By analyzing a participant's argument structure using this framework, a researcher can map the quality of students' arguments over time.

An early work conducted by Kelly (1998) applied Toulmin's framework to the analysis of students' spoken arguments when working on hands-on performance assessment in the topic of electricity. In particular, this author classified warrants based on warranting strategies, referent of the warrant, and the warrant type. Based on this analysis, Kelly found that students did not always need to provide warrants in order to solve problems. More recently, Erduran et al (2004) and Osborne et al (2004) defined standards for measuring the quality of arguments that can be applied on a large scale. These authors proposed a coding scheme in which arguments are classified into five levels of sophistication. The first level includes arguments that consist only of claims. Arguments that also contain some sort of justification are classified at the second level. Arguments that also involve the occasional weak rebuttal besides claims and warrants belong to the third level, while arguments consisting of one or more rebuttals and build strong connection between evidence and claims belong to levels four or five (Nielsen, 2011). These types of structural analyses of students' arguments allow us to evaluate the quality of arguments based on organizational elements (Sandoval & Millwood, 2005).

Toulmin's analytical framework has been criticized because it fails to consider the actual scientific validity of an argument (Hofstein, Kipnis, & Kind, 2008). In fact, there are several factors that may lead to fallacious argumentation, beyond the nature of the structural elements. The quality of an argument may be tainted by the subject's scientific misconceptions, strength of initial core beliefs, or the use of inferior evidence (Zeidler, 1996). Therefore, more and more researchers have been incorporating other aspects besides argument structure to evaluate the quality of argumentation. For example, some authors have built coding schemes to capture how well the evidence responds to the claims based on appropriateness and sufficiency. Appropriateness has been described as relevant data to the problem whereas sufficiency is defined as providing enough data to warrant the claim (Ruiz-Primo, Li, Tsai, & Schneider, 2010).

In summary, students' learning can be shaped by peer interactions in inquiry-based context and by proper writing strategies. The present work aimed to explore students' learning in terms of social interaction and writing literacy in an inquiry-based general chemistry laboratory. The next chapter describes the research methods and results of the first study, which focused on the analysis of students' interactions in collaborative groups and the impact of level of inquiry on such interactions.

CHAPTER 3: STUDENT INTERACTIONS IN CHEMISTRY LABS WITH DIFFERENT LEVELS OF INQUIRY

As students engage in collaborative small groups in general chemistry labs, it is beneficial for educational researchers to explore the interaction dynamics within groups in order to identify strategies that better support student reasoning in such environments. This chapter describes the first part of our study which focused on the analysis of student interactions within small groups in General Chemistry laboratories with different levels of inquiry.

Methodology

Goals and Research Questions

The central goal of this study was to characterize the effects of experiments involving different levels of inquiry on students' approaches to lab work, looking to identify mechanisms to better support and scaffold productive engagement and meaningful learning in these different contexts. In particular, our investigation was guided by the following research questions:

- What interaction patterns characterize students' work in a General Chemistry laboratory?
- How does the level of inquiry of an experiment affect students' interactions in the laboratory?

Research Context

This study was conducted in the Department of Chemistry and Biochemistry at the University of Arizona. The University of Arizona is a public research-extensive institution with a total enrollment of about forty thousand undergraduate and graduate students. These students are enrolled in a variety of programs from social sciences to natural sciences to engineering. The Department of Chemistry and Biochemistry at this institution offers a two semester sequence of general chemistry courses for science and engineering majors addressing fundamental ideas in the areas of structure of matter and chemical reactivity. Students in these courses, mostly in their first year of university studies, attend a 150-minute weekly laboratory class where they work in self-selected groups of three or four people under the supervision of a teaching assistant (TA); most TAs are graduate chemistry students completing Ph. D. work in our department. On average, twenty four students divided in six groups of four students are engaged in experimental work in a given laboratory class and they attend fourteen laboratory sessions in a given academic semester (lasting around 15 weeks). Most experiments in the general chemistry course ask students to apply diverse analytical techniques (e.g., chromatography, emission and absorption spectroscopy, titration) to the study of diverse chemical systems and processes.

When this study was conducted in the fall of 2008, the department was at the first stages of redesigning the General Chemistry lecture and laboratory. The main goals of this redesign project were to integrate the lecture and lab courses, ensure the implementation of a common curriculum, create a more student-centered learning environment, and increase opportunities for students to participate in guided and open inquiry investigations in the lab setting. The new, more coherent course was expected to improve both students' success and the quality of their educational experience.

Participants

Participants in this study were drawn from five different collaborative groups that were attending the reformed General Chemistry laboratory. The groups were randomly selected, in which three of the groups were recruited from one lab section in the first semester laboratory course (Chem 151) and the other two groups were recruited from one lab section in the second semester laboratory course (Chem 152). The first semester course was offered in the fall of 2008, and the second semester course was given in the spring of 2009. The main topics addressed during the two-semester lab course are listed in Table 3.1. The two lab sections were taught by the same experienced graduate teaching assistant. Consent forms to participate in the study, approved by the Institutional Review Board of the University of Arizona, were signed by the teaching assistant and the targeted students at the beginning of the research project (a copy of the consent form can be found in Appendix D). Lab groups in the observed General Chemistry course were self-selected and students usually worked on the same lab bench. Students worked as a group during the experiment and also in the lab discussion periods. All of the observed groups kept a quite consistent composition throughout this study, although one student from one particular group dropped the class during the research period. The composition of the groups was diverse, including different proportions of female and male students (see Table 3.1) and students from different majors. A total of 20 students participated in the study, which included 11 females and 9 males. Each student was assigned a specific code during the analysis of the data to ensure confidentiality. Observed groups were labeled Group 1 through Group 5 for reference purposes.

Table 3.1. The topics and the group compositions for the observed groups in the two-semester general chemistry laboratory.

	Group Observed	# of Participants (Female/Male)	Lab Experiment	# of Weeks Observed	Inquiry Level
Chem 151	Group 1	4/0	Measurement (Identification of plastics by mass/volume measurements)	1	2
			Separation (Chromatography of food pigments)	1	3
			Identification (Identification of gases by molar mass determination)	1	1
	Group 2	3/1	Emission (Detection of ions via emission spectroscopy)	1	1
			Absorption (Quantification of colorants via absorption spectroscopy)	1	2
	Group 3	1/3	Qualitative Analysis I (Detection of cations in solution)	1	2
			Qualitative Analysis II (Detection of cations in minerals)	1	3
			Chemical Analysis (Open investigation designed by students)	2	4
Chem 152	Group 4	0/4	Kinetics (Determination of reaction rates for bleaching)	2	3
			Water Project (Analysis of local water composition)	2	2
	Group 5	3/1	Acids and Bases I (Quantification of substances by titration)	1	1
			Acids and Bases II (Identification of substances by titration)	1	3

	Research Project (Open investigation designed by students)	1	4

Description of the Learning Environment

The overall goal of the reformed General Chemistry laboratories was to create a student-centered environment in which understandings about the experiments and related chemistry concepts were built in a collaborative manner. Some of experiments were designed to be more traditional, in which most of the investigation questions, background information or procedure were provided by the instructor or the lab manual, while some other experiments were more open. In these latter cases, students were expected to generate research questions, design experimental procedures and control the conditions for their investigations. Although different experiments involved different inquiry levels, each experiment followed the same fundamental format of operation. At the beginning of each experiment, students attended a pre-lab discussion session inside the lab. The instructor outlined the challenge of the week's laboratory and provided background knowledge or supported students to build sufficient background content knowledge in order to promote the generation of questions. Then students took charge of the experimental activity by constructing beginning questions and doing the experiments. Students were provided with the types of questions and the detailed procedure in the less inquiry-based activities. They worked in small groups of three or four people. After the experimental work, students were asked to return to the lecture area and presented their major claims and the evidence that they found to support the answer to their original questions. Discussions may be prompted by the instructor depending on the topic and the experimental results. A reflective writing assignment (lab report) was required as a way to derive meaning from the laboratory work. The analysis of these reflective writing tasks will be discussed in the following chapter (Chapter 4) as a separate study.

Research Methods

Qualitative methods of research were used in this study (Bruce, 2001). Qualitative methods are usually situated in natural research settings including classrooms, laboratories, or communities. The researcher is usually responsible for both qualitative data gathering and data analyzing; qualitative data can be collected in the form of observational field notes, interview transcripts, etc. This type of research can be influenced by the researcher's personal beliefs and biases. Another obvious limitation of this approach is that statistical analysis can be overlooked because of the in-depth and comprehensive nature of the qualitative approach. It is thus necessary to use strategies to minimize subjectivity yet maintain the richness of an in-depth analysis. To accomplish this goal, the qualitative data collected in our study was examined for patterns and themes, coding systems were developed to capture and represent those trends, and then the coding was analyzed quantitatively (Chi, 1997). In particular, the quantitative coding was translated into quantifiable charts and graphs that allowed us to more clearly identify trends in the data.

Instruments

Observational Notes: Data were collected through direct observation (Bernard, 2000) of students working in small collaborative groups during experimental activity.

The author of this thesis acted as a detached observer of group work, trying to be as unobtrusive as possible while completing the observations. There was no observation protocol since students performed many different activities in a given lab session. However, the researcher consistently made observations and took field notes of what the students were doing moment-to-moment in the laboratory and what they were talking about as they engaged in experimental activity. Direct observation by a researcher present in the lab was selected over other research methods (e.g., video or audio recording) given the specific characteristics of experimental work in the observed chemistry laboratories. In this setting, students frequently move to various parts of the lab room (e.g., lab benches, weighing tables, fume hoods) to complete different activities in a single lab session. There is also constant background noise generated by over 20 people actively working in a closed space and by fume extractors and air filtration systems. Following and capturing student actions, as well as registering the nature of student conversations was facilitated by the presence of a direct observer that could quickly react to the changing dynamics of group work in this environment. Difficulties using audio and video recording to register student conversations in college lab settings have been reported by several authors (Krystyniak & Heikkinen, 2007; Tapper, 1999).

Restrictions imposed by personnel resources and our research methodology limited our observations to one single group per lab session. Thus, in order to increase the diversity of the groups subject to study, we chose to follow the work of different groups throughout the academic semester. This approach allowed us to observe a total of five different groups of students, three of them working on Chem 151 labs and two of them engaged in Chem 152 labs. Analysis of general achievement data indicated that the 20 students involved in these groups had, on average, a grade point average (GPA = 2.40/4.00) slightly lower than the average GPA for all of the students in the general chemistry course (GPA = 2.60/4.00). However, the difference in the distribution of grades was not statistically significant as indicated by a t-test.

General observations were made of each laboratory group to note the interactions and detailed actions of the group. For the first three groups observed in the first semester, each group was observed for three consecutive weeks for the entire lab period. In the second semester, we observed one group at the beginning of the semester for three weeks and a second group for the following three weeks. Then, we repeated the same cycle of observations with these two groups in the second half of the semester. The change in the observation pattern from the first to the second semester was driven by our interest in analyzing how group interactions might change over time. For instance, some students might be shy and silent when the group first met. They might not be interacting very often with other group members. But as time passed and they felt more comfortable in their groups, they might interact more and contribute more.

At the beginning of each lab, students usually would sit together as a group to discuss and generate beginning questions. The researcher took notes of the topic and the dialogues among group members during this time. It was common for the TA to initiate the discussion of background information for the lab and ask questions to the students. This supplemental information was also recorded so that we could keep track of the context in which dialogues took place. Most of the lab time was spent by the students working in their lab benches. During this time, the researcher observed and recorded the different activities and interactions among different group members. The observation notes included details such as: the task that students were performing, the name of the specific student performing a particular task, the kind of problems that students encountered and how they solved the problem, the content of students' discussions, and any other significant events during the experiment. Researcher's comments on how each student participated in different parts of the experiment, such as "Student A did the hands-on work all of the time" also served as additional notes to help the researcher recall the situation later when analyzing the data.

The researcher made every effort to act as a nonparticipant observer during the observation process, as the intent was not to interfere with group work. The researcher did not initiate any content-related conversations during the observation periods. In addition, students were notified that the observation was only for a research project and not for any evaluation of their work.

Data Analysis

Since little research has been done on students' interactions in General Chemistry laboratories with different levels of inquiry, this project was exploratory in nature. Our main goal was to characterize the effect of different types of laboratory activities on small group interactions in the lab setting. A description-analysis-interpretation approach has been suggested as one of the most suitable data analysis methods for research studies that are based on observational qualitative data. This method begins with the development of a coherent representation of the observation field notes. The field notes were read over and over again by the researcher to extract aspects that the researcher could pay attention to. The second phase, analysis, is aimed to expand and extend the description and generate systematic themes in order to identify key factors and relationships between them. After generating general themes, it is then important to make sense of what is going on, to maximize the explanations that can be revealed by analysis solely. However, the researcher often needs to go back and forth during the analysis. Additional data collection may be needed during this phase depending on the sufficiency and appropriateness of the data (Wolcott, 1994) As stated by Agar (1980): "*Ethnography…you learn something ('collect some data'), and then you try to make sense out of it ('analysis'), then you go back and see if the interpretation makes sense in light of new experience('collect more data'), then you refine your interpretation('more analysis'), and so on. The process is dialectic, not linear*."

In this study, this interactive, non-linear analysis method was applied to the data collected and themes were categorized by coding common terms and ideas that were related to the guiding research questions. To be specific, the field notes for a given lab session were divided into a sequence of "episodes" with boundaries determined by perceived changes in the nature of the discourse or in the nature of the students involved in the interaction (Lemke, 1990). Then anthropological descriptions of episodes were written to draw an overall picture of what happened during the labs. The richness of the interactions patterns started to emerge from the description. A well known situated analytic framework (Kumpulainen & Mutanen, 1999) which examined multidimensional perspectives to interaction was applied in our study to generate an initial list of categories and codes for different dimensions of interactions. In particular, this coding system was revised in our study to reveal the specific types of social and cognitive interactions in the context of General Chemistry laboratories. The frequency of each code was registered so that quantitative data could be extracted from the qualitative analysis. By contextualizing the subsequent quantitative data, general claims on the patterns of verbal and social interactions were generated. Statistical analysis was used to examine the effect of the level of inquiry on interaction patterns. In addition, as the researcher coded the field notes, the uneven social status of different groups drew the researcher's attention. Road maps sketching role shifting during the experiment period were constructed by the researcher to identify variations in the social roles of each group member.

The detailed field notes and the coding system that was applied and modified by the observer were reviewed by another chemical education researcher. This other researcher went over the field notes and coding system and the observer then explained how she coded the episodes to the other researcher. Based on the suggestions by the other researcher, the coding system was then modified by the observer and new codes or alternative codes were integrated in the analysis. The strategy was repeated until total disagreements were less than 10% of the total episodes and codes. The final agreed set of codes was then applied by the observer on the rest of the data.

Our analysis focused on two aspects in order to answer the research questions. One examined the laboratory activities in order to identify inquiry levels, and the other focused on students' work in collaborative groups looking to characterize the nature of peer interactions, the focus of students' talk, and the adopted social roles. The following sections describe the analysis of these two aspects in detail.

Inquiry Levels of Experiments in the General Chemistry Laboratory

Group interactions in our study were situated in laboratory activity corresponding to tasks with different levels of inquiry. The work done by Buck, Bretz, & Towns (2008), as described in the framework presented in Chapter 2, suggested that inquiry can be classified as "full" or "partial" based on the proportion of the learning process that is dominated by students or not. We applied the ideas presented in that study to create a rubric to classify the inquiry level of the observed lab experiments in our study. In particular, we paid attention to the extent to which students had ownership in the development of an experiment's research questions, required background knowledge, experimental procedure, explanatory outcomes, and communication of results. This rubric is shown in Table 3.2.

Table 3.2. Classification of inquiry levels based on the openness of the essential elements.

Features	**Level 1 (Verification)**	**Level 2 (Structured)**	**Level 3 (Guided)**	**Level 4 (Open)**
Questions	Learner is provided questions by teachers, or materials	Learner sharpens questions provided by teachers or materials	Learner selects among questions and also poses new questions	Learner poses questions
Background	Learner provided background before experiment	Learner provided background during experiment	Learner provided background during experiment as needed	Learner gathers background information
Procedure	Learner directed to collect certain data	Learner directed to collect certain	Learner determines what	Learner determines what

	and follow pre-determined procedure	data and determine detailed procedure	constitutes evidence and how to collect it, sample procedure provided	constitutes evidence and how to collect it
Explanations	Learner asked to answer certain questions	Learner provided sample questions	Learner provided framework to build explanations	Learner formulates explanation after summarizing evidence
Communication	Learner provided detailed ideas	Learner provided partial ideas	Learner provided with a framework	Learner forms reasonable and logical argument

The main instructional materials used in this lab included the general chemistry laboratory manual and also instructional PowerPoint slides presented during the class hours. The lab manual and slides were examined to reveal to which degree students took the initiative according to the essential elements stated in the developed rubric. As a result, all of the experiments in the lab were categorized in different levels of inquiry based on the levels of the essential elements.(Table 3.3.)

Table 3.3. The inquiry levels of the experiments based on the essential features.

	Level 1 (Verification)	**Level 2 (Structured)**	**Level 3 (Guided Inquiry)**	**Level 4 (Open Inquiry)**
Experiments	• Identification • Emission • Acids and Bases I	• Measurement • Qualitative Analysis I • Absorption • Water Project	• Separation • Qualitative Analysis II • Kinetics • Acids and Bases II	• Research Project • Chemical Analysis

Dimensions of Students' Interactions

To investigate the dynamics of group interaction, an analytic framework, focusing on the moment-to-moment character of interaction, was adopted in our study. Many analytic frameworks have been developed and used in other studies in the past decades. (Oliveira & Sadler, 2008). Most of those studies focused on the functional analysis of the narrative in interactions. The selected framework for our study concentrates not only on the verbal language, but also on the interactive dynamics among students. There are three analytic dimensions in this approach: functional analysis, cognitive processing, and social processing. Each function in this framework reflects the "*Social-cognitive-discursive*" process in which students are involved during social verbal interactions. None of these functions can be viewed as reflecting a distinct dimension, thus these three dimensions are inter-connected in a complex way. (Kumpulainen & Mutanen, 1999),

The first function, the *functional analysis*, investigates the character and purpose of student utterances in peer group interaction. It characterizes the communicative strategies used by participants in social activities. From the functional meaning of an utterance, students' interactions can be identified with different function codes. Some of the functions portray the on-going activities to represent the nature of the interaction. For instance, a function such as "Reading aloud" corresponds to the activity "students read the text". Meanwhile, social networking can also be described by some functions. For example, the "Organizational" function records the social activities in which students are engaged in organizing their work.

The second dimension, *cognitive processing*, examines the ways in which students approach and process learning tasks in their social activities. It highlights students' working strategies and situated positions towards learning, knowledge, and themselves as problem solvers. It is highly related to the learning environment and task-oriented. Three broad modes are identified to distinguish different cognitive strategies that are involved in lab activities. *Procedural processing* describes cognitive activities in which students merely focus on the execution of operational tasks. Speculation of ideas and critical thinking are not needed during this type of strategy. *Exploratory processing*, on the other hand, requires students to exert more mental effort, including planning, designing, and testing. Finally, *interpretative processing* refers to the approach that students take to make sense of a situation. Ideas are made explicitly about what is happening and how one can explain the phenomena (Kumpulainen & Mutanen, 1999). To be noticed, the three modes require different levels of students' cognitive engagement. The procedural processing requires less mental effort than the exploratory and interpretative processing as students can simply execute tasks by following the instructions.

The third dimension of the analysis, *social processing*, focuses on the nature of social relationships that are developed as a result of students' social activities. This includes examining the types and forms of student participation in peer groups (Kumpulainen & Mutanen, 1999). Unlike the functional analysis aimed to characterize the functions of the narrative, or the cognitive processing which examines the cognitive strategies students apply during various situations in an experiment, the social processing characterizes the social relationship and levels of participation in student groups. The various modes that demonstrate the social relationships among group members are *Collaborative, Argumentative, Domination, Conflict, Tutoring, Confusion, Sharing and TA*. Modes such as *Argumentative* and *Conflict* signal that interactions in a group lack shared understanding of specific concepts or ideas. Students explicitly point to each other what they disagree on and support their reasoning through arguments. The typical social interaction among a collaborative group are characterized as *Collaborative, Confusion, Tutoring, sharing and TA* modes. In these cases, meaning is made by working collaboratively and sharing the experience or understandings. In general meaning-making in this type of context requires negotiation, sharing and elaboration. The types of coding categories associated with the three core dimensions guiding our analysis are summarized in Table 3.4, together with specific examples from our observational notes. These three dimensions are strongly related and should not be viewed as isolated, independent categories.

Table 3.4 Functions and modes of processing that characterized student interactions in collaborative groups in the observed college general chemistry labs. (The table includes specific examples and the percentage of instances of each function or mode observed across all types of labs.)

Dimension	**Categorization**	**Description**	**Examples (as captured in the field notes)**	**% Instances**
Functional Analysis (Language Functions)	Acknowledge	Acknowledging other people's ideas or comments	A1: "Shall we practice this (capillary use)" L1: " Yes." Then she gets the paper towel.	1.81
	Argumentational	Justifying information, opinions, or actions	H3: "Do you want to do a table?" Jo3: "No, I think a chart is better." H3: "Well, it is easier to read."	2.11
	Compositional	Proposing ideas	B1 and N1 finish fast. And	**19.3**

			then N1 suggests they split up again.	
	Directive	Assigning tasks or controlling other's behavior	B1 asks N1 " Can you go and measure the mass for these unknowns?"	**16.0**
	Evaluative	Evaluating work or action	L1 and A1 both do the measurement and compare their number and find difference. A1: "I will do it again" L1: " Yeah." And then they both redo the measurement.	5.44
	Experiential	Sharing personal experience	B1goes to the balance and weighs the plastic, L1 goes there and they share the experience of using a balance.	1.21
	Informative	Providing information	M3 shows Jo3 how to make a table.	6.95
	Interrogative/ Responsive	Asking/Answering questions	N1 and L1 go to B1 and ask "what we do next?" B1: " We need to weigh all the plastics and get the cylinder"	**27.5**
	Organizational	Organizing group work	B1 and N1have a small discussion. N1: "We have spinach and raspberry." B1: "We can start with one to one hexane/ acetone" N1: " to spinach"	4.23
	Pacing	Expressing concern about task completion or progress	N1goes to A1 and L1 and asks if they have finished or not and then copy the data from them.	2.72
	Reading aloud	Reading lab manual or data	N1: "So we need to come up with different solvent for TLC, like which separates better."	2.11
	Reasoning	Reasoning about a problem or task	L1 (asks about the raspberry): "Did you try different ratios?" B1: "we tried 2/1 acetone/hexane. But it didn't work. Maybe 1/1 is the best ratio"	0.30
	Seeking TA help	Requesting help from TA	J2 and T2 are making graphs on the computer. They find that the graph is not right, so T goes to the TA	**10.3**
Dimension	**Categorization**	**Description**	**Examples**	**%**

			(as captured in the field notes)	Instances
Cognitive Processing	Exploratory	Exploratory activity which includes planning, hypothesis testing, and evaluation.	A1: "Shall we practice this (capillary use)" L1: " Yes" Then she gets the paper towel. L1 and A1 are practicing. N1: "So we need to come up with different solvent for TLC, like which separates better."	**33.9**
	Interpretative	Activity focused on generating explanations or arguments	L1: " How to use density to decide the identify of those" B1: " We can compare to that table" (pointing to the board)	**11.4**
	Procedural	Procedural on-task activity which focuses on handling, organizing, and executing the task without much reflective analysis.	N1 (to B1): "We need to measure the mass of the flask before we do it"	**54.7**
Social Processing	Argumentative	Students are faced with cognitive/ social conflicts which are resolved and justified in a rational way	H3: "Do you want to do a table?" Jo3: "No, I think a chart is better." H3: "Well, it is easier to read."	0.77
	Collaborative	Joint activity characterized by equal participation and meaning making	L1 and A1 both do the measurement, compare their numbers and find differences. A1 "I will do it again." L1: " Yeah." And then they both redo the measurement.	9.02
	Conflict	Social or academic conflict	B1 asks N1: "Do you want to do the hot water? N1 laughs and says " I don't know how to do it"	2.58
	Confusion	Lack of shared understanding. Students do not understand the task or each other.	L1: "What are you trying to do?" A1 "Figure out the volume" L1: "What is that?" A1: " The water displacement step"	**22.4**
	Domination	Student dominating the work or decision-making process	B1 asks A1 to fill in water. B1 ask L1 to wash the flask.	**28.6**
	Interacting TA	Interaction with the TA	TA comes over and asks them to prepare another hot water bath.	10.0
	Sharing	Checking progress	N1 goes to A1 and L and ask	2.84

		or sharing information	if they have finished or not and then copy the data from them.	
	Tutoring	Student helping another student or answering questions	L1: "What are you trying to do?" A1 "Figure out the volume" L1: "What is that?" A1: "The water displacement step"	**23.7**

During our analysis, we also paid attention to the focus of students' talk during laboratory group work. A detailed description of the codes associated with this analysis is presented in Table 3.5. We found that students' conversations could focus on different task-related activities, such as *task organization*, *experimental results*, *experimental apparatus*, and *experimental phenomena*. The talk could be also related to the discussion of background concepts or information about the experiment, such *as facts*, *recourses*, and *answers*. Additionally, student talk could also focus on the *strategies* that they followed to perform experimental tasks.

Table 3.5. The focus of the talk.

Codes	**Descriptions**
Strategies	Strategies to solve problems
Task organization	Task sequence, steps, procedures
Resources	Materials used for activity
Answers	Seeking correct or accurate answers
Facts	Factual content
Experimental phenomena	Discussing the phenomena
Experimental apparatus	Discussing the instruments
Experimental results	Discussing the results

Detailed descriptions of group work provided hints on the levels of students' participations, how students made decisions, and what students focused on during the experiment. An example of such ethnographic description for one of the observed groups is shown in the following paragraph:

> *In the first experiment I observed, they split up into two smaller groups spontaneously: B1 and N1, L1 and A1. B1 did most of the hands-on work while N1 recorded data and made some preparations for B1.L1 and A1 contributed the same to the group work. There were little interactions between the two groups. They exchanged the data and other information when they had the post-lab discussion. When they analyzed the data, B1 did most of the calculations and reported the results to the whole class.*

This paragraph reveals how some group members such as B1 were very active in the operational activities and group decision making processes, while other students adopted more passive roles. Based on these types of descriptions, it was apparent that students' social status might be uneven in a group. To better understand a group's interactions, we attempted to identify possible roles that students took in the observed groups. For this purpose, students' interactions were separated into segments according to the activity types, such as different experiment tasks, and roles were identified based on the participation levels of group members in different activities.

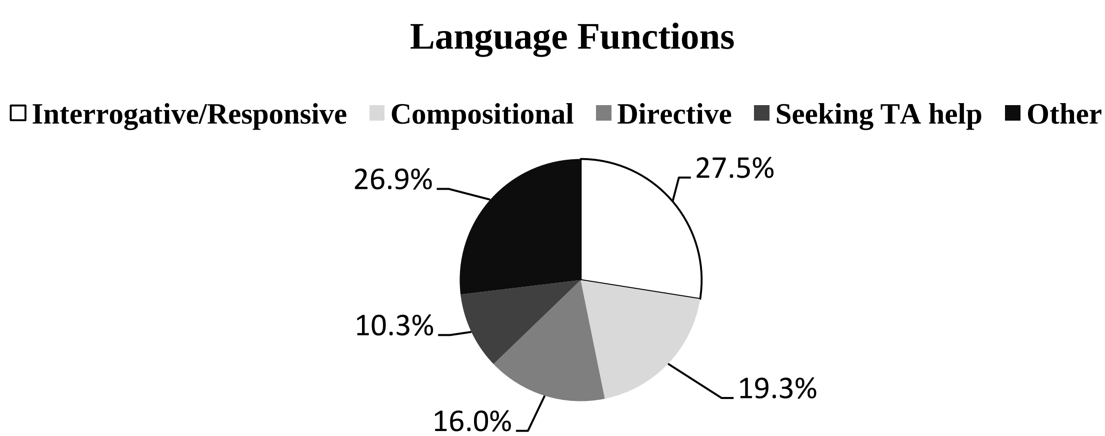
Results

In the following paragraphs, the results of our first study are organized according to the associated research questions. Thus, in each subsection we first present results for the dimensional analysis of students' interactions, and then we describe the effect of level of inquiry on each dimension of students' interactions. In later sections we discuss the roles adopted by different group members during such interactions. Our analysis is based on the comparison of relative number of instances of different functions or modes within students' discourse while performing different types of experiments. Statistical comparison of all of the observed experiments in terms of both the total number of distinct interaction episodes (an average of M = 24.1 episodes per experiment, SD = 7.3) and the total number of instances of functions or modes within each category of analysis per experiment (functional analysis, M = 25.5, SD = 8.2; cognitive processing, M = 24.3, SD = 7.4; social processing, M = 29.8 , SD = 9.6) did not reveal any significant difference between labs within the same and across different levels of inquiry. These results imply that, on average, the total number of distinct interaction episodes among students was not significantly affected by the nature of the experiments and thus comparison of relative instances across labs can be used to elicit general trends.

Dimension 1: Language Functions of Verbal Interactions

The extent to which students engaged in different language functions varied among the different groups. Overall, there were four functions that contributed more than 10 percent of these types of interactions: Interrogative/Responsive (27.5% of all of the coded instances across all experiments), Compositional (19.3%), Directive (16.0%), and Seeking TA Help (10.3%). Figure 3.1 shows the language functions that characterized all five observed groups' interactions. For all the groups, the general trend was that the most frequent language function was related to students asking or responding to peer questions (Interrogative/Responsive). Questions played a critical role in students' interactions. Students asked questions related to the tasks or simply drew direct attention from their group members. The second most frequent language function was proposing ideas to the group. When engaged in lab activities, students encountered situations that were not designed or listed by the lab manual or instructions. Students needed to generate their own plans or solutions to problems and proposing ideas thus became crucial in completing the assigned tasks. The third most common language function was the Directive function. The existence of directing activity indicated that students in the observed groups took on different roles. Some students in the group took on the leader role and assigned tasks to group members, scheduled group activities, and led group discussions. This phenomenon will be further analyzed in a later section. Although interactions with the TA accounted for close to 10% of all of the language functions, most group decisions were made by one or more group members without much TA help. According to our observations, the TA usually stayed at the discussion area that was remote from where the groups were. Students sometimes would look for the TA, but they frequently moved on with their work when they found that their TA was not around or was working with other groups.

Figure 3.1. Distribution of instances associated with different language functions for all of the observed groups.



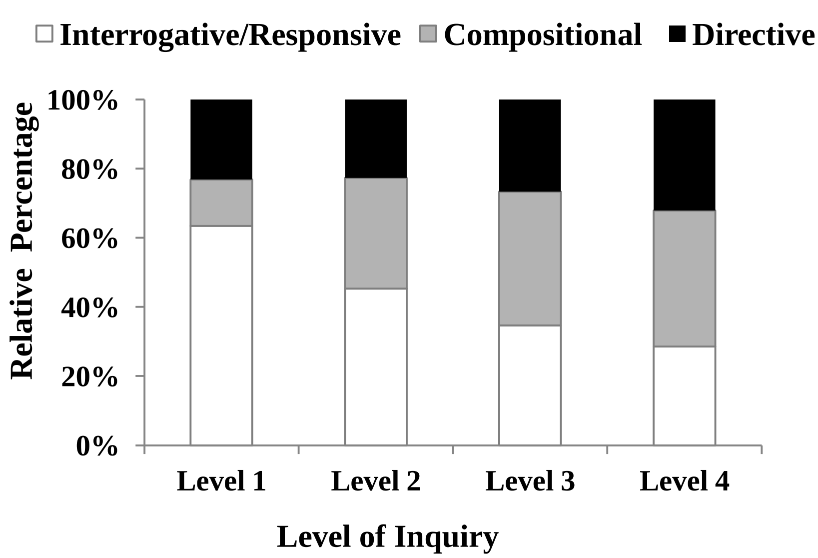
To obtain a better sense of the types of interactions associated with the different language functions, a specific example of our analysis is shown in Table 3.6. Students in this example were engaged in diverse activities such as decision-making, collaborative work, problem-solving, and tutoring episodes. As demonstrated in these field notes, N1 acted as a decision-maker by suggesting the direction for group tasks. Other group members followed her suggestions. This behavior was commonly observed in different episodes, as group members rarely disagree with other persons' suggestions. A group leader (B1 in this case) emerged as the experiment proceeded. The directive behavior was often characterized by one person assigning tasks to other group members. The analysis of all transcripts for the five observed groups indicated different levels of participation of different group members, resulting in uneven social status. The functional analysis of students' interaction demonstrated that their interaction was mostly characterized by the interrogative/responsive function. Some other functions (e.g., evaluative, pacing, compositional and directive) took place but in a much smaller proportion. However, the language function itself cannot capture the complexity of the interactions. Social and cognitive aspects will be discussed in the following sections.

Table 3.6. Sample interaction analysis of Group 1 in the experiment "Introduction to measurement".

Transcribed peer interaction	**Language function**
B1 and N1 finish fast. And then N1 suggests they split up again. B1 goes ahead and takes two out of four.(Plastics) ……	Compositional
B1 takes the two unknowns to the balance. L1 comes over and asks B1, " All right, how can I calculate the volume of these?" (Cubes and balls) B1 shows her how to calculate the volume of a cube on paper. ……	Interrogative / Responsive
B1 asks N1 "Can you go and measure the mass for these unknowns?" (The unknowns L1 and A1 took, because L and A1 did not know what to do so they did not really measure anything) ……	Directive

Our analysis revealed that the level of inquiry affected in a distinct manner the relative proportion of the Interrogative/Responsive, Compositional, and Directive language functions that characterized students' interactions. This effect can be seen in Figure 3.2 where we present the relative percentages of episodes associated with only these three major language functions in relation to the level of inquiry of the observed lab experiments. As shown in the graph, increasing levels of inquiry were associated with a lower frequency of Interrogative/Responsive interactions and a higher proportion of Compositional and Directive interactions. From this perspective, our results suggest that experiments with a higher level of inquiry prompted students to propose more ideas and to more frequently direct each other's actions, reducing the amount of peer questions related to the tasks at hand.

Figure 3.2. Relationship between the level of inquiry of experiments and observed language functions



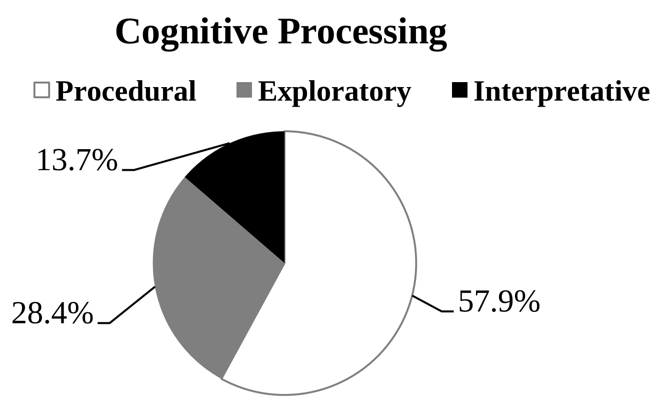
Analysis of the functional analysis data using a chi-square test indicated the existence of a significant difference in the use of the three major language functions across inquiry levels ($\chi^2 = 15.6$; df = 6; $p < 0.025$). A subsequent post-hoc test used to evaluate the standardized residuals for each language function (at a level of significance of 0.05) indicated that contributions to this significance were mainly associated with the decrease of the Interrogative/Responsive language function and the increase of the Compositional function in moving from inquiry Level 1 (verification labs) to higher levels in the inquiry scale (Table 3. 2). Thus, although our data reveals a clear trend in the relative variation of the three dominant language functions, changes between inquiry levels 2, 3, and 4 were not statistically significant for our sample. It is important to point out that our analysis did not reveal any clear trends in the effect of level of inquiry on students' independence from their instructor (Seeking TA Help). This result differs from those from prior studies (Roychoudhury & Roth, 1996; Krystyniak & Heikkinen, 2007).

Given that we did not have the opportunity to observe several groups working on the same experiment, the described changes in the purpose of students' interactions with level of inquiry may have been influenced by the specific characteristics of the observed lab groups (e.g., knowledge and motivation of their group members). However, statistical comparison of student interactions in lab groups working on different experiments with the same level of inquiry did not elicit significant differences in language functions. This result suggests that the described trends in the purpose of students' interactions (Figure 3.2) were likely more influenced by the level of inquiry of the lab activities than by individual group characteristics. Similar results were obtained when comparing content processing, social processing, and focus of the talk in groups working on experiments with the same level of inquiry.

Dimension 2: Cognitive Processing Analysis

The analysis of the types of cognitive processing associated with students' interactions in chemistry labs elicited the central role that "Procedural" thinking played in most of the observed experiments (see Figure 3.3). Overall, 57.9% of all of the observed episodes were associated with instances in which students were focused on handling, organizing, or executing experimental tasks. Only 28.4% of the coded episodes were related to Exploratory activities which included planning, hypothesis testing, and exploring alternatives, and a small percentage of the coded interactions (13.7%) involved Interpretative work (i.e., generating explanations or building arguments).

Figure 3.3. Distribution of the cognitive processing modes for all of the observed groups.



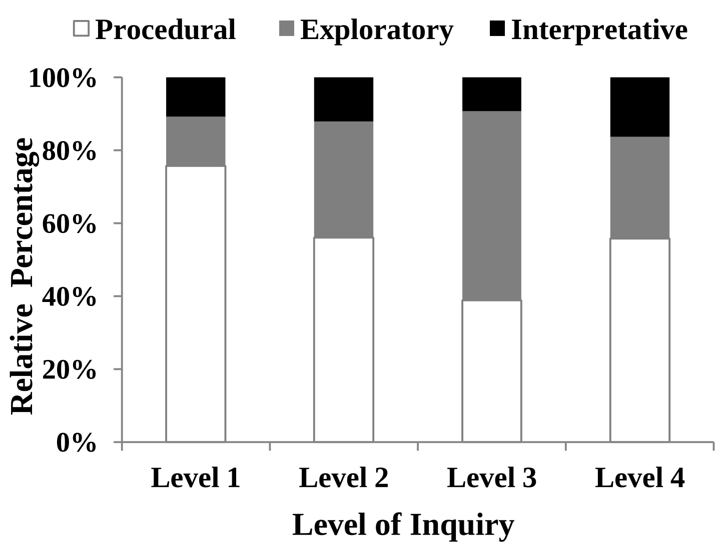
The field notes presented in Table 3.7 illustrate the three levels of cognitive processing in which students were involved during their lab activities. In the first episode, Procedural processing happened when the students were executing routine work of the experiment. They asked each other questions to check the progress and also worked on the experimental data. All these actions were aimed to finish the task. The next episode provides an example of Interpretative processing, in which Student L1 noticed a problem that she did not understand; B1 in turn attempted to interpret the problem. The last episode represents an instance of Exploratory activity in which suggestions are made to solve a problem. The analysis based on all the cognitive processing involved in the five groups' interactions showed that Procedural processing outweighed Exploratory processing. The majority of students' actions were focused on completing the experimental tasks. They asked each other questions, shared experiences, completed calculations, etc. They seldom engaged in exploratory activity, mostly when they noticed discrepancies in their experimental results or certain tasks failed. Engagement in interpretative processing was even more limited. Students rarely focused on the interpretation of their results as their major concern seemed to be finishing the experimental tasks.

Table 3.7. Sample interaction analysis of Group 1 in the experiment "Introduction to measurement".

Transcribed peer interaction	**Language function**	**Cognitive processing**
N1 goes to A1 and L1and ask if they finish or not and then copy the data from them	Pacing	Procedural
L1" How to use density to decide the identify of those" B1: " We can compare to that table"(pointing to the board) ……	Interrogative / Responsive	Interpretative
A1 suggests redoing the measurements to resolve discrepancies. Others agree. ……	Compositional	Exploratory

Even though Procedural thinking accounted for a large part of the cognitive processing, the level of inquiry of the experiments affected the extent to which Procedural versus Exploratory modes of cognitive processing dominated the nature of students' interactions (as shown in Figure 3.4). In general, our results indicate that higher levels of inquiry favored Exploratory reasoning over Procedural thinking, but had no major impact on the Interpretative component. Statistical analysis of these data revealed significant differences in the types of cognitive processing observed at different levels of inquiry (χ^2 = 32.2; df = 6; p < 0.0001). Analysis of standardized residuals indicated that major differences were associated with a) the over presence of procedural episodes and under presence of exploratory episodes in experiments at inquiry Level 1 (verification), and b) the under presence of procedural episodes and over presence of exploratory instances in experiments at inquiry Level 3 (guided).

Figure 3.4. The relationship between inquiry level and cognitive processing.



According to our results, there was a decrease in Exploratory instances of cognitive processing in moving from Level 3 (guided) to Level 4 (open) in the inquiry scale. This result may be an artifact of our data given the limited number of observed lab experiments (only two) corresponding to the highest level of inquiry. However, the increase in the Procedural component for Level 4 labs may be linked to intrinsic demands of the open-inquiry experiments that required students to come up with their own procedures to solve their proposed research questions. All of the experiments identified as belonging to inquiry Level 3 consistently involved a higher percentage of Exploratory episodes than other types of labs. In these guided-inquiry labs, students frequently received general guidance (road map) in performing experimental procedures, which may had created more opportunities for exploratory cognitive processing.

Dimension 3: Social Processing Analysis

The most common social processing mode in the observed collaborative groups was Domination (28.6%). The Domination mode involved actions such as leading group work and assigning group tasks, which reflected an uneven distribution of power and social status in the group. (Figure 3.5) The other three characteristic modes that contributed more than 10 percent to all the social processing modes included Tutoring (23.7%), Confusion (22.4%), and Interacting TA (10.0%). Students interacted mostly by asking each other questions or checking their progress. As there was a TA in the lab, it was not surprising that they interacted with the TA as well. However, it seemed that most interactions were between the group members, not with the TA. Interactions with other groups were infrequent. Although all lab groups worked in the same environment, they seemed to focus on their own tasks.

Figure 3.5. Distribution of the social processing modes for observed groups.

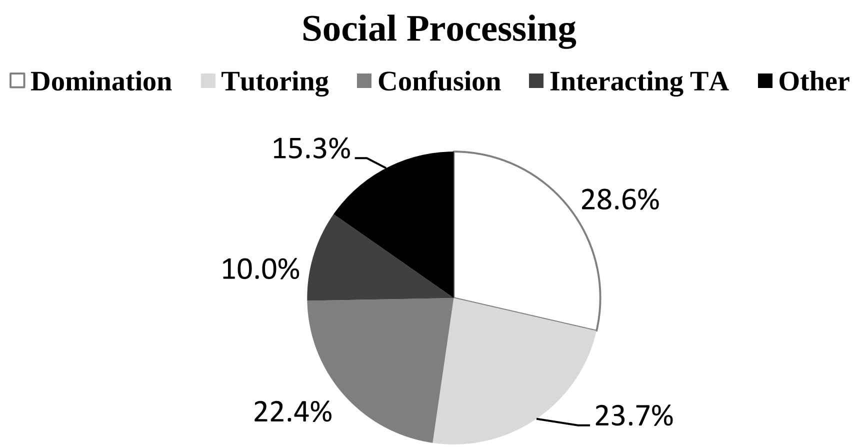


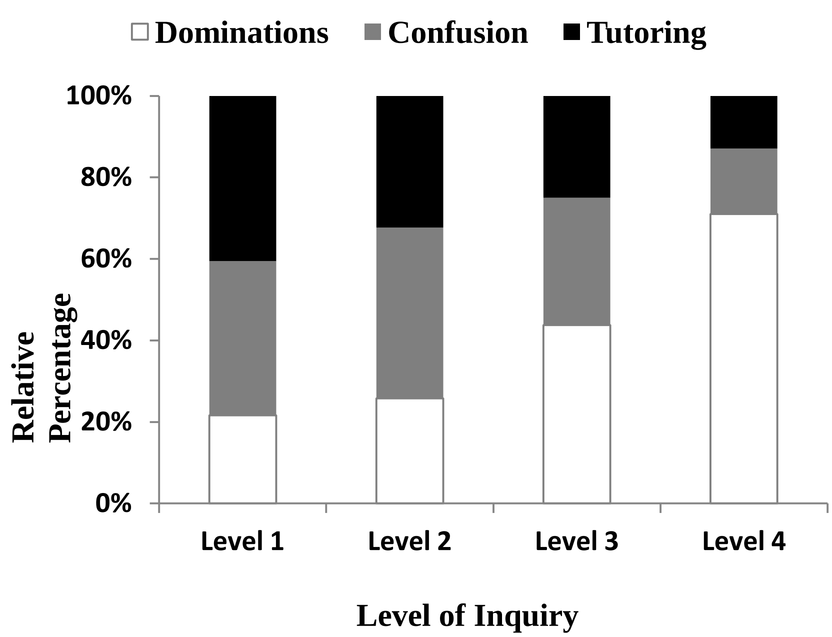
Table 3.8 illustrates the different modes of social processing observed in the general chemistry laboratories. In the first episode, two students A1 and L1 were working collaboratively on different tasks. They performed the tasks together and made collaborative decisions. Confusion and Tutoring modes are illustrated by the second episode when one student L1 was confused about what the other student A1 was doing. Although students in this group sometimes worked collaboratively as demonstrated in the first episode, there were also instances when Student B1 took a leadership role which created asymmetrical interactions. She dominated the social interaction among group members by assigning tasks to different group members and proposing detailed procedures. Instances of Domination were frequently observed in other groups where one person in the group tended to make many decisions about what tasks to do or what procedure to follow.

Table 3.8. Sample interaction analysis of Group 1 in the experiment "Introduction to measurement".

Transcribed peer interaction	**Language function**	**Cognitive processing**	**Social processing**
L1 and A1 both do the measurement and compare their number and find difference. A1 "I will do it again" L1 "Yeah" And then they both redo the measurement. ……	Evaluative	Exploratory	Collaborative
L1: "What you trying to do?" A1 "Figure out the volume" L1: "What is that?" A1: " The water displacement step"	Interrogative / Responsive	Procedural	Confusion/Tutoring
B1 asks N1 " Can you go and measure the mass for these unknowns?" (The unknowns L1 and A1 took, because L and A1 did not know what to do so they did not really measure anything.	Directive	Procedural	Domination

Modes of social processing changed significantly with the level of inquiry as shown in Figure 3.6 ($\chi^2 = 30.0$; df = 6; $p < 0.0001$). In particular, the frequency of episodes of Domination consistently increased with increasing levels of inquiry, while instances of Tutoring and Confusion became more infrequent. Analysis of standardized residuals from a post-hoc test of these data revealed that the under presence of the Domination mode in inquiry Level 1 (verification) and its over presence in Level 4 (open inquiry) were the major contributors to the significance. Our observations of lab group work across different types of experiments indicated that some students were likely to adopt the role of leaders or facilitators of group work when facing non-routinary tasks that required them to come up with their own ideas or make their own decisions. In these situations, it was common to observe one or two members of a group taking on or asserting a facilitation or leadership role. Thus, instances of Domination of lab activity were more frequently observed in experiments with a higher level of inquiry. Episodes of collaboration in which group members equally participated in decision-making or meaning-making were infrequent (an average of 9% of all interaction episodes) and remained at a similar low level across different types of experiments.

Figure 3.6. The relationship between inquiry level and major social processing modes.



Identification of Roles of Members in the Group

Group role refers to a student's responsibility and status in a group. Our analysis of social interactions and activity in lab groups also allowed us to identify four major roles typically adopted by different members of a group: *Facilitators*- Facilitate the group work by answering questions, explaining things to others, and assigning tasks. *Active*

Participants- Know what to do and are motivated to do different tasks. *Passive Participants*- Act as the "assistant" for the facilitator. *Non Participant*- Do not participate in group work at all. Students tended to take on the same role for an entire experiment or across the observed experiments. However, students did change roles sometimes based on various reasons.

In the five groups that we observed in the two-semester course, students demonstrated various social relationships. In the first observed group, student B1 took the facilitator role when decisions had to be made or problems arose. She facilitated group work by assigning tasks to different members or by providing relevant information. However, when someone else took on the facilitator role, she could also follow directions. One of the other members, L1, acted as an active participant during most of the observation time. She in fact took on the facilitator role when she knew the experiment better. When she was not familiar with the topic, however, she could act as a passive participant by following B1's instructions. Student N1 was very active in the discussions and she did a significant amount of group calculations, while she was passive in hands-on activities. Participant A1 was passive most of time since she did not propose ideas or interact much with other members. She usually acted as an "assistant" for the facilitator.

In the second group, Student J2 did most of the hands-on work. One of the other students, D2, was quite self-motivated to perform different tasks in most situations. But she acted as an "assistant" for J2 sometimes, such as holding a test tube for him or bringing a reagent for him. However, the other two group members, A2 and T2, did not contribute to experimental work most of the time. They were involved in off-task conversations usually. They became passive participants when there were not enough people to perform the task. On the contrary, all of the group members in the third group were very active. They engaged in discussions about experimental procedures, proposed ideas, and performed different tasks. However, there was one student who facilitated the group work sometimes by answering questions or assigning group tasks. Group members tended to rely on that specific student when they had questions.

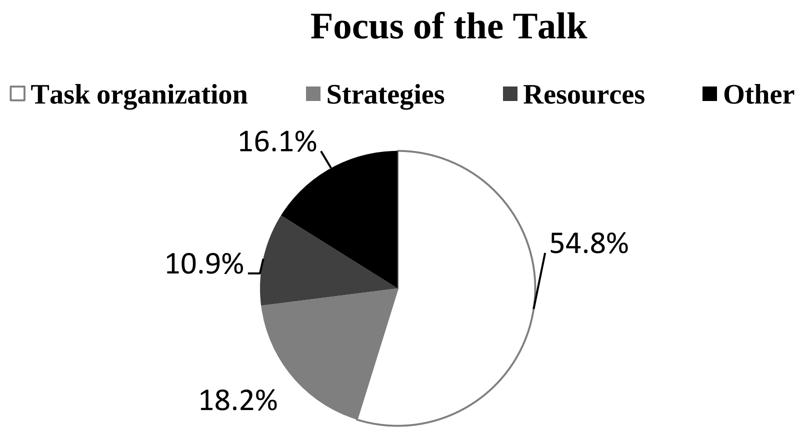
In the case of the fourth observed group, participants J4 and C4 were much more active in group work than the other two group members, D4 and R4. On some occasions, J4 served as group facilitator by solving problems for the group, analyzing group data or directing others to perform tasks. C4 was very active in the way that he discussed with J4 and also worked collaboratively with J4. On the contrary, D4 and R4 were either passive or did not participate in experimental work. Social interactions in the fifth observed group were very similar to those just described for the fourth group. Two of the group members were much more active than the other two participants.

As we can see, students took on different roles in their laboratory groups and exhibited different levels of participation in experimental activity. Our results indicated that students were likely to preserve their roles within and across different experiments, but role change occurred from time to time. When role change was observed, it was frequently associated with one of the following situations: a) The nature of the experimental task changed and particular students seemed to have more knowledge or familiarity with the experimental procedures. These more knowledgeable or more skilled students frequently adopted the roles of Facilitator or Active Participant; b) Students encountered a problem or were confused about how to proceed. In these cases, some students often adopted a more passive role while others directed group activities; c) The demands of laboratory work increased. In these situations, passive or non participating students often took on a more active role. Given the increased levels of uncertainty and complexity associated with experiments with higher levels of inquiry, these types of labs created more opportunities for some students to take on the role of Facilitator, but they also led some individuals to sustain such role for longer periods of time and direct other students' actions.

Focus of the Talk

As part of our analysis, we also paid attention to the specific focus of students' talk. The most common topics of conversation included: Task Organization (54.8%), Strategies (18.2%), Resources (10.9%), and Experimental Phenomena (5.2%). Regardless of the level of inquiry, over fifty percent of coded conversations were focused on issues related with organization, implementation, or completion of experimental tasks. A much smaller proportion of all of the observed conversations (18.2%) focused on the discussion of different experimental strategies to solve a problem, or on the analysis of experimental phenomena (5.2%). A small fraction of student talk in the laboratory (10.9%) referred to available resources to complete experimental work. The number of instances in which students talked about their experimental results (2.5%) or discussed related scientific ideas or concepts (<1%) was minimal. (Figure 3.7)

Figure 3.7. Distribution of the focus of the talk for observed groups.



The first episode in Table 3.9 presents an example of students' conversation related to Task organization. In this case, students were focused on the experimental tasks they should perform. In the second episode, students' conversation was related to the use of certain instrument in the lab. The last episode provides an example of "focusing on strategies" to solve a problem.

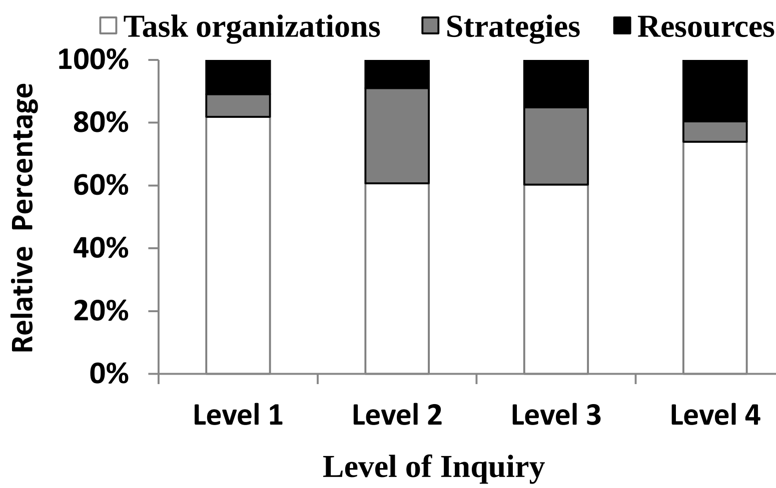
Table 3.9. The interaction analysis of Group 1 in the experiment "Introduction to measurement".

Transcribed peer interaction	**Language function**	**Cognitive processing**	**Social processing**	**Focus of the talk**
N1 and L1 go to B1 and ask "what we do next?" B1: " We need to weigh all the plastics and get the cylinder" ……	Interrogative / Responsive	Procedural	Confusion /Tutoring	Task organization
B1 goes to the balance and weighs the plastic, L1 goes there and they share the experience of using a scale. …….	Experiential	Procedural	Collaborative	Experimental apparatus
A1 suggests redoing	Compositional	Exploratory	Domination	Strategies

the measurements to resolve discrepancies. Others agree. …………	

Figure 3.8 depicts the effect of the level of inquiry of the observed experiments on the major categories of student talk (i.e., Task Organization, Strategies, and Resources). Our data indicate that conversations focused on the discussion of experimental strategies were significantly more common ($\chi^2 = 22.4$; df = 6; $p < 0.005$) in experiments with intermediate levels of inquiry (Levels 2 and 3) than in verification (Level 1) and open-inquiry (Level 4) labs. In accordance with the results of our cognitive processing analysis summarized in Figure 3.4, experiments at the extremes of the inquiry scale were characterized by a larger proportion of conversations in which students' concerns were mostly procedural. Particularly, students' conversations in these types of labs were more focused on facilitating the implementation and completion of experimental tasks than on exploring problems, analyzing and interpreting data, or reflecting on experimental results. We did not observe any major effect of the level of inquiry on the extent to which students' conversations were focused on analyzing experimental phenomena and results.

Figure 3.8. The relationship between inquiry level and major talk focus.



Further Discussion and Conclusions

By focusing on the analysis of student interactions using a moment-by-moment framework, we were able to gain valuable insights into common cognitive as well as social processing modes when working in chemistry labs with different levels of inquiry. Our analysis elicited several specific language functions that characterized students' interaction in the observed laboratory: Interrogative/Responsive (students ask each other questions) and Compositional (students propose ideas to the group). However, the prevalence of these two dominant languages was significantly influenced by the level of inquiry. Higher levels of inquiry were associated with an increase in the relative frequency of episodes where students engaged in proposing ideas versus asking and answering each others' questions about the tasks at hand.

Further analysis on the cognitive processing showed that the type of questions asked by the students and the ideas that they proposed were mainly procedure-oriented.

Students did not frequently engage in asking critical thinking or high quality cognitive questions; on the contrary, most of their questions were factual, procedural, and close-ended (Chin & Osborne, 2008). Students spent very little time on exploratory activities including planning or hypothesis testing, especially in lower inquiry level experiments. Higher levels of inquiry, particularly Level 3 (guided inquiry) in our inquiry scale, favored episodes in which experimental work was approached in a more exploratory (versus procedural) manner. This shift in how the experimental tasks were approached and processed was also evident in the focus of students' conversations, which was frequently dominated by issues of task organization and completion at all inquiry levels but included more frequent discussions of different strategies to complete tasks or solve problems in experiments at inquiry Levels 2 and 3. In general, students tended to pay little attention to the reasons for why certain phenomena were observed or why the experiment was performed in certain ways.

Our observations revealed that social status of students in the groups were not equal. This led us to further analyze student roles while engaged in experimental activity. Students took on different roles in peer groups, with some students contributing more than others to group work. Students tended to preserve their roles throughout the experiment or across the experiments, but their level of involvement changes under certain circumstances such as encountering problems. The analysis of social processing also suggested that inquiry level significantly influenced social interaction modes. While experiments classified as Level 1 (verification) and Level 2 (structured) were characterized by the dominance of tutoring events in which most students' interactions were directed at resolving confusion or uncertainty about procedures and equipment use, experimental activity in open-inquiry labs (Level 4 in our scale) was characterized by instances of domination in which one or two students in a group made most decisions and directed the actions of others. Increased levels of uncertainty in experimental tasks tended to favor acts of domination by more knowledgeable, skilled, or motivated students, rather than instances of collaboration. Episodes of collaborative work in which a group of students co-regulated their behavior or co-constructed understanding were infrequent in all types of experiments.

Implications

Our results show positive shifts in the nature of students' interactions during lab work with increasing levels of inquiry, particularly when engaged in guided inquiry activities. This latter outcome suggests that a basic degree of structure and guidance may be needed to facilitate the emergence of more exploratory and propositive reasoning in college science laboratories at the introductory levels. However, increasing openness in the lab experiments did not necessarily result in more interpretative, evaluative, reflective, and collaborative ways of thinking. Although this result may be an artifact of the small size of our sample both in terms of observed student groups and number of experiments at each inquiry level, we suspect that the overall expectation and structure of the observed labs, together with students' beliefs about practical work, may have been partly responsible for the observed interaction patterns.

In the chemistry laboratory that we observed, student groups engaged in different types of experiments without expectation that their ideas and results would have to be shared and discussed with the rest of the class in order to collectively evaluate and explain findings. However, analyses of learning environments that have successfully created opportunities for students to engage in interpretative and explanatory reasoning suggest that recurrent opportunities for small group and whole class discussion, reflection, and self-assessment are critical to foster such types of reasoning (Jiménez-Aleixandre, 2008; Kind, Kind, Hofstein, & Wilson, 2010). Conversations during these group activities should be carefully structured by using questions or specific tasks that push students to self-assess their knowledge, skills, decisions and actions, critically think about their data, and begin building arguments based on evidence. Related research in university chemistry labs indicates that lab environments that constantly challenge students to think through experimental problems and figure out solutions promote metacognition and problem solving skills (Sandi-Urena, Cooper, Gatlin, & Bhattacharyya, 2011). Our results thus suggest that changes in level of inquiry of lab investigations need to be accompanied by carefully planned lab activities that explicitly engage students in interpretative, explanatory, and argumentative reasoning.

Students in the observed laboratory groups exhibited an apparent lack of epistemic fluency, which is defined as ‘‘the ability to identify and use different ways of knowing, to understand their different forms of expression and evaluation, and to take the perspectives of others who are operating within a different epistemic framework” (Morrison & Collins, 1996)(p109). As suggested by previous studies, learning environments that are more open and provide various kinds of scaffolding are more likely to foster epistemic fluency (Kreijns, Kirschner, & Jochems, 2003). Since the intent of this laboratory reform was to prompt a better understanding of chemistry, it is critical to enhance students' epistemic fluency to attain a better cognitive understanding. The epistemic fluency can be achieved by having students engage in various epistemic tasks, which include "describing, explaining, predicting, arguing, critiquing, evaluating, explicating and defining" (Kreijins, Kirschner, & Jochems, 2003).

Group work in the observed labs was also never explicitly monitored or evaluated to ensure productive collaborations. Many students in this environment seemed to have relied on more knowledgeable or more outspoken individuals to guide practical work (particularly in the more open investigations). Research in collaborative learning indicates that domination of group work by some individuals may be avoided by organizing activities to ensure interdependence, co-regulation, and individual accountability (Webb & Palincsar, 1996). From this perspective, our results suggest that laboratory instructors at the college level should ensure that all members of a group have a significant role to play, both procedurally and cognitively, as they engage in more open investigations. Assigning rotating managerial (e.g., procedure-reader, supply-getter) and cognitive (e.g., clarifier, questioner, explainer) roles could be highly beneficial (Lumpe & Staver, 1995).

Several research studies on the implementation of inquiry activities in secondary school classrooms have highlighted the challenges associated with using practical work to promote high levels of cognitive processing and productive argumentation (Abrahams & Millar, 2008; Kind et al., 2011; Watson, Swain, & McRobbie, 2004). These studies have shown that despite working in learning environments that encourage analysis, discussion, and evaluation of strategies and experimental evidence, a large proportion of students' time still typically focuses on task implementation and data gathering. According to existing research, the routinized nature of traditional laboratory work at different educational levels shapes how most students frame and approach practical activity (Kind et al., 2011). In particular, students seem to conceive practical work as implementing well-defined procedures to collect data that will prove a scientific principle. Within this conceptualization, experimental success is measured as the ability to correctly implement set procedures and collect 'good' data (i.e., data that matches expected outcomes). It is likely that this type of epistemological frame (Scherr & Hammer, 2009) may also guide and constrain the reasoning and actions of many students in college laboratories (Russell & Weaver, 2011).

If the excessive focus on procedural issues across types of experiments demonstrated by our study participants was partly determined by a traditional view of practical work (as described above), it would be convenient to expose and challenge such beliefs in the laboratory setting. In the chemistry laboratory that we observed, students were asked to engage in experiments with different levels of inquiry without much explicit awareness of underlying differences. Experimental guides and support materials were presented to them using a common format across experiments. The behavior and interactional patterns of the instructor in charge of guiding student work did not change from one lab session to another. Requirements for laboratory reports did not vary based on the nature of experimental activity. In general, students did not receive any explicit cues about the changing nature of the experiments and were not guided to behave or reason in different ways from one experiment to another. Thus, students were not made aware of changes in the nature of their investigations and were not challenged to reflect on the different expectations and demands of the experiments in which they were engaged.

Engaging students in small group and whole class discussions about the nature of their work, both before and after each experiment, may help elicit their personal beliefs, challenge their ideas, and expose students to different conceptualizations of scientific inquiry. In particular, it would be desirable to explicitly engage students in the evaluation of the level of inquiry of lab activities by having them discuss the extent to which different experiments create opportunities to generate hypotheses, explore ideas, evaluate strategies, and generate arguments in a collaborative manner. Research on students' ideas about the nature of science has shown that involvement in these types of explicit-reflective group activities has a positive impact on people's beliefs about the nature of science and scientific work (Abd-El-Khalick & Akerson, 2009).

Limitations

One of the major limitations of the project design lies on the fact that our results are based on data collected in the form of observational field notes rather than audio-recording or video-recording of all of the students' conversations. The college chemistry laboratory is a complex environment in terms of social interactions and actions. Students frequently move from one station to another, thus it was difficult to audio-record or video-tape the process. Results based on field observations have several limitations. Due to the forgetful- nature of human observers, it was likely that some details were ignored and went unrecorded. In the laboratory setting, students were not limited to the bench area, thus they often moved around the lab to collect materials and equipment or to complete measurements in designated areas. It was thus impossible to record all their actions. In addition, groups often split into smaller groups of two people. It was then difficult to keep track of what both subgroups were doing or discussing. Additionally, although the researcher tried to have minimal interaction with the groups, students may have perceived that they were closely observed and they may have performed differently.

Since only one of the researchers involved in the study was present in the laboratory, the co-researcher did not necessarily have the same perspective as the main researcher did. Thus, when the co-researcher went over the observation notes and coding systems, he might have had a different interpretation or understanding of the situation. To avoid bias from one perspective, thorough discussions were needed to build a common understanding of the observed laboratory activity.

Related research literature suggests that there are other factors that influence students' interaction in collaborative groups, such as gender. Harskamp et al (2008) points out that gender plays an important role in students' interaction in groups. For example, that study reported that females in mixed-gender groups were less active in solving problems, asked more questions, and gave more negative feedback than males. We did recruit mix-gendered groups. Nevertheless, the effect of gender on students' interactions was not examined in our study.

Our observations were restricted to a rather small scale, as only five groups with twenty students participated in the study. Thus, it is uncertain whether this study can be representative of any other social groups. As our investigation was conducted during a transition stage of the general chemistry laboratory curriculum in the University of Arizona, one needs to be cautious in generalizing our findings to other contexts.

CHAPTER 4: EXPLORING STUDENTS' LAB REPORT WRITING BY USING THE SCIENCE WRITING HEURISTIC UNDER DIFFERENT INQUIRY LEVELS

This chapter describes the second part of our study which focused on the analysis of students' arguments and reflections in their written lab reports using the Science Writing Heuristic (SWH) for experiments with different levels of inquiry.

Methodology

Goals and Research Questions

Students' lab reports written in the SWH format provide a rich source of data for exploring students' argumentation and explanation building process while working in experiments with different levels of inquiry. The construction of evidence to support the claims based on the experimental data provides insights into students' argumentation. In addition, students were asked to include a reflective writing section at the end of their lab reports. The reflective writing is aimed to reveal what students learned as a result of practical work, how they conceptualize their work during the lab, what suggestions they have for improvement, and what additional questions they may have after conducting the experiments. Therefore, the central goal of this study was to characterize the effects of experiments involving different levels of inquiry on the structure and adequacy of college general chemistry students' written arguments, as well as on the nature of their reflections about laboratory work. In particular, our investigation was guided by the following research questions:

- What differences do exist in the structure and adequacy of written arguments in students' lab reports for experiments with different levels of inquiry?
- What differences do exist in the nature of the written reflections in students' lab reports for experiments with different levels of inquiry?

Data Collection

Collection of Laboratory Reports

The main data source of this study was students' individual lab reports written by using the SWH approach as a framework. In particular, we collected copies of the written lab reports produced by the observed students for experiments performed during the duration of our study. This approach allowed us to collect 36 laboratory reports from 16 students. To be noted, some students did not turn in their lab reports on time. So the author was not able to collect the lab reports from those students. Additionally, students were not required to submit a lab report for some experiments, such as the "Research Project;" students presented their results in a poster format instead. Therefore there were no lab reports collected for those experiments either. There were some experiments, such as the "Properties of Light" and "Indigo Synthesis" laboratories, for which we were unable to analyze students' interactions as students did not work in groups, but we were able to collects individual written reports. Thus, the collected lab reports corresponded to a set of laboratory experiments that was slightly different from the set used for the analysis of students' interactions described in the previous chapter (see Table 4.1).

Table 4.1. Laboratory reports collected for all the observed groups.

	Group	# of Participants (Female/Male)	Lab Experiment	# of Reports Collected	Inquiry Type
Chem 151	Group 1	4/0	Measurement	4	Structured
			Separation	4	Guided
			Identification	4	Verification
	Group 2	3/1	Properties of Light (Determination of efficiency of common light sources)	2	Guided
			Emission	3	Verification
			Absorption	3	Structured
	Group 3	1/3	Qualitative Analysis	4	Structured
Chem 152	Group 4	0/4	Indigo Synthesis	4	Structured
			Kinetics	4	Guided
			Water Project	4	Structured

Experimental activity in the observed laboratory was framed using the Science Writing Heuristic and students were asked to build their written lab reports using the SWH template. Table 4.2 summarizes the main components of the SWH template that the students were asked to follow when writing their lab reports.

Table 4.2. The SWH template that students use

Phase	Questions Related to Phase
Beginning questions	What questions guided your explorations?
Safety Considerations	What did you do to stay safe in the lab?
Procedures and Tests	What experiments did you do to answer your questions?
Data, calculations, and representations	What observations did you make? What data did you collect? What calculations and representations helped you make sense of the data?
Claims	What can you claim to answer your questions?
Evidence and Analysis	How did you interpret your results to support your claims?
Reflections and additional questions	What did you learn? What do you not completely understand? How have your ideas changed as a result of this lab? What new questions do you have? How would you improve what you did?

As stated in Chapter 3, we used a rubric to determine the level of inquiry of the different experiments that were observed (See Table 3.2.) All of the experiments for which we collected lab reports could be grouped into three levels based on the same rubric (see Table 4.3). Unfortunately, we were unable to collect written lab reports corresponding experiments in the highest level of inquiry (Open Inquiry) as students were required to report their results using different formats (e.g., poster, oral presentation) in those cases.

Table 4.3. Level of inquiry of the experiments for which written lab reports were collected.

	Verification (Level 1)	**Structured (Level 2)**	**Guided (Level 3)**
Experiments	• Identification • Emission	• Measurement • Absorption • Water Project • Indigo Synthesis	• Separation • Qualitative Analysis • Kinetics • Properties of Light

Data Analysis

Our study focused on the analysis of the following components of the written lab reports: Claims, evidence and analysis, and reflections and additional questions. The first two sections were analyzed to characterize the structure and adequacy of the written arguments generated by the study participants, while the latter section was analyzed to characterize the nature of students' reflections.

Students' Written Arguments as Evidence to Support the Claims

Scientific inquiry has been considered as a knowledge construction process in which students generate explanations to make sense of the data and present it to the community (Sandoval, 2003). To measure the quality of arguments developed by students, we adapted the classification method proposed by Osborne et al (2004) based on Toulmin's argumentation framework. Osborne et al (2004) classified students' arguments into Level 1 through 5 based on the presence of different argument components, such as data, warrant, backings or rebuttals to substantiate a claim. The existence of rebuttals in arguments played an important role in separating the two highest levels of argumentation (Level 4 and Level 5). In our study, however, almost none of the students included rebuttals in their arguments. Therefore, we constructed a modified rubric to evaluate the structure of students' arguments which contained only Level 1 through 4 as shown in Table 4.4.

Table 4.4. Levels, descriptions, and examples of argumentation patterns extracted from students' lab reports.

Level	Description	Examples	Adequacy
Level 1	Claim	The times that were measured did not have a significant effect on the results has seen in the data table. (*claim*)	Not applicable
Level 2	Claim, data, and warrant	In order to identify the unknown plastics, the densities of the known and unknown plastics had to be compared. *(warrant*) Based on our values for density (*reference to data*),the first unknown sample could have been LDPE,HDPE, or PP. The second sample and third samples could have been PVC and PETE. The fourth sample could have been LDPE or HDPE.(*claim*)	Adequate
Level 3	Claim, data, warrant and backing.	Since density is a differentiating characteristic in substances, (*backing*) it can be claimed that plastics with similar densities are most likely the same types of plastics. (*warrant*) The evidence to support the claim that unknown plastic type A is PP (*claim*) is that the density of type A is 0.92 g/cm3 and the density of PP is 0.909 g/cm3 these two densities are the most similar. (*data*)	Adequate
Level 4	Claim, data, warrant, backing and qualifier	The best method of determining what type of plastic the samples represented was to find the density of the plastic by dividing its mass by its volume. (*warrant*) Because density is an intensive property of a substance, it is completely independent of the amount of the substance present(*backing*) Therefore, if we can match the density of an unknown plastic with that of a known plastic, regardless of different in size or shape, we can successively identify the known.(*Qualifier*) Unknown plastic#1 had a density of 0.8953g/ML and most closely matched the density of PP, which was 0.909 g/ML (*data, claim*)	Adequate

The rubric shown in Table 4.4 was applied to the analysis of each distinctive argument made by students in their lab reports. In several lab reports, students repeated the same argument while making claims about the identity, properties, or behavior of different systems studied in the lab. This set of arguments was characterized as a single distinctive argument. The adequacy of an argument was analyzed by paying attention to the scientific appropriateness of the data, concepts, or ideas used to build such an argument. In particular, an argument was judged to be inadequate if it referred to one or more inadequate or irrelevant features (e.g., data, concepts) in supporting the core claim.

Students' Reflective Writings

Student writing in the "reflection and additional questions" section of the lab reports was guided by the following questions: What did you learn in this lab? What do you not completely understand? How have your ideas changed as a result of this lab? What new questions do you have? How would you improve what you did? Based on these guiding questions, as well as on the associated students' responses, our analyses targeted four major areas of reflection: 1) *Learning*- Focused on students' reflections about their learning and understanding as a result of lab work. In this part of the analysis, we adopted the revised Bloom's Taxonomy (Krathwohl, 2002) to characterize reflections along four main types of knowledge dimensions: Factual knowledge, conceptual knowledge, procedural knowledge, and metacognitive knowledge as described in Table. 4.5.

Table 4.5. Structure of the knowledge dimension of the revised taxonomy.

A Factual knowledge: The basic elements that students must know to be acquainted with a discipline or solve problems in it.
a. Knowledge of Terminology
b. Knowledge of specific details of a term. (Elements)
c. Knowledge of facts

B Conceptual knowledge: The interrelationships among the basic elements within a larger structure that enable them to function together.
a. Knowledge of classifications and categories
b. Knowledge of principles and generalizations
c. Knowledge of factors that influence a system

C Procedural knowledge: How to do something; methods of inquiry, and criteria for using skills, algorithms, techniques, and methods.
a. Knowledge of subject-specific skills and algorithms
b. Knowledge of subject-specific techniques and methods
c. Knowledge of criteria for determining when to use appropriate procedures

D Meta-cognitive knowledge: Awareness of what they do not understand.
a. Raise questions that require exploratory activities
b. Raise questions that require further analysis
c. Show understanding defect about methodology
d. **Misconception** about certain ideas or concepts.

The second area was 2) *Evaluation* – Focused on students' self-evaluation of their lab work, their results and the results' implications. The third area corresponded to 3) *Improvements* – Focused on students' discussions of what and how they would improve their lab work or the experimental design; and the last area of analysis was 4) *New Questions* – Focused on the researchability of the new questions posed by students as a result of their lab work. To complete these different aspects of our analysis we segmented students' writing into sub-units with boundaries determined by perceived changes in the focus of the reflections. The nature of each sub-unit was then characterized by a specific code indicating the general and specific foci of attention, for example: Learning- Procedural knowledge; Evaluation- Methodology; Improvements- Analysis; New Questions- Researchable (see Table 4.6 for specific examples of our coding system). We used the number of words associated with each identified sub-unit to explore the relative weight of different areas of reflection in students' reports.

Table 4.6. Coding categories for students' written reflections and some examples.

General Code	Specific Code	Example
Learning	Factual Knowledge	"I learned what the actual meaning of "energy efficiency" is. I had heard the term before, but I now know the exact meaning of that: I know that it means the percentage of visible energy given off out of the total energy."
	Conceptual Knowledge	"Every substance has a different density and as a strictly unique characteristic is the best method of identification for the purpose of this lab."
	Procedural Knowledge	"I learned the amount of food dye in a sample can be calculated by taking and absorption spectroscopy and by doing mathematical manipulations with the values obtained through the spectroscopy and physical experiment like making different concentrations."
	Metacognitive Knowledge	"I don't completely understand how the wavelength was affecting our calculations or how come the wavelength was the same in all the concentrations we ran experiments on in the crystal light sample."
Evaluation	Methodology	"Originally, we thought that the best way to measure volume would be the water displacement method, but since we had regular shapes, using the caliper would have been more effective."
	Assumption	"We thought that once we found the densities, it would be easy or straight forward to determine what types of plastic each of the unknown were, but that was not the case. The values for density only narrowed down the possibilities."
	Application	"This data would be very helpful in defending a campaign that wants to replace incandescent light bulbs with compact fluorescent light bulbs."
Improvements	Methodology	"To make the experiment more accurate instead of using the water displacement to find volume to use the vernier calipers."

	Design	"If I were to improve what I did I would use different brands of bottled water to see if there was a difference between the companies."
New Questions	Researchable	What is the difference between the composition of the blue and the green LED lights?
	Non-Researchable	Are these samples of plastics having other differentiating characteristics like melting points or composition?

In general, data analysis was completed in various steps. Once an initial analytical framework and coding system was discussed by the two main researchers, the first author of this paper applied it to the analysis of the lab reports for one lab session. During this task, coding segments were defined at the sub-unit level in the analysis of students' reflections. Both the proposed segmentation of the lab reports and the specific codes assigned to each sub-unit were then independently reviewed by the second researcher, who either agreed with the assignations or proposed alternative segmentations or codes. Comparison and discussion of ideas helped refine the coding system and the identification of boundaries between sub-units. Once agreement was reached in the analysis of the initial data set, the process was repeated with more lab reports until achieving over 90% agreement in 20% of the collected reports. The more refined analytical procedure was then applied by the first author to analyze the totality of the data.

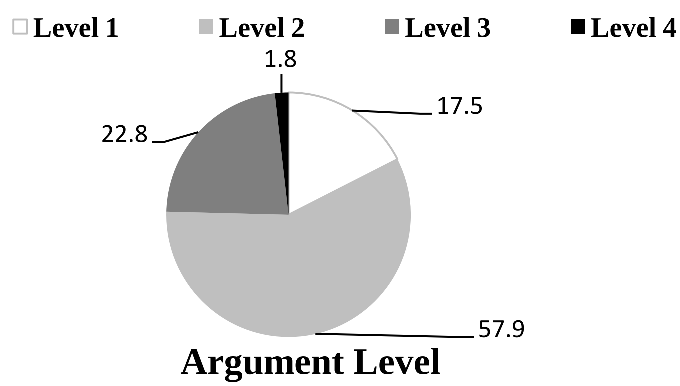
Results

The results section is organized according to our research questions. First, we describe the structure and adequacy of the arguments generated by the students as well as the influence of the level of inquiry. Then we present the effect of the level of inquiry on students' reflections.

Argument Structure and Adequacy

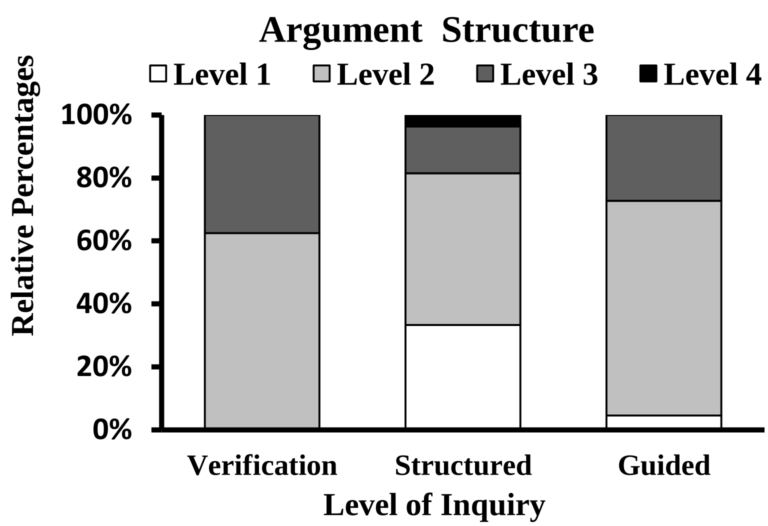
Our analysis of the quality of the arguments generated by study participants indicated that over three quarters of all of the generated arguments belonged to Level 1 (17.5%) and Level 2 (57.9%) as described in the rubric presented in Table 4.4. Approximately, 22.8% of all of the arguments corresponded to Level 3 and only 1.8% demonstrated the highest structure according to our argumentation criteria (see Figure 4.1).

Figure 4.1. Distribution of levels of identified arguments generated by students.



The analysis of the impact of inquiry levels revealed that the most common arguments students made consisted of a claim, some data and a warrant (Level 2) regardless of the inquiry level of the experiment. Chi square analysis of our data indicated that the level of inquiry did not have a significant impact on the structure of the written arguments included in the analyzed lab reports (see Figure 4.2.) (χ^2 =11.05, df = 6, $p< 0.01$) It is important to point out that in this chapter we chose to label the different levels of inquiry as verification, structure, and guided to avoid confusion with different levels of argument structure

Figure 4.2. Argument structure in lab reports for experiments with different levels of inquiry.



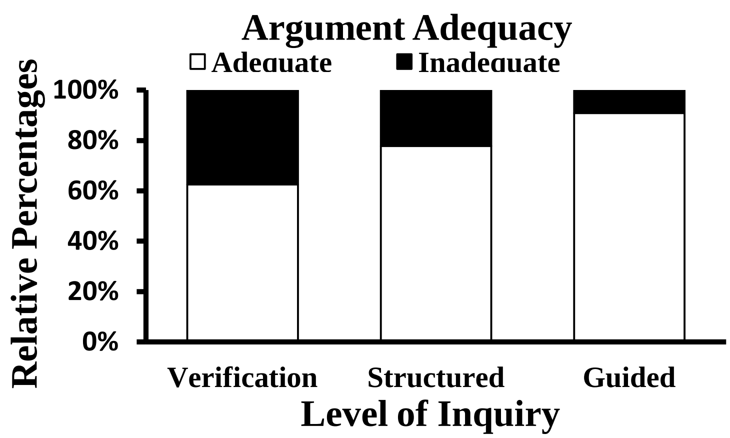
In general, most students incorporated scientifically relevant data, concepts and ideas to support the claims they made in arguments. Less than 20% (19.3%) of all the arguments analyzed quoted irrelevant features in their arguments. For instance, one student used an irrelevant feature (physical appearance) of unknown and known plastic as evidence to identify the unknown plastic in one experiment:

> *"In order to narrow the possibilities further, it was necessary to look at the physical properties of both the known and unknown plastics. The first sample was PP because it was frosty white and the fourth sample was most likely LDPE because of its opaque, white color."*

As shown in Figure 4.3., the percentage of adequate versus inadequate arguments tended to be higher for experiments with higher levels of inquiry. However, statistical analysis of the data revealed that the observed differences were not significant.

(χ^2 =3.32, df = 2, p< 0.01). It is important to point out that observed differences in argument adequacy may not be related to the level of inquiry of the experiments performed, but rather to students' level of chemistry knowledge and experience in the laboratory. In the observed laboratory section, experiments with higher levels of inquiry were often performed after students had completed more prescriptive labs.

Figure 4.3. Adequacy of argument in lab reports for experiments with different levels of inquiry.

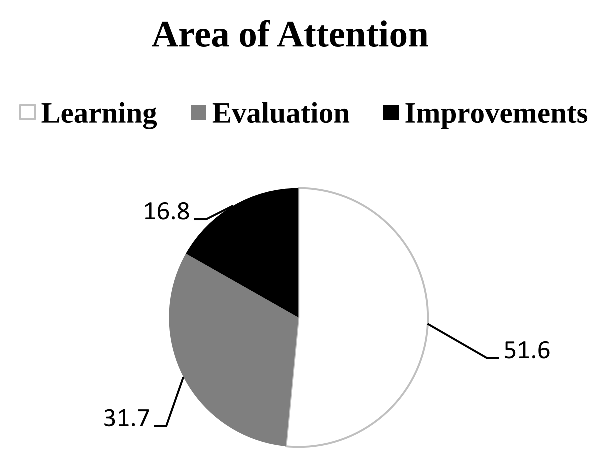


Nature of Students' Reflective Writings

Four major areas of attention were identified based on our data analysis of students' reflective writings: *Learning, Evaluation, Improvements* and *New Questions.* The core narrative of students' reflections focused on the first three areas, while the latter aspect was often incorporated as a list of questions motivated by lab work. Thus, we opted for separating the analysis of these new questions from that of the core narrative.

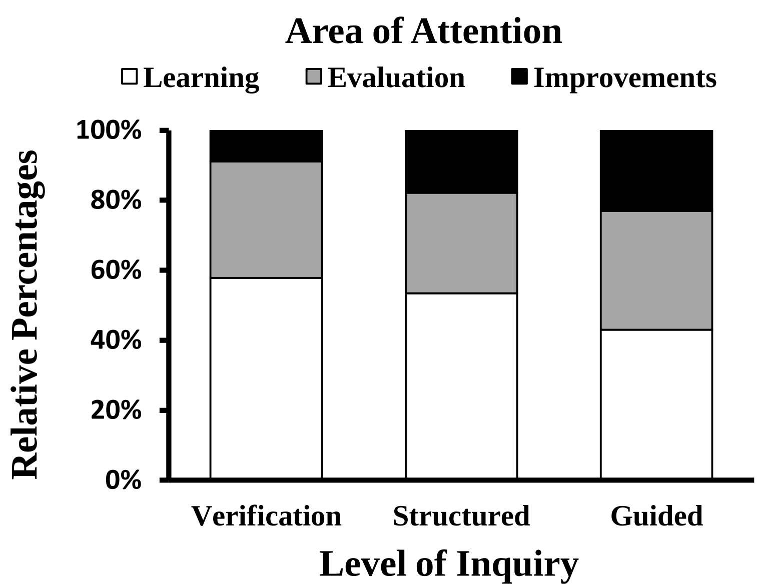
Comparison of the number of written words in all lab reports across different experiments indicated that over half of the students' reflections (51.6%, *SD* = 8.7) focused on writing about what they learned. Secondly, they focused on the evaluation of the experimental procedures, the results and the results implications (31.7%, SD = 12.9). The least attention was paid to providing suggestions for improvement to lab work or for experimental design (16.8%, *SD* = 8.5) (See Figure 4.4.

Figure 4.4. Distribution of main areas of attention in students' reflections across all types of experiments.



Our results indicate that the level of inquiry of the experiments did have a significant influence on the relative proportion of the areas of attention as described above. As shown in Figure 4.5, students' reflections about *Learning* decreased while reflections about *Improvements* increased when the inquiry level increased. Statistical analysis using a Chi-Square test confirmed the existence of a significant difference in different areas of attention across inquiry levels (χ^2 = 100.6; df = 4; p < 0.01). A subsequent post-hoc test used to evaluate the standardized residuals (at a level of significance of 0.05) indicated that contributions to this significance were mainly associated with the decrease of reflections about *Learning* and the increase of reflections about *Improvements.* Reflections about how to improve both the experimental design and the lab procedures became more prominent as the inquiry level increased and students were asked to make decisions about those same issues. Given that the length of students' written reflections (M = 210.7 words , SD = 115.5) was not significantly affected by the level of inquiry of the different labs, more attention to one area always resulted in less attention to other areas.

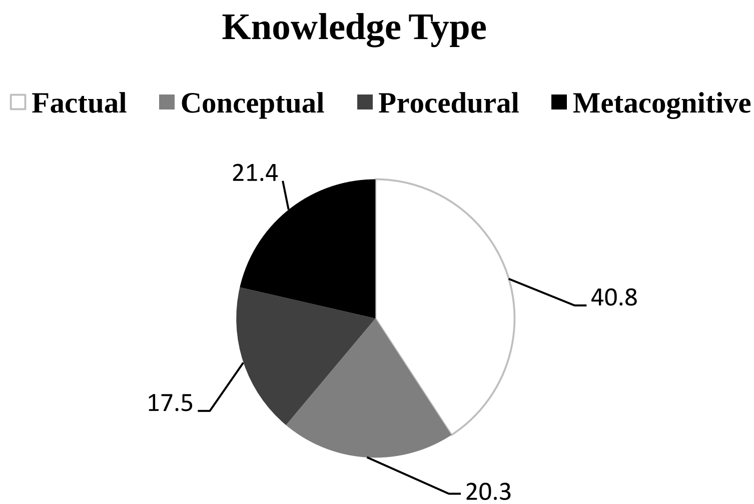
Figure 4.5. Effect of the level of inquiry of lab experiments on main areas of attention in students' written reflections.



Focus on Learning

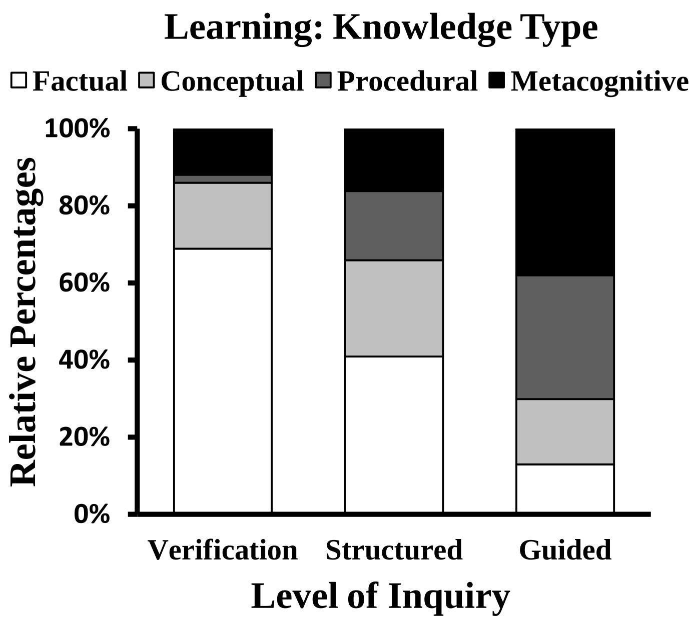
Our analysis based on the revised Bloom's Taxonomy (Krathwohl, 2002) indicated that the most common type of knowledge that students reflected on across all experiments was factual knowledge (40.8%, *SD* =31.1). On average, emphasis on each of the other knowledge categories was very similar: Conceptual (20.3%, *SD* = 13.4), Procedural (17.5%, *SD* = 16.9), and Metacognitive (21.4%, *SD* = 19.1) (Figure 4.6.)

Figure 4.6. Distribution of types of knowledge targeted in students' reflections across all types of experiments.



However, the level of inquiry seemed to influence students' reflections on different types of learning knowledge as illustrated in Figure 4.7. Statistical analysis using the Chi-Square test as well as the post-hoc analysis identified a significant change with the inquiry level ($\chi^2 = 663.8$; df = 6; $p < 0.01$) mostly associated with the decreased focus on factual knowledge and increased focus on procedural and metacognitive knowledge in students' reflections associated with experiments with higher inquiry levels. Working on less structured labs seemed to promote more reflections not only about knowledge of experimental skills or procedures, but also about what was understood or not as a result of lab work.

Figure 4.7. . Effect of the level of inquiry of lab experiments on the type of knowledge targeted in the Learning area of students' reflections.

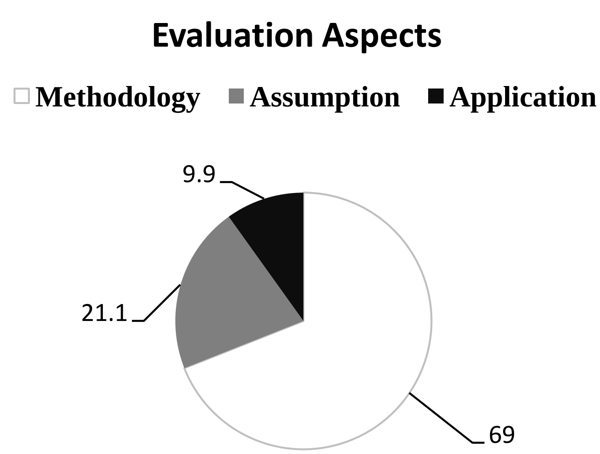


Focus on Evaluation

Students often wrote about what was wrong with their experiments in terms of incorrectly operation of instruments, data collection, or inappropriate procedures. These reflections were coded as evaluation of Methodology. Another type of reflection in this area involved evaluating initial Assumptions. Students held prior knowledge or assumptions before they came to the lab (Lazonder, Hagemans, & Jong, 2010). After conducting the experiment, students tended to talk about what they originally thought about a phenomenon and how that idea changed as a result of the investigation. Even though students were not asked to talk about how the experiments could be related to real world, some of them described how the investigation outcomes could be applied to other areas (Application).

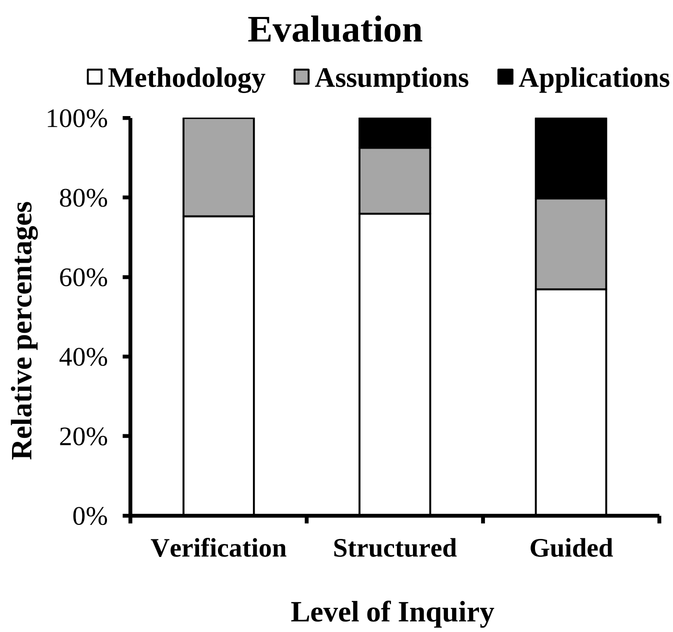
Analysis based on comparison of number of words associated with different aspects of Evaluation across all the experiments revealed that over half of the reflection on Evaluation was about Methodology (69.0%, SD= 24.8). There was much less reflection on changes in prior Assumptions or beliefs as a result of completing the lab (21.1%, SD = 20.4). Only 9.9% (SD= 20.4) of the overall reflection was related to evaluating the application of their results to solve or understand other problems. The data distributions for these two latter categories were rather skewed, with at least half of the students' reports not including any reflections in these two areas (Figure 4.8.)

Figure 4.8. Distribution of different aspects of reflection on evaluation across all types of experiments.



Chi-Square test on the effect of the level of inquiry on the focus of students' reflections in this area demonstrated an existence of a significant change ($\chi^2 = 138.2$; df = 4; $p < 0.01$). A subsequent post-hoc test revealed that the significance was largely associated with a decreased focus on methodological issues and an increased focus on both the self-evaluation of prior-assumptions and the description of potential applications of experimental results in written reflections for labs with higher levels of inquiry. (Figure 4.9.)

Figure 4.9. Effect of the level of inquiry of lab experiments on the evaluation of lab work and lab results.



Focus on Improvements

The analysis on students' reflection about potential improvements to the experimental procedure or design indicated a predominance of reflections associated with Methodology (89.1%, SD = 11.6). Students provided suggestions regarding possible changes to the current procedure in order to solve problems that they encountered. Only 10.1% (SD = 11.6) of the reflection was related to potential modifications to the experimental design to enrich or improve the results (See Figure 4.10). Suggestions for improvement of experimental design were mostly identified in lab reports constructed in Structured and Guided inquiry labs. (See Figure 4.11). However, statistical analysis demonstrated that there was no significant difference between the results for these two levels of inquiry (χ^2 =0.05, df = 1, p< 0.01).

Figure 4.10. Distribution of reflections in the area of Improvements across all types of experiments.

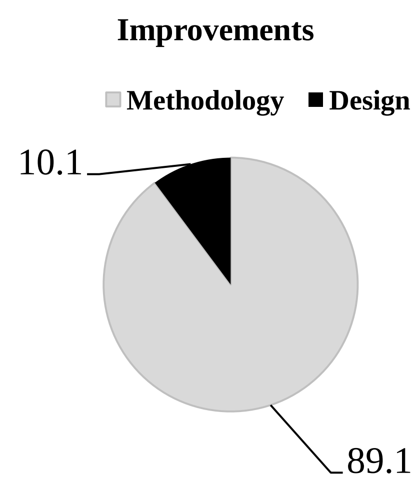
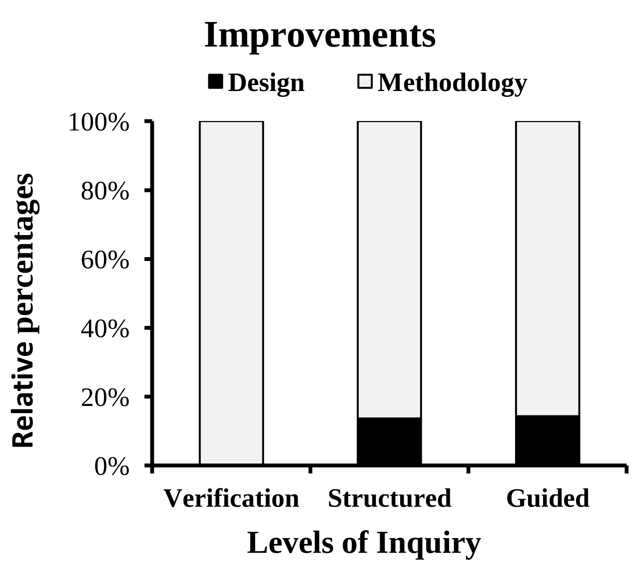


Figure 4.11. Effect of the level of inquiry of lab experiments on reflection about potential improvements.



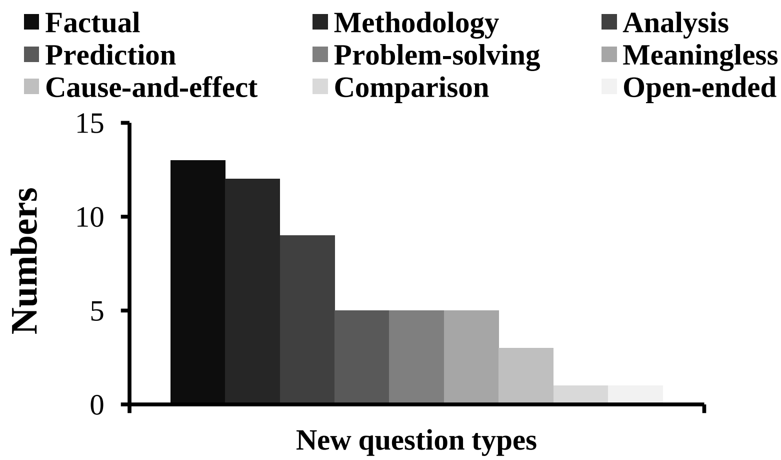
New Questions

As part of the reflection, students were asked to list any new questions they had after executing the experiments. The new questions that students posed in their reflective writing enabled them to test themselves, to check what they have learned and what they could do in terms of generating researchable questions (Hofstein, Navon, Kipins, & Mamlok-Naaman, 2005). During our analysis, the questions that required simple information or basic facts were identified as *Factual* questions; their answers could be found without investigation. *Analysis* questions included those that asked "what is…", "How much…"and "What kind of …" The preliminary goal of this type of question was to determine the identity or amount of some substances. *Methodology* questions asked about specific procedures or steps that were involved for certain part of an experiment. Given the information in laboratory manual, this type of question usually could be answered without any hands-on investigations. *Open-ended application* questions involved questions that were broad and required an integration of complex information that probed an underlying mechanism or required application of theories. Finally, *Meaningless* questions were those that were difficult to interpret as they revealed students' misunderstandings or misconceptions.

We also coded some questions based on the adaptation of existing categories in the research literature (Chin & Kayalvizhi, 2002; Chin & Brown, 2002; Ciardiello, 1998) For example, *Comparison* questions were defined as "make-a-choice" type of questions. Students asked questions such as "What is the most.." or "What is the best.." to choose among different options. *Prediction* questions such as "Is it still the case when…." "Are there similar…” shared the characteristic of predicting outcome. *Problem-solving* questions asked “How to….”,”How can we” and “Was there any way to ….”. This type of question required students to design a method or procedure to solve a given problem. The key feature of problem-solving questions was seeking a feasible method of implementation. *Cause-and-effect* questions included questions such as “What effect …have on..?” and “How does…affect…?” Such questions allowed students to think about the relationship between two variables. Students needed to design experiments in which they manipulated one variable to observe the effect on another variable.

Although all of the above different types of questions were identified in our analysis of students’ written reflections (see Figure 4.12), there were three prominent categories: Factual (24.5%), Methodology (22.6%), and Analysis (17.0%). In general, students tended to ask factual and methodology questions that could be answered without hands-on investigations. The fraction of methodology questions posed by the students decreased while the fractions of factual questions increased with increasing level of inquiry. However, the small number of questions identified in several categories did not allow us to evaluate the statistical significance of this effect.

Figure 4.12. Number of new questions generated by students across different types of experiments.



As part of our analysis we also categorized students' new questions as researchable or non-researchable questions (see Table 4.7). A researchable question was characterized as a query about a problem or issue that could be investigated and would provide useful new information. On the contrary, non-researchable questions referred to questions that could not or did not need to be answered by performing an investigation (Beitz, 2006).

Table 4.7. Examples of new questions and their researchability

Question Type	Example	Reasearchability
Analysis	How accurate the ideal gas equation is for a real gas?	Researchable
Methodology	Is there a way to measure temperature in a more direct way?	Researchable
Open-ended application	What could be done to create an even better plastic that is less hazardous to the environment?	Non-researchable
Comparison	What is the difference between the composition of the blue and the green LED lights?	Researchable
Problem-solving	How is it that we can find the exact molar mass of a substance since the error margin is so high in this experiment and results are sometimes not consistent.	Researchable

Meaningless	Why the intensities for the pink sparkler are exactly the same?	Non-researchable
Factual	Which makes me wonder what is it about certain plastics that make them recyclable while others are not?	Non-researchable
Cause-and-effect	If there was more than one color in the solution, would it have affected the results that were obtained from the color that was measured?	Researchable
Prediction	Are all reactions effected by these variables In the same way? Does a higher molar mass of a cation mean the test will be more reliable?	Researchable Non-researchable

Overall, students generated more researchable (63.0%, SD =22.9) than non-researchable (37.0%, SD =22.9) questions as part of their lab reports across all types of experiments. (Figure 4.13). The results shown in Figure 4.14 indicate that observed students tended to generate more non-researchable questions as opposed to researchable question as the inquiry level increased. However, statistical analysis of our data showed that this effect was not significant (χ^2 =2.12, df = 2, p< 0.01).

Figure 4.13. Distribution of the researchability of new questions across different types of experiments.

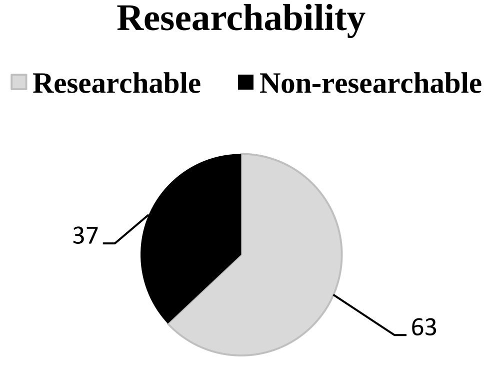
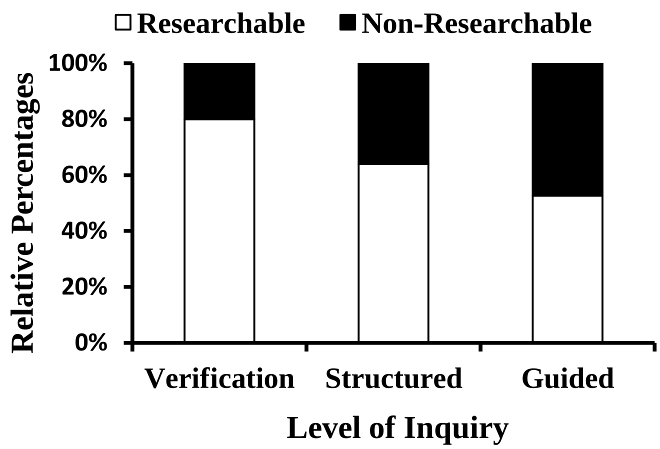


Figure 4.14. Effect of the level of inquiry of lab experiments on the researchability of new questions.



Further Discussion and Conclusions

In this study, we analyzed students' written laboratory reports to explore the effect of levels of inquiry on the structure and adequacy of students' generated arguments as well as on their reflective writings. The level of inquiry of lab experiments showed no statistically significant influence on either the argument structure or the adequacy of arguments. In general, approximately 75% of all the arguments generated by students across different experiments belonged to low quality levels (Level 1 and Level 2) based on the rubric presented in Table 4.4. By examining the distributions of argument levels in different types of inquiry, we identified that the most common argument structure (Level 2) was characterized by the presence of a claim supported by a single type of experimental data and a single warrant. This low level of argumentation was similar to that reported by a variety of authors in their analysis of secondary school students' argumentation skills (Katchevich et al., 2011; Kind et al., 2011). Although the quality of students' generated arguments based on their structure seemed to be quite low, the scientific adequacy of these arguments was consistently high across inquiry levels. As shown in Figure 4.3, scientific adequacy increased with increasing level of inquiry. However, it is likely that other factors, such as increased chemical knowledge and laboratory experience, influenced this result.

Although students enrolled in the observed general chemistry laboratory received basic training in how to use the SWH in building their lab reports, no explicit interventions or efforts were made to improve their argumentation reasoning skills during the duration of our investigation. The teaching assistant responsible for supervising and evaluating student work did not make any explicit efforts to provide feedback to the students in terms of the quality of the arguments that they included in their lab reports. Under such circumstances, our results suggest that the actual nature of the experiments in which students were engaged, in specific the experiments' level of inquiry, did not have a significant effect on how students approached the analysis of their results with the purpose of generating and supporting claims.

The level of inquiry of lab experiments seemed to have a significant impact on several areas of students' written reflections including Learning, Evaluation, and Improvements. By comparing the relative weight of these three core components for all of the experiments, we found that students seemed to reflect more on what they have learned than on the evaluation of their work or on suggestions for improvements. However, the level of inquiry influenced the relative weight of these different aspects of students' reflections. In the case of Learning, statistical analysis indicated a significant change in the types of knowledge targeted in students' reflections in different types of experiments. In particular, these reflections shifted from mostly focusing on factual knowledge to largely concentrating on procedural knowledge and metacognitive knowledge with increasing openness in practical work. Student engagement in the actual design of the experimental procedures to solve a problem in guided inquiry experiments seemed to dramatically shift students' reflections from the facts that they have learned to the problem-solving skills that they have developed. It also motivated a larger proportion of metacognitive reflections about the extent to which relevant concepts, ideas, or methodologies were understood.

Regarding students' reflection on Evaluation, a large proportion of students focused on evaluating the errors that they made or on the difficulties that they encountered during the experiments. Evaluation of existing assumptions or ideas was not very common in written reflection, nor were comments on potential applications of experimental results to other problems. However, the inquiry level significantly affected the way in which students evaluated their work. In particular, students were more likely to consider the value of their experimental findings for solving similar problems in higher inquiry level experiments. Guided-inquiry laboratories also seemed to prompt students' to shift emphasis from the evaluation of methodological performance to the evaluation of ideas or applications

Another important component of students' reflection belonged to their suggestions for potential improvements of their experimental performance or the experimental design. The majority of students' suggestions were directed at improving what they did in terms of procedure. However, guided-inquiry laboratories seemed to provide opportunities for students to move beyond reflecting on how they could have improved their experimental performance, to suggest improvements in the actual experimental design in order to collect better or more useful data.

Many of the new questions posed by the students after completing the experiments belonged to three main types: Factual, Methodological and Analytical. These questions were commonly associated with concepts or procedures that students did not fully understand. Approximately two thirds of all of the new questions were researchable questions. However, students seemed to generate more non-researchable questions in higher inquiry level experiments. In general, students posed more factual, non-researchable questions in the reflections associated with the less structured labs. Reflections linked to verification labs included mostly researchable questions that were largely focused on methodological issues. These results suggest that as students shift the focus of their reflections away from issues of procedural performance, they may struggle to pose valid researchable questions in other areas.

Implications

Considering the major findings, our study has important implications for teaching and learning when inquiry is incorporated in science classrooms or laboratories. As discussed by the science education community, argumentation is a key component of scientific inquiry. However, our findings revealed that the quality of college general chemistry students' arguments was generally low. This suggests that instructors need to provide more explicit opportunities for students to develop and practice their argumentation skills. In particular, chemistry teaching assistants could facilitate this process by scaffolding the construction of sound arguments based on the evidence available. In particular, it would be convenient to involve students in discussions about the structure of sound arguments using a framework such as Toulmin's. These discussions could be based on peer-evaluation of arguments generated by different students in a laboratory class.

Our findings indicated that the level of inquiry seemed to shift in positive ways the manner in which students reflected on their experiments. For example, higher levels of inquiry seemed to increase the frequency of metacognitive statements and redirect self-evaluation from largely focusing on procedural mistakes to the evaluation of problem-solving skills. This result supports efforts to reform - traditional chemistry labs to increase their level of openness. However, solely increasing the level of inquiry is likely not to be sufficient to promote conceptual understanding. In general, the level of inquiry of the observed experiments had no significant impact on students' reflections on conceptual knowledge. Research has shown that explicit instructional approaches may be required to accomplish this goal (Schwartz, Lederman, & Crawford, 2004). Implicit approaches assume that students achieve conceptual understanding as a "by-product" of practical work, while explicit approaches include structured activities or prompts to facilitate conceptual understanding. Thus, explicit efforts seem to be needed to focus students' attention on the relationship between the results of their investigations and the models and theories developed by chemists to make sense of the properties and behavior of chemical substances and processes.

Limitations

One of the major limitations of this study is the small number of lab reports that were analyzed (thirty-six lab reports from sixteen students). Additionally, these lab reports corresponded to a small number of experiments at each inquiry level: two experiments at the verification level, four experiments at the structured inquiry level, and four experiments at the guided inquiry level. Our findings could thus be significantly influenced by individual characteristics of the study participants. However, we believe that our results elicit trends in students' written reflections that can help us identify instructional strategies to better support and scaffold student reasoning in the laboratory.

We also recognize that the generalizability of our results to other contexts may be limited given that written reflections were guided by a set of specific questions provided to students within the SWH template. Different course design, instructional guidelines as well as student population could certainly influence the way students reflect on practical work.

CHAPTER 5: MAJOR INSIGHTS AND FUTURE WORK

Major Insights

There is now ample evidence that student positive attitudes and interest towards chemistry are enhanced by appropriately implementing scientific inquiry into chemistry laboratories (Green, Elliott, & Cummins, 2004). However, how do these types of interventions affect learning opportunities? Productive learning opportunities seem to be linked to situations in which students are engaged in tasks that demand high-level cognitive processing such as building explanations, developing models, drawing inferences, synthesizing ideas, or critically evaluating arguments (McNeill & Krajcik, 2008; Osborne, 2010; Volet et al., 2009). Our results provide insights into the extent to which experiments with different levels of inquiry create those types of productive learning opportunities in college chemistry laboratories.

This dissertation investigated the impact of incorporating experiments with different levels of inquiry on general chemistry students' interactions in the laboratory, as well as on students' written arguments and reflections. To accomplish our goals, we first analyzed students' interaction patterns by applying a moment-by-moment socio-cultural discourse framework targeting three dimensions: language functions, cognitive processing, and social processing. Secondly, we explored students' lab reports in terms of students-generated arguments and reflections as required by the Science Writing Heuristic template.

Our results revealed that students' utterances in the lab could be characterized by three basic language functions: asking each other questions, proposing ideas, and directing others. Examination of whether the inquiry level affected the discourse patterns revealed that increasing openness of lab experiments favored the compositional function (proposing ideas) and reduced the predominance of the interrogative/responsive function (asking each other questions). Although less structured experiments required students to generate their own ideas, they also favored domination by single individuals who directed the actions of the group.

Analysis of cognitive processing during practical work suggested that students' cognitive strategies were mainly focused on executing different tasks to finish the experiments. Much less time was spent on exploratory and interpretative activities. However, experiments with higher inquiry levels, especially guided-inquiry labs, seemed to favor students' engagement in more exploratory activity. Guided-inquiry experiments also seemed to facilitate students talk about potential strategies that they could take to complete the tasks. Unfortunately, the level of inquiry had no significant effect on interpretative reasoning.

Analysis of the social relationship among group members suggested that students tended to adopt rather fixed roles in their small groups. Their interactions were often dominated by single individuals and domination tended to increase with increasing levels of inquiry. Students' roles resulted in different levels of participation. Some students took on the facilitator role, leading group work, while other students contributed much less to the group by acting as assistants for facilitators. Some students played the role of active participants who were actively engaged in the experiments but did not make major decisions. There were also students who did not participate in group work at all. Role change could occur, particularly when the group encountered experimental difficulties. For instance, one student could take on the leader role as the task became more difficult since others students had no idea of what to do.

We also analyzed students' written arguments and reflections as presented in their lab reports. Argument structure was analyzed using a modified Toulmin's argumentation framework. In general, we observed that students' arguments commonly consisted of a claim supported by some data and a single warrant regardless of the level of inquiry. Although the structural quality of arguments seemed to be low, on average students could list adequately concepts or ideas to support their claims.

The level of inquiry had a significant impact on the nature of students' reflections. Less structured experiments appeared to motivate students to reflect more on potential improvements to experimental procedures than on what they learned as a result of practical work. Specific exploration of different knowledge types demonstrated that increasing levels of inquiry were associated with more frequent reflections on procedural and metacognitive understandings as opposed to factual knowledge.

Even though over half of reflective statements in the area of Evaluation focused on the discussion of experimental errors, guided-inquiry experiments seemed to promote more evaluation on students' initial assumptions and on potential applications of the experimental results. In general, students' suggestions for improvements focused on how to modify the way they performed the experiments so they could improve their results. Suggestions for modification of the experimental design were only observed in structured and guided inquiry labs. Finally, our analysis of students' new questions indicated that students were able to generate more researchable questions than non-researchable questions as part of their reflections across different types of experiments.

Future Work

Given the limitations of our research as highlighted in previous chapters, further studies involving a larger sample of students would be needed to confirm our major claims. In particular, it would be important to collect data from different groups performing the same experiment and increase the number of observations of experiments at any given level of inquiry. In addition, longitudinal studies focused on the observation of groups through an entire academic semester in the general chemistry laboratories would strengthen our claims about the effect of inquiry levels on students' reasoning.

Our analysis of students' written lab reports focused on only two sections of these documents. As future work we propose to examine the quality of the overall lab reports. In particular, we could investigate the alignment between different components (Beginning questions, Experimental Design, Claims, Evidence, and Reflections), looking to analyze how the level of inquiry of the experiments affects students' ability to build coherent investigations and reports of laboratory activity.

Finally, our studies indicated a strong need for instructors to provide explicit interventions in order to better guide student work in the laboratory and strengthen their argumentation reasoning skills. It would be important then to design research studies to explore the type of explicit interventions that have the most positive influence on student reasoning while engaged in practical work as well as when communicating their results in writing.

APPENDIX A: EXAMPLE OF OBSERVATIONAL NOTES OF ONE GROUP IN THE STUDY OF " STUDENTS' INTERACTIONS"

These excerpt of our "observational notes" come from Group 1, in the experiment of "Separation of pigments". Four students were present (N,B,L and A) and performing the tasks together. The Teaching Assistant also interacted with the group at times. The observation was made on September 8^{th}, 2008.

B1 and N1 have a small discussion.

N1: "We have spinach and raspberry."

B1: "We can start with one to one hexane/ acetone"

N1: "to spinach"

L1 leaves the bench and tries to find mortar and sand. She can't. So she asks TA, and TA shows her where they are.

A1 got the solvents, and she is mixing the solvent.(10ml/10ml acetone/ hexane)

L1 pulls the solvent in the mortar. B1 and A1 are watching. N1 is taking notes.

The extraction is not very well. They stop and take notes.

B1 "We can add more 50/50 mixture of solvents"

B 1faces to L1 "can you pull more in to the beaker?"

TA comes over.

L1: "It is not absorbing the solvents"

B1 "Yeah..."

TA looks at the solution and says "All right, try to use some other ratio"

B1: "maybe we could try raspberry"

A1: "Are we just use spinach but try different ratios?"

L1: “Yeah. If we use different ratio, we can compare….”

L 1suggests they divide as last time.

They are not sure about how to use the sand, they go to their classmates. Not helped

B1 and L1 are washing stuff. A1 and N1 stand by and waiting.

N 1suggests a different solvent ratio.

B1 gets the raspberry.

A1 mixes the solvent (2/1 Hexane/ acetone)

B 1prepares the raspberry sample. L1 still doing the spinach one (using 2/1 hexane /acetone)
N 1is adding the solvent to raspberry. B finds that raspberry reject the solvent.

A1: “Shall we try 2/1 acetone/ hexane?”

L1: “yeah. Try different ratio.”

B1 is comparing the two spinach sample.(One 1/1 hexane/acetone the other 2/1 hexane/ acetone)

B1“I mean they seem to have the same color” She looked for a while and picked one. “ All right, this is better”

L1 asking about the raspberry “Did you try different ratios?”

B1: “we tried 2/1 acetone/hexane. But it didn’t work. Maybe 1/1 is the best ratio”

B1 asks L if she wants to use 2/1 hexane/acetone.

L1 is pipeting out the solution to another beaker as TA told her to.

(Go back to the lecture area.)

(Then come to the lab.)

L1 is trying to re-dissolve the raspberry. N1 taking notes and A1 watching.

B1 tries to pure acetone. It works.

B1 “Look”

N1,L1 “ Yeah…”(They are very happy about the result, but not asking why)

B1 asks L1 to write down observations.

B1 “let the raspberry settle and I’ll check to see if the TLC is ready”

N1 and A1 prepare the capillary and parafilm.

A1: “shall we practice this (capillary)”

L1: “Yes” Then she gets the paper towel.

L1 and A1 are practicing.

N1 : “ So we need to come up with different solvent for TLC, like which separates better.”

L1: “OK, let’s do acetone”

L1: “We will do three strips for spinach”

N1 gets the solvents.

L1 prepares the solvent for developing.

A1 is spotting.

L1 prepares the solvent for raspberry.

N1 is taking notes for all the jars.

N1: Look at the bubbles, why is that”

B1: “That is acetone evaporating”

L1 “So when do we stop?”

N1: “When it gets close to the top”

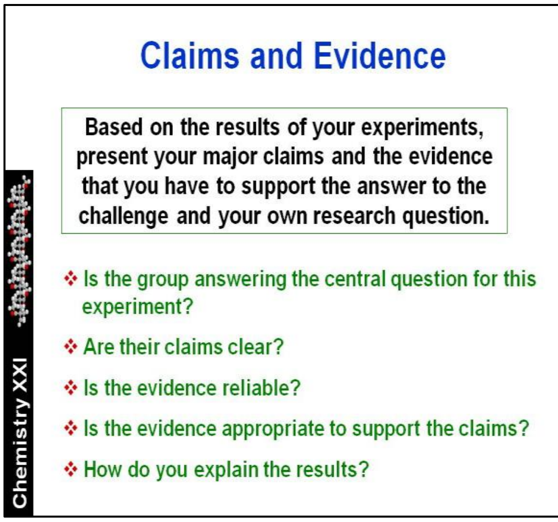
N1 L1 and A1 are taking notes.

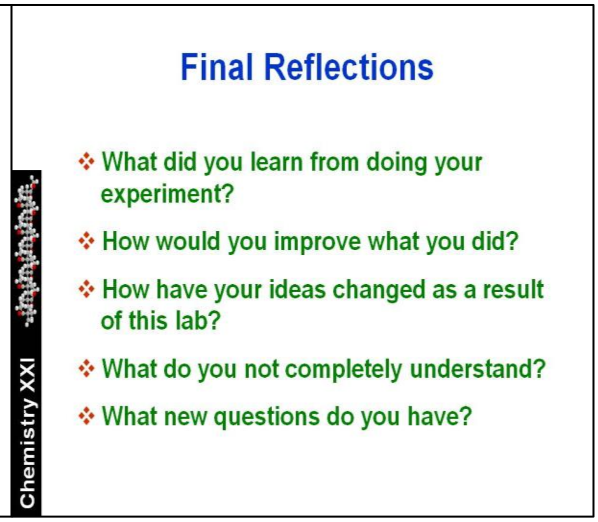
A1 pulls one out and marks the line.

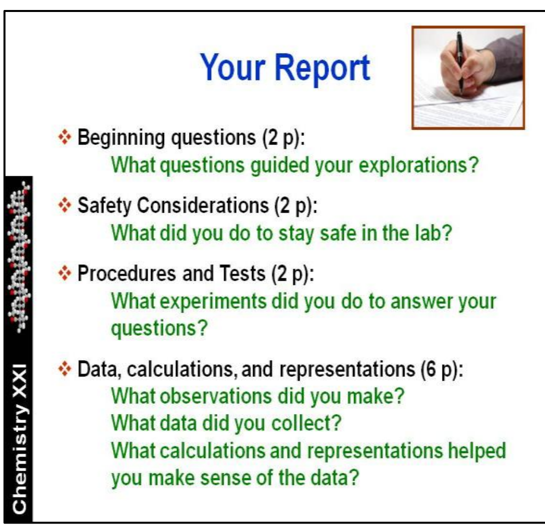
B1 takes all the strips out then. They are taking notes of the observations. L1 and B1 measure the length.

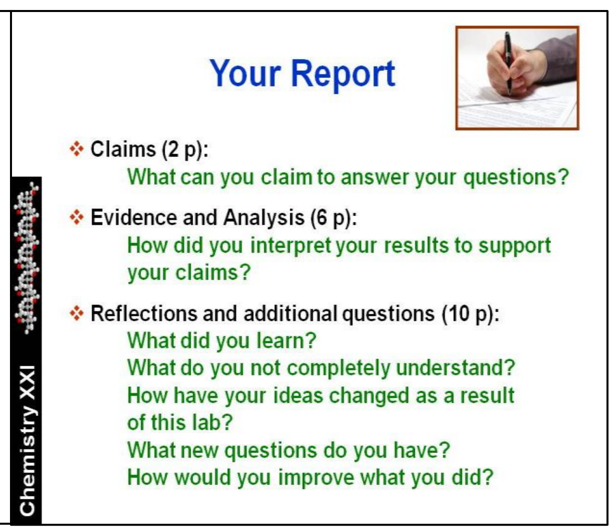
B1 asks TA what to do with the TLC strips. TA showed them to the UV lamp.

APPENDIX B: INSTRUCTIONAL GUIDING MATERALS FOR LAB REPORT WRITING









APPENDIX C: SAMPLE OF STUDENT LAB REPORT

Gas Behavior

Question

The main question leading this experiment is how to identify gases using their properties. Following this question opened up newer questions such as how is the mass of the gas measured and what tools are presented to help finding the mass. To measure the mass of the gases, an important question is what procedures will be used to measure it.

Safety

Lab coats were used to prevent any chemicals from spilling on arms and clothes. Goggles were used to prevent chemicals from entering the eyes. Closed toed shoes are to prevent broken glass to cutting the foot. Fume hoods were used to take out some of the gases in the room that have evaporated. Hot hands were used to handle hot glassware to prevent skin burns.

Procedure and Experiment

This part of the experiment will answer the question of how to measure the mass of the gas. The first step is to get out two 125 mL flasks and rinse them out with acetone to remove any particles of other components in the flask. There will be two tests running at the same time to speed things up. Then get two 400 mL beakers and fill with water and place on hot plates, this will be used for the hot bath. The water will heat up while preparing for the experiment. Take a tube and fill with water and add ice, this will be used for the cold bath. The flask will then be weighted on an electronic balance. About 3 mL of acetone (liquid phase of the gas) was poured into the flasks and a capillary cap is placed on the flask and the rubber part bent down to prevent air from coming in. The flask is then placed into the hot bath until all the liquid has evaporated. The temperature was also taken at the time all of the gas was evaporated. After all liquid has been evaporated the flask was placed into the cold bath to restore the gas to liquid phase. This process will give the measurement of mass of the gas to volume of the flask.

After it seems that the gas is completely liquid, it is then taken to a balance and weighted. When weighing the flask with the liquid gas, the reading of the mass will have to be done as quickly as possible so that the liquid does not evaporate. After the mass as been taken down it is subtracted from the mass of the flask alone to get just the mass of the gas. The substance is then poured out into the liquid disposal bucket and water is filled into the flask until it is full then the capillary cap is placed back on. The water is then poured out into a graduated cylinder to find the volume of the flask.

For the second part the question of how is a substance identified will be answered. For the experiment the same procedures were done for C1 and C2 substances. The work was split up in the group to form two sub groups. One was measuring C1 and the other measured C2.

Data

For both trials of acetone the results were completely different. When the results were combined with the classes, our group's results were removed from the list. The molar mass for acetone for the first trial was 28.3 g/mol, the second trials molar mass was 139.7 g/mol. The temperatures for both trials were very close to each other however the mass the gas was significantly different. With trial one the gas's mass was 73.787 g while trial two was at 93.58 g.

For the unknown substances our group split up the work to get more trials done for each unknown. C1 was the one being examined. There were four trials of C1. Trial one the temperature was at 90.7 C and a mass of .961, the volume was at 142 and the molar mass ended up to be 220.6 g/mol. Trial two had a temperature of 89.9 C a mass of .452 and a molar mass of 103.6 g/mol. Trial three had a temperature of 90.5 C a mass of .486 and a molar mass of 111.6. Trial four had a temperature of 91.1 C a mass of .506 g and a molar mass of 115.7 g/mol.

C2 had four trials done. For trial one the temperature was 88 C, the mass was 4.86 g and the volume was 135.5 mL. The molar mass for trial one is 116.2 g/mol. Trial two the temperature was 90.2 C the mass was .445 g and the volume was 13.1 mL. The molar mass for trial two is 110.6 g/mol. Trial three the temperature was 90 C the mass was .552 g, the volume was 135.3 mL and the molar mass is 132.9 g/mol. In trial four the temperature was 93 C, the mass was .521 g, the volume was 135 and the molar mass is 126.7 g/mol.

Since none of the data went close to the actual molar masses of any of the substances a formula was used to match the results closer to the known substances. The R value was changed from the ideal to the one in the experiment which is now 0.059491. The new results for C1 trial one was 160.1 g/mol, trial two is 75.1 g/mol, trial three is 80.9 g/mol and trial four is 83.8 g/mol. For C2 the new results are for trial one 84.21 g/mol, trial two is 80.18 g/mol, trial three is 96.318 g/mol and trial four is 91.864 g/mol.

Evidence and Claims

C1 seems to match up with Cyclohexane the most. Cyclohexane has a molar mass of 84.16 g/mol. Trial one was removed from the results because of its outrageous values, leaving only trial two, three and four. Those trials were then averaged to have a molar mass of 79.9 g/mol. The closest value to 79.3 g/mol is cyclohexane. The next closest is butanone.

C2's average molar mass is 88.143 g/mol. The average of C2 is very close to Ethyl Acetate which has a molar mass of 88.10. With the molar masses being so close alike it can be assumed that C2 is Ethyl acetate.

Reflections

Finding the true molar mass of an unknown substance is extremely difficult because there can be so many obstacles and errors in the experiment such as the gas evaporating too fast when measuring it or the temperature it is taken at. The temperature is taken at the temperature of the water and not the boiling point of the gas causing some errors in the calculation. To get more precise results a change in the R constant had to be made by using the first experiment values to find the new constant. By doing that the molar masses dropped so we can make claims to which unknowns are which substances. I still do not understand how the equation $PV=nRT$ is put into this experiment since the equation $M_{na}=MT/PV$ is used instead. New questions arise is how is it that we can find the exact molar mass of a substance since the error margin is so high in this experiment and results are sometimes not consistent. To find better results more trials would have to be made. Four trials is not enough to find close values of a substance.

Post-Laboratory Questions

1. Based on the results of the lab, this method of finding molar mass of a substance is ineffective. The results were far higher than the actual molar mass of any of the known substances. The way of measuring temperature is not accurate since we were not measuring the boiling point, we were measuring the temperature the gas was at.
2. Instead of measuring the temperature of the water we should test the gas to see what temperature it boils at by placing a sample of the gas onto the hot place and measure the point it starts boiling.

1. We can measure the gases volume and mass to figure out its density to help figure what gas it is. Using the temperature will help with finding the identity since the gases are liquids at room temperature, we can find the boiling point.

2. How do we measure the mass of the gas?

3. How does the equation $PV = nRT$ come into this experiment?

$P = k\frac{NT}{V}$ Equation of State

k = proportionality constant

$N = \frac{M}{m_1}$ → total mass / → mass of 1 particle

$P = k\frac{MT}{m_1 V}$

$m_1 = k\frac{MT}{PV}$

$m_{N_A} = N_A m_1$

$N_A = 6.022 \times 10^{23}$

$m_{N_A} = N_A k\frac{MT}{PV} = R\frac{MT}{PV}$

$R = 0.082057 \frac{atm\,L}{mol\,K}$

model using → $M_{N_A} = R\frac{MT}{PV}$

Substances

Butanone

Ethanol

Cyclohexane

Procedure

1. Take 125 mL flask clean with acetone
2. take 400 mL beaker fill with 100 mL water for hot bath
3. Put ice in tub for cold bath
4. Add 3 mL of substance in flask
5. Add in hot bath to get it to gas phase
6. measure water temperature when all is gas.
7. Put in cold bath
8. take off cap to measure mass
9. Find volume filling up with water and put cap back on. Pour in graduated cylinder.

SIGNATURE	DATE	WITNESS/TA	DATE

NOTE: INSERT BACK COVER UNDER COPY SHEET BEFORE WRITING

<u>Measurments</u> Atm = .915 Pressure: 1 atm = 1013 mbar
Acetone C_3H_6O P_{lab} = 927 mbar

) Flask with no mark
mass - 93.580 g
Volume - 136.2 ~~g~~ mL

with gas: 94.164 g
temp: 90.3 °C
mass of gas: .584 g

molar mass - 139.7 g/mol

) Flask with red mark
mass - 73.787 g
Volume - 137.5 mL

with gas mass: 73.906 g
temp ~~91.1~~ 91.1 °C
mass of gas: .119 g molar mass - 26.3 g/mol

Real Molar mass: ~~56.068~~
C_3H_6O 58.078 g/mol

Class avg 79 g/mol

<u>Unknowns</u>

Butanone (T_b = 80° C) C_4H_8O MM = 72.11

Cyclohexane (T_b = 80.7 °C) C_6H_{12} MM = 84.16

Ethanol (T_b = 78.4 °C) C_2H_6O mm = 46.07

Ethyl Acetate (T_b = 77.1 °C) $C_4H_8O_2$ 88.10 = mm

Hexane (T_b = 69.0 °C) C_6H_{14} mm = 86.17

Our group will do
C_1 and C_2

SIGNATURE	DATE	WITNESS/TA	DATE

C1

Trial 1
Temperature 90.7°C
mass w/Beaker : 74.593 g
mass of Beaker 73.632 g
M_g = .961

Molar mass
165.8 g/mol (wrong)
220.8 g/mol

Trial 2
Temperature 89.9 °C
mass w/ beaker 74.084 g
mass of beaker 73.632 g
m_g = .452

Molar Mass
78.0 g/mol
103.6 g/mol

Trial 3
mass of Beaker 73.653 g
Temperature 90.5 °C
mass w/ Beaker 74.139 g
Vol 142 M_g = .486

Molar Mass
~~83.81 g/mol~~
111.6 g/mol

Trial 4
Mass of Beaker - 73.566 g
Temperatures 91.1 °C
Mass w/ Beaker 74.072
Vol 142.9 mL m_g = .506 g

115.7 g/mol

$R_{ideal} = 0.082057$

$R_{exp} =$

$$\frac{80 = R_{ideal}\left(\frac{MT}{PV}\right)}{58 = R_{exp}\left(\frac{MT}{PV}\right)} = \frac{80 = 0.082057}{58 : R_{exp}}$$

$R_{exp} = 0.059491$

SIGNATURE	DATE	WITNESS/TA	DATE

NOTE: INSERT BACK COVER UNDER COPY SHEET BEFORE WRITING

APPENDIX D: INFORMED CONSENT

Informed Consent

CHEMISTRY XXI: A NEW CURRICULUM FOR A MODERN ERA

Introduction
You are being invited to take part in a research study. The information in this form is provided to help you decide whether or not to take part. Study personnel will be available to answer your questions and provide additional information. If you decide to take part in the study, you will be asked to sign this consent form. A copy of this form will be given to you if you request it.

What is the purpose of this research study?
You are being invited to participate voluntarily in the above-titled curriculum project. The purpose of this project is to pilot-test a new, viable, and coherent curricular approach for teaching general chemistry at the college level.

Why are you being asked to participate?
You are being invited to participate because you are currently enrolled in the general chemistry course in which the new curriculum will be tested.

How many people will be asked to participate in this study?
Approximately 2500 subjects will be enrolled in this project.

What will happen during this study?
If you agree to participate, you will be asked to consent to the following: complete one or two on-line surveys throughout the semester, allow project personnel to observe your work in the classroom and laboratory, participate in a one-hour focus group at the end of the semester.

How long will I be in this study?
You will be a participant as long as you are enrolled in this general chemistry course.

Are there any risks to me?
There are no major risks involved with this project. Although we have tried to avoid risks, you may feel that some observations or questions we ask will be stressful or upsetting. If this occurs you can stop participating immediately. We can give you information about individuals who may be able to help you with these problems.

Are there any benefits to me?
You will not receive any benefit from taking part in this project. The information obtained through this project will benefit the quality of chemistry education at undergraduate level.

Will there be any costs to me?
Aside from your time, there are no costs for taking part in the project.

Will I be paid to participate in the study?
You will not be paid for your participation in this project.

Will video or audio recordings be made of me during the study?
No.

Will the information that is obtained from me be kept confidential?
The only people who will have access to the results of the observations and focus groups will be the Principal Investigator, Dr. Vicente Talanquer. All of your records will be confidential. You will not be identified in any reports or publications resulting from the project. Representatives of regulatory agencies (including The University of Arizona Human Subjects Protection Program) may access your records. If that occurs, a copy of the information may be provided to them but your name will be removed before the information is released.

May I change my mind about participating?
Your participation in this project is voluntary. You may decide to not begin or to stop your participation at any time. Your refusing to participate in the observations, focus groups, or on-line surveys will have no effect on your student status or grades in any course. You can discontinue your participation with no effect on *[your student status, employment, evaluation, etc.]*. Also any new information discovered about the research will be provided to you. This information could affect your willingness to continue your participation.

Whom can I contact for additional information?
You can obtain further information about the research or voice concerns or complaints about the project by calling the Principal Investigator Vicente Talanquer, Ph.D., at (520) 626-8169. If you have questions concerning your rights as a project participant, have general questions, concerns or complaints or would like to give input about the project and can't reach the research team, or want to talk to someone other than the project team, you may call the University of Arizona Human Subjects Protection Program office at (520) 626-6721. (If out of state use the toll-free number 1-866-278-1455.) If you would like to contact the Human Subjects Protection Program via the web, please use the following website http://www.irb.arizona.edu/suggestions.php.

Your Signature

By signing this form, I affirm that I have read the information contained in the form, that the study has been explained to me, that my questions have been answered and that I agree to take part in this study. I do not give up any of my legal rights by signing this form.

____
Name (Printed)

_______________________________ ____________
Participant's Signature Date signed

Statement by person obtaining consent

I certify that I have explained the research study to the person who has agreed to participate, and that he or she has been informed of the purpose, the procedures, the possible risks and potential benefits associated with participation in this study. Any questions raised have been answered to the participant's satisfaction.

____
Name of study personnel

_______________________________ ____________
Study personnel Signature Date signed

REFERENCES

Abd-El-Khalick, F., & Akerson, V. L. (2009). The influence of metacognitive training on preservice elementary teachers' conceptions of nature of science. *International Journal of Science Education , 31* (16), 2161-2184.

Abrahams, I. and Millar, R., (2008), Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science, *International Journal of Science Education*, 30, 1945–1969.

Agar, M. (1980). *The professional stranger: An informal introduction to anthropology.* New York: Acdemic Press.

Akkus, R., Gunel, M., & Hand, B. (2007). Comparing an Inquiry-based Approach known as the Science Writing Heuristic to Traditional Science Teaching Practices: Are there differences? *International Journal of Science Education , 29* (14), 1745-1765.

Aufschnaiter, v., Erduran, S., Osborne, J., & Simon, S. (2008). Arguing to learn and learning to argue: Case studies of how students' argumentation relates to their scientific knowledge. *Journal of Research in Science Teaching , 21* (1), 101-131.

Ausubel, D. (1968). A subsumption theory of meaningful verbal learning and retention. In R. Kuhlen, *Studies in educational psychology.* Boston: Blaisdell Publishing Company.

Barneaa, N., Doria, Y., & Hofstein, A. (2010). Development and implementation of inquiry-based and computerized-based laboratories: reforming high school chemistry in Israel. *Chemistry Education Research and Practice , 11*, 218-228.

Barron, B., (2000), Achieving coordination in collaborative problem solving groups, *Journal of the Learning Sciences*, 9, 403–436.

Barron, B., (2003), When smart groups fail, *Journal of the Learning Sciences*, 12, 307–359.

Bates, G. (1978). What research says to the science teacher. In M. Rowe, *The role of the laboratory in secondary school science programs.* (Vol. 1). Washington D.C: National Science.

Beitz, J. (2006). Writing the Researchable Question. *Journal of Wound Ostomy Continence Nurs* , 122-124.

Bennett, W., & O'Neale, K. (1998). Skills development and practical work in chemistry. *University Chemistry Education , 2*, 58-62.

Bereiter, C., & Scardamalia, M. (1987). *The psychology of written composition.* Hillsdale,NJ: Lawrence Erlbaum.

Berland, L., & Reiser, B. (2009). Making Sense of Argumentation and Explanations. *Science Education , 93*, 26 – 55.

Bernard, H. R. (2003). *Social research methods : qualitative and quantitative approaches.* Thousand Oaks: SAGE.

Blonder, R., Mamlock-Naaman, R., & Hofstein, A. (2008). Analyzing inquiry questions of high-school students in a gas chromatography open-ended laboratory experiment. *Chemistry Education Research and Practice , 9*, 250-258.

Bloome, D., Puro, P., and Theodorou, E., (1989), Procedural display and classroom lessons, *Curriculum Inquiry*, 19, 265–291.

Bruce, B. (2001). *Qualitative Research Methods for the Social Sciences.* Boston: Allyn and Bacon.

Buck, L. B., Bretz, S. L., & Towns, M. (2008). Characterizing the Level of Inquiry in the Undergraduate Laboratory. *Journal of College Science Teaching* , 52-58.

Burke, K., Greenbrowe, T., & Hand, B. (2006). Implementing the Science Writing Heuristic in the General Chemistry Laboratory. *Journal of Chemical Education , 83* (7), 1032–1038.

Carlsen, W. S. (1991), Saying what you know in the biology laboratory, *Teacher Education*, 3(2), 17–30.

Chi, M. (1997). Quantifying Qualitative Analyses of Verbal Data: A Practical Guide. *The Journal of the Learning Sciences* , 271-315.

Chin, C., & Brown, D. (2002). Student-generated questions: a meaningful aspect of learning in science. *International Journal of Science Education , 24* (5), 521-549.

Chin, C., & Kayalvizhi, G. (2002). Posing Problems for open Investigations: what questions do pupils ask? *Research in Science and Technological Education , 20* (2), 269-287.

Chin, C., & Osborne, J. (2008). Students' questions: a potential resource for teaching and learning science. *Studies in Science Education* , 1-39.

Chui, M. (2000). Effects of status on solutions, leadership, and evaluations during group problem solving. *Sociology of Education* , 175-195.

Ciardiello, A. (1998). Did You Ask a Good Question Today? Alternative Cognitive and Metacognitive Strategies. *Journal of Adolescent & Adult Literacy , 42* (3), 210-219.

Cornelius, L. L., & Herrenkohl, L. R. (2004). Power in the Classroom: How the Classroom Environment Shapes Students' Relationships With Each Other and With Concepts. *Cognition and instruction , 22* (4), 467-498.

Craig, T. (2011). Categorization and analysis of explanatory writing in mathematics. *International Journal of Mathematical Education in Science and Technology , 42* (7), 867-878.

Creswell.J. (2008). *Educational research:planning,conducting,and evaluating quantitative and qualitative research.* Upper Saddle River: Pearson Education.

Dembo, M. H., & McAuliffe, T. J. (1987). Effects of perceived ability and grade status on social interaction and influence in cooperative groups. *Journal of Educational Psychology , 79*, 415-423.

Domin, D. (1999). A review of laboratory instructional styles. *Journal of Chemical Education , 76*, 543-547.

Eijck, M. (2010). Addressing the Dynamics of Science in Curricular Reform for Scientific Literacy: The case of genomics. *International Journal of Science Education , 32* (18), 2429-2449.

Emig, J. (1977). Writing as a mode of learning. *College Composition and Communication , 28*, 122-128.

Erduran, S., Simon, S., & Osborne, J. (2004). Tapping into argumentation: developments in the application of Toulmin's argument pattern for studying science discourse. *Science Education , 88* (6), 915–933.

Flower, L., & Hayes, J. (1980). The cognition of discovery: Defining a rhetorical problem. *College Composition and Communication , 31*, 21-32.

Galbraith, D. (1999). Writing as a knowledge-constituting process. In M. D. Galbraith, *Knowing what to write: Conceptual processes in text production* (pp. 139-159). Amsterdam: Amsterdam University Press.

Gallagher, J. T. and Tobin, K.G., (1987), Teacher management and student engagement in high school science, *Science Education*, 71, 535–555.

Glaesser, J., Gott, R., Roberts, R., & Cooper, B. (2009). Underlying success in open-ended investigations in science: using qualitative comparative analysis to identify necessary and sufficient conditions. *Research in Science & Technological Education , 27* (1), 5-30.

Green, W., Elliott, C., & Cummins, R. (2004). “Prompted” Inquiry-Based Learning in the Introductory Chemistry Laboratory. *Journal of Chemical Education , 81* (2), 239-241.

Grimberg, B., & Hand, B. (2009). Cognitive Pathways: Analysis of students' written texts for science understanding. *International Journal of Science Education , 31* (4), 503-521.

Gunstone, R. F. (1991). Reconstructing theory from practical experience. In B. E. Woolnough, *Practical science* (pp. 67-77). Milton Keynes: Open University Press.

Hand, B., Wallace, C., & Yang, E. (2004). Using the science writing heuristic to enhance learning outcomes from laboratory activities in seventh grade science: Quantitative and qualitative aspects. *International Journal of Science Education , 26*, 131-149.

Harskamp, E., Ding, N., & Suhre, C. (2008). Group composition and its effect on female and male problem-solving in science education. *Educational Research* , 307-318.
Herron, M. D. (1971). The nature of scientific enquiry. *The School Review* , 171-212.

Hofstein, A., & Lunetta, V. (1982). The role of the laboratory in science teaching: Neglected aspects of research. *Review of Educational Research , 52*, 202-217.

Hofstein, A., Kipnis, M., & Kind, P. (2008). Learning in and from science laboratories: enhancing students’ meta-cognition and argumentation skills. In C. L. Petroselli, *Science education issues and* (pp. 59-94). New York: Nova.

Hofstein, A., Navon, O., Kipins, M., & Mamlok-Naaman, R. (2005). Developing Students’ Ability to Ask More and Better Questions Resulting from Inquiry-Type Chemistry Laboratories. *Journal of Research in Science Education , 42* (7), 791-806.

Hohenshell, L. M., & Hand, B. (2006). Writing-to-learn Strategies in Secondary School Cell Biology: A mixed method study. *International Journal of Science Education* , 261-289.

Hythecker, V., Dansereau, D., & Rocklin, T. (2010). An Analysis of the Processes Influencing the Structured Dyadic Learning Environment. *Educational Psychologist , 23* (1), 23-37.

Jimenez-Aleixandre, M., & Reigosa, C. (2006). Contextualizing Practices Across Epistemic Levels in the Chemistry Laboratory. *Science Education , 90*, 705-733.

Johnstone, A. (1982). The demands of practical work. *Education in chemistry , 19* (3), 71.

Johnstone, A., & Al-Shuaili, A. (2001). Learning in the laboratory; some thoughts from the literature. *University Chemistry Education* , 42-57.

Jonassen, D. H. (2003). *Learning to solve problems with technology: A constructivist perspective.* Columbus, OH: Merrill/Prentice-Hall.

Kaberman, Z., & Dori, Y. (2009). Metacognition in chemical education: question posing in the case-based computerized learning environment. *instructional Science , 37*, 403-436.

Kaplan, W. G. (1997). On the Writing of Science and Science of Writing:Hedging in Science Context and Elsewhere. In H. S. Raija Markkanen, *Hedging and discourse: approaches to the analysis of a pragmatic phenomenon in academic texts* (pp. 151-167). Walter de Gruyter.

Kelly, G., Druker, S., & Chen, C. (1998). Students' reasoning about electricity: Combining performance assessments with argumentation analysis. *International Journal of Science Education , 20*, 849-871.

Kerr, N. (1983). Motivation losses in small groups: A social dilemma analysis. *Jourml of Perwncrlity and Social Phychology,* , 819-828.

Keys, C. (1999). Language as an Indicator of Meaning Generation: An Analysis of Middle School Students'Written Discourse About Scientific Investigations. *Journal of Research in Science Teaching , 36* (9), 1044-1061.

Keys, C., Hand, B., Prain, V., & Collins, S. (1999). Using the Science Writing Heuristic as a Tool for Learning from Laboratory Investigations in Secondary Science. *Journal of Research in Science Teaching , 36* (10), 1065–1084.

Kind, P. M., Kind, V., Hofstein, A., & Wilson, J. (2011). Peer Argumentation in the School Science Laboratory—Exploring effects of task features. *International Journal of Science Education , 33* (18), 2527–2558.

Klein, P. (1999). Reopening inquiry into cognitive processes in writing-to-learn. *Educational Psychology Review* , 203-270.

Krathwohl, D. (2002). A Revision of Bloom's Taxonomy: An Overview. *THEORY INTO PRACTICE, , 41* (4), 212-218.

Kreijins, K., Kirschner, P., & Jochems, W. (2003). Identifying the pitfalls for social interaction in computer-supported collaborative learning environments: a review of the research. *Computers in Human Behavior* , 335-353.

Krystyniak, R. A., & Heikkinen, H. W. (2007). Analysis of verbal interactions during an extended, open inquiry general chemistry laboratory investigation. *Journal of Research in Science Teaching , 44* (8), 1160–1186.

Kumpulainen, K., & Mutanen, M. (1999). The situated dynamics of peer group interaction: an introduction to an analytic framework. *Learning and Instruction , 9,* 449-473.

Lamba,R., & Creegan, F. (2008). The process-oriented guided inquiry(discovery) laboratory. *ACS Symposium Series*. 994, 186-199.

Langer, J., & Applebee, A. (1987). *How writing shapes thinking:A study of teaching and learning.* National Concil of Teachers of English.

Lazonder, A., Hagemans, M., & Jong, T. (2010). Offering and discovering domain information in simulation-based inquiry learning. *Learning and Instruction , 20,* 511-520.

Lemke, J. L. (1990). *Talking Science: Language, Learning and Values.* Norwood, NJ: Ablex.

Leonard, W. H. (1994). The Laboratory Classroom. In K. W. Prichard, & R. Mclaran-Sawyer (Ed.), *Handbook of College Teaching.* Westport, CT: Greenwood Press.

Lock, R. (1990). Open-ended,problem-solving investigations. *School Science Review , 71* (256), 63-72.

Lumpe, A., & Staver, J. (1995). Peer collaboration and concept development: Learning about photosynthesis. *Journal of Research in Science Teaching , 32,* 71-98.

McCreary, C., Golde, M., & Koeske, R. (2006). Peer Instructionin the General Chemistry Laboratory:Assessment of Student Learning. *Journal of Chemical Education* , 804-810.

McNeal, A., & D'Avanzo, C. (1997). Student-Active Science: Models of Innovation in College Science Teaching. Philadelphia: Saunders College Publishers.

McNeill, K. L. and Krajcik, J., (2008), Scientific explanations: Characterizing and evaluating the effects of teachers' instructional practices on student learning, *Journal of Research in Science Teaching*, 45(1), 53–78.

Michael, J. (2001). In Pursuit of meaningful learning. *Advances in Physiology Education , 25*, 145-158.

Morrison, D., & Collins, A. (1996). Epistemic fluency and constructivist learning environments. In B. Wilson, & B. Wilson (Ed.), *Constructivist learning environments* (pp. 107-119). Englewood Cliffs: Educational Technology Press.

Nielsen, J. A. (2011). Dialectical Features of Students' Argumentation:A Critical Review of Argumentation Studies in Science Education. *Science Education* , 1-23.

National Research Council. (1996). *National science education standards.* Washington, DC: National Academies Press.

National Research Council.(2000). *Inquiry and the National Science Education Standards*. Washington, D. C.: National Academy Press

Oliveira, A., & Sadler, T. (2008). Interactive Patterns and Conceptual Convergence During Student Collaborations in Science. *Journal of Research in Science Teaching , 45* (5), 634-658.

Osborne, J., (2010), Arguing to learn in science: The role of collaborative, critical discourse, *Science,* 328, 463–466.

Osborne, J., & Dillon, J. (2008). Science education in Europe:Critical reflections. *Nuffield Foundation* .

Osborne, J., Erduran, S., & & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching* , 994–1020.

Ozdem, Y., Ertepinar, H., Cakiroglu, J., & Erduran, S. (2011). The Nature of Pre-service Science Teachers' Argumentation in Inquiry-oriented Laboratory Context. *International Journal of Science Education* , 1-28.

Poock, J., Burke, K., Greenbowe, T., & Hand. B. (2007). Using the Science Writing Heuristicin the General Chemistry LaboratoryTo Improve Students' Academic Performance W. *Journal of Chemical Education , 84* (8), 1371-1379.

Reusser, K., (2001), Co-constructivism in educational theory and practice. In N. J. Smelser, P. Baltes, and F. E. Weinert (Eds.*), International encyclopedia of the social and behavioral sciences* (pp. 2058–2062), Oxford, UK: Pergamon/Elsevier Science.

Reid, N., & Shah, I. (2007). The role of laboratory work in university chemistry. *Chemical Education Research and Practice , 8* (2), 172–185.

Richmond, G. and Striley, J., (1996),Making meaning in classrooms: Social processes in small group discourse and scientific knowledge building, *Journal of Research in Science Teaching,* 33(8), 839–858.

Roychoudhury, A. and Roth,W., (1996), Interactions in an open inquiry physics laboratory, *International Journal of Science Education*, 18, 423–445.

Rudd J, Greenbowe T, Hand B, Legg M. (2001). Using the Science Writing Heuristic to Move toward an Inquiry-Based Laboratory Curriculum: An Example from Physical Equilibrium. *Journal of Chemical Education , 78* (12), 1680-1686.

Ruiz-Primo, M., Li, M., Tsai, S., & Schneider, J. (2010). Tesing One Premise of Scientific Inquiry in Science Classrooms: Examining Students' Scientific Explanations and Student Learning. *Journal of Research in Science Teaching* , 583-608.

Russell, C. B., & Weaver, G. C. (2011). A comparative study of traditional, inquiry-based, and research-based laboratory curricula: impacts on understanding of the nature of science. *Chemistry Education Research and Practice , 12*, 57-67.

Sadi, Ö., & Cakiroglu, J. (2011). Effects of hands-on activity enriched instruction on student's achievement and attitudes towards science. *Journal of Baltic Science Education , 10* (2), 87-97.

Salomon, G., & Globerson, T. (1989). When teams do not function the way they ought to. *International Journal of Educational Research , 13* (1), 89-99.

Sandi-Urena, S., Cooper, M., Gatlin, T., & Bhattacharyya, G. (2011). Students' experience in a general chemistry cooperative problem based laboratory. *Chemistry Education Research and Practice , 12*, 434-442.

Sandoval, W. (2003). Conceptual and epistemic aspects of students' scientific explanations. *Journal of the Learning Sciences , 21* (1), 5-51.

Sandoval, W., & Millwood, K. (2005). The Quality of Students' Use of Evidence in Written Scientific Explanations. *Cognition and Instruction , 23* (1), 23-55.

Scherr, R. E. and Hammer, D., (2009), Student behavior and epistemological framing: Examples from collaborative active learning activities in physics, *Cognition and Instruction*, *27*(2), 147–174.

Schwab, J. (1962). The teaching of science as enquiry. In S. J. F, *The teaching of science.* Cambridge, MA.: Harvard University Press.

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education* , 610-645.

Seery, M. K. (2009). The role of prior knowledge and student aptitude in undergraduate performance in chemistry: a correlation-prediction study. *Chemistry Education Research and Practice* , 227-232.

Shibley, I. (2002). The influence of Collaborative learning on student attitudes and performance in a introductory chemistry laboratory. *Journal of Chemical Education , 79* (6), 745-748.

Stamovlasis, D. (2006). A Study of Group Interaction Processes in Learning Lower Secondary Physics. *Journal of Research in Science Teaching* , 556-576.

Tamir, P., & Lunetta, V. (1978). An analysis of laboratory inquiries in the BSCS yellow version. *American Biology Teacher , 40* (6), 353-357.

Tapper, J. (1999). Topics and manner of talk in undergraduate practical laboratories. *International Journal of Science Education , 21*, 447–464.

Tien, L. T., & Stacy, M. (1996). The effects of instruction on undergraduate students' inquiry skills. *Pape rpresented at the meeting of the American Educational Research Association* . New York.

Tobin, K. (1990). Research on science laboratory activities. In pursuit of better questions and answers to improve learning. *School Science and Mathematics , 90*, 403-418.

Toulmin, S. E. (1958). *The uses of argument.* Cambridge: Cambridge University Press.

Trumbull, D., Bonney, R., & Grudens-Schuck, N. (2005). Developing materials to promote inquiry: Lessons. *Science Education , 99* (6), 879-900.

Tweedy, M., & Hoese, W. (2005). Diffusion activities in college laboratory manuals. *Journal of Biological Education , 39* (4), 150-155.

Volet, S., Summers, M., and Thurman, J., (2009), High-level co-regulation in collaborative learning: How does it emerge and how is it sustained? *Learning Instruction*, 19, 128–143.

Watson, J., Swain, J., and McRobbie, C., (2004), Students' discussions in practical scientific inquiries, *International Journal of Science Education*, 26, 25–45.

Webb, N., and Palincsar, A., (1996), Group processes in the classroom. In D. Berliner and R. Calfee (Eds.), *Handbook of educational psychology* (pp. 841–873), New York, NY: Macmillan.

Wolcott, H. F. (1994). *Transforming qualitative data: description, analysis, and interpretation.* Thousand Oaks, Califonia: SAGE publications .

Yoon, S. Y., Bennett, W., Mendez, C. A., & Hand, B. (2010). Setting up conditions for negotiation in science. *Teaching Science* , 51–55.

Zeidler, D. (1996). The central role of fallacious thinking in science education. *Science Education* , 483-496.

Zimmerman, C. (2000). The development of scientific reasoning skills. *Developmental Review , 20*, 99-149.