Teacher Practices and High School Chemistry Students' Metacognitive Skillfulness

Joni Jordan

Clemson University, jettejoule@gmail.com

Follow this and additional works at: https://tigerprints.clemson.edu/all_dissertations

Part of the Secondary Education and Teaching Commons

Recommended Citation

https://tigerprints.clemson.edu/all_dissertations/688

This Dissertation is brought to you for free and open access by the Dissertations at TigerPrints. It has been accepted for inclusion in All Dissertations by an authorized administrator of TigerPrints. For more information, please contact kokeefe@clemson.edu.
ABSTRACT

The research literature has been dominated with information about teacher practices that promise to help chemistry students improve their problem-solving abilities and maneuver the conceptual complexities inherent in learning chemistry. Drawing on this research, this study proposes that teaching for metacognition may equip students to learn science authentically and more responsibly. Research related to teaching for metacognition has provided some evidence that strategic questioning, specific feedback, and engaging activities help students become more metacognitive. Furthermore, research has shown that enhanced student metacognition improves problem-solving skills, enhances conceptual change, and may even compensate for lower cognitive abilities.

This study was inspired by the Cooper Research Group at Clemson University. The research group has explored students’ metacognition, including various teaching interventions designed to enhance students’ problem-solving abilities and metacognition. This mixed-method study explores what, if any, high school chemistry teachers’ practices might help explain students’ metacognition. Quantitative measures characterized students’ metacognitive skillfulness while qualitative case studies examined four high school chemistry teachers’ practices. This study found four common teacher practices that may help explain why students in all four classrooms progressed to only an intermediate level of metacognitive skillfulness. These teacher practices include (a) a routine use of teacher-question student-answer, well-practiced mathematics aspect of chemistry; (b) an abundant use of step-wise, prescriptive, rote verification experiments;
(c) an absence of proactive, probing questions during all phases of instruction; and (d) an absence of purposeful and critical instructional design.

The results of this study suggest that teacher practices that do not encourage students to reflect deeply on their knowledge may instill a passive and task-accomplishment approach to learning. This study provides additional insight into promising teacher practices that may enhance students’ development of metacognition and, in turn, help students become more conscientious learners. Insights may be used to review current undergraduate chemistry education preparation.
DEDICATION

I dedicate my doctoral degree to my parents who have provided me with unwavering love and support all of my life, especially during the very long Ph.D. journey. I would not be who I am, nor will I become who I’m meant to be, without you. You are indeed the wind beneath my wings.

I also appreciate the enduring love, support, and comic relief provided by my entire family.

I would like to thank God, with whom all things are possible.
ACKNOWLEDGMENTS

I would like to thank my committee members for their patience, enduring support. Thanks to Dr. Bea Bailey for providing consistent and sustained encouragement, Dr. Melanie Cooper for being an inspiring role model, Dr. Larry Grimes for providing statistical advice (and patience), and Dr. Bob Green for his willingness to join the committee late in the process.

I am especially grateful to my study participants for allowing me into their classrooms without inhibition. I would not have been able to complete my study without their willingness to cooperate and to provide time, energy, and resources.

Finally, I would like to recognize the friends who believed in me – my neighbors, the White and Rentz families. Special thanks to Dr. Michael Farmer and Libby Higgins for lifting my spirits daily for 10 years during this process. Very special thanks and infinite gratitude goes to Dr. Glenda Ferguson who carried me across the finish line.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>TITLE</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE PAGE</td>
<td>i</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td>iv</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>viii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>x</td>
</tr>
</tbody>
</table>

## CHAPTER

### I. INTRODUCTION ......................................................................................... 1

- Purpose of the Study ................................................................. 3
- Limitations .................................................................................. 3
- Site and Participant Selection .................................................. 3
- Research Design ........................................................................... 4
- Validity ....................................................................................... 5
- Significance of the Study .......................................................... 5

### II. REVIEW OF THE LITERATURE ............................................................... 7

- Metacognition .............................................................................. 7
- Teaching for Metacognition ....................................................... 10

### III. RESEARCH DESIGN ............................................................................. 21

- Research Questions .................................................................... 21
- Research Context ....................................................................... 21
- Site Selection ............................................................................. 22
- Cases .......................................................................................... 26
- Methodology ................................................................................. 28
- Mixed-Method Design ............................................................... 30
- Quantitative Phase ..................................................................... 32
- Qualitative Phase ....................................................................... 44
- Validity ....................................................................................... 52
Ethical Issues ................................................................. 53

IV. RESULTS .............................................................................. 55

Overview ................................................................. 55
Laura – The Passionate Newcomer to Chemistry Teaching ........... 57
Dr. Wise – The General of Chemistry Teaching .................... 78
Suzy – The Former Chemist and Semi-Veteran Chemistry Teacher ........................................ 101
Ted – The Chemistry Teacher Practitioner .................... 118
Cumulative Interpretive Summary ......................................... 132

V. DISCUSSION ........................................................................ 136

Conclusion ................................................................. 136
Implications for School Administrators .................................. 139
Implications for Chemistry Teachers ................................. 140
Recommendations for Future Research ............................. 141
Limitations ................................................................... 141

APPENDICES ............................................................................. 143

A: Email to Schools for Site Selection ................................. 144
B: Institutional Review Board Application ............................ 146
C: Teacher Consent Form .................................................. 154
D: Student Assent Form ...................................................... 156
E: Parent Permission Form .................................................. 157
F: Hazmat Problem Resources Screen Shots ........................ 159
G: Teacher Observation Protocol ........................................ 165
H: Semi-Structured Interview Form .................................... 173
I: Teacher Questionnaire .................................................. 176

REFERENCES ............................................................................ 182
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Student Actions Related to Specific Metacognitive Skills</td>
</tr>
<tr>
<td>2.2</td>
<td>Classification of Questions Types, Purpose, and Examples</td>
</tr>
<tr>
<td>3.1</td>
<td>Site Composition Attributes</td>
</tr>
<tr>
<td>3.2</td>
<td>Selected Sites’ School 2007 Report Card Ratings</td>
</tr>
<tr>
<td>3.3</td>
<td>Shared Participant Teacher Qualifications</td>
</tr>
<tr>
<td>3.4</td>
<td>Teacher Participant Comparison</td>
</tr>
<tr>
<td>3.5</td>
<td>Metacognitive Activities Inventory, MCA-I</td>
</tr>
<tr>
<td>3.6</td>
<td>MCA-I Item Analysis for Metacognitive Skills of Planning, Monitoring, and Evaluation</td>
</tr>
<tr>
<td>3.7</td>
<td>State Descriptions for the Hazmat Problem Set</td>
</tr>
<tr>
<td>3.8</td>
<td>Summary of Qualitative Data Component of the Mixed-Method Study</td>
</tr>
<tr>
<td>4.1</td>
<td>Summary of Laura’s Students’ Pre- and Post-MCA-I Results</td>
</tr>
<tr>
<td>4.2</td>
<td>Summary of Laura’s Students’ IMMEX Results Shown by Level</td>
</tr>
<tr>
<td>4.3</td>
<td>Summary of Dr. Wise’s Students’ Pre- and Post-MCA-I Results</td>
</tr>
<tr>
<td>4.4</td>
<td>Summary of Dr. Wise’s Students’ IMMEX Results Shown by Level</td>
</tr>
<tr>
<td>4.5</td>
<td>Summary of Suzy’s Students’ Pre- and Post-MCA-I Results</td>
</tr>
<tr>
<td>4.6</td>
<td>Summary of Suzy’s Students’ IMMEX Results Shown by Level</td>
</tr>
<tr>
<td>4.7</td>
<td>Summary of Ted’s Students’ Pre- and Post-MCA-I Results</td>
</tr>
<tr>
<td>4.8</td>
<td>Summary of Ted’s Students’ IMMEX Results Shown by Level</td>
</tr>
<tr>
<td>4.9</td>
<td>Summary of Emergent Teacher Practices</td>
</tr>
</tbody>
</table>
4.10  Comparison of Promising Metacognitive Practices with Observed Teaching Practices ............................................................................................................. 135
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Subdivisions of Metacognition</td>
</tr>
<tr>
<td>3.1</td>
<td>Map of South Carolina, Including the Upstate Region</td>
</tr>
<tr>
<td>3.2</td>
<td>Mixed-Method Sequential Explanatory Design</td>
</tr>
<tr>
<td>3.3</td>
<td>A Prolog Statement for Hazmat</td>
</tr>
<tr>
<td>3.4</td>
<td>Immediate Feedback for the Proposed Solution</td>
</tr>
<tr>
<td>3.5</td>
<td>Epilog Summary of Key Points of the Problem’s Solution</td>
</tr>
<tr>
<td>3.6</td>
<td>Strategic Performance Map</td>
</tr>
<tr>
<td>3.7</td>
<td>Probability Transitions between IMMEX States</td>
</tr>
<tr>
<td>3.8</td>
<td>Summary of Quantitative Data Collection and Qualitative Narrative Interpretative Analysis</td>
</tr>
<tr>
<td>4.1</td>
<td>Laura’s Sample Lesson Plan</td>
</tr>
<tr>
<td>4.2</td>
<td>Comparison of Laura’s Student’ IMMEX Results Shown by Level</td>
</tr>
<tr>
<td>4.3</td>
<td>Dr. Wise’s Sample Lesson Plan</td>
</tr>
<tr>
<td>4.4</td>
<td>Comparison of Dr. Wise’s Student’ IMMEX Results Shown by Level</td>
</tr>
<tr>
<td>4.5</td>
<td>Suzy’s Sample Lesson Plan</td>
</tr>
<tr>
<td>4.6</td>
<td>Comparison of Suzy’s Student’ IMMEX Results Shown by Level</td>
</tr>
<tr>
<td>4.7</td>
<td>Ted’s Sample Lesson Plan</td>
</tr>
<tr>
<td>4.8</td>
<td>Comparison of Ted’s Student’ IMMEX Results Shown by Level</td>
</tr>
</tbody>
</table>
CHAPTER ONE

INTRODUCTION

"Teaching for conceptual change is explicitly metacognitive."

Hewson (1996, p. 126)

A barrage of initiatives challenge high school chemistry teachers to enhance students’ problem solving abilities and bring about meaningful conceptual change. All stress the importance of students taking control of their learning and teachers facilitating their ability to do so (American Association for the Advancement of Science, AAAS, 1990; American Chemical Society, ACS, 2008; National Research Council, NRC, 1996). The National Science Education Standards (NSES), for example, encourage replacing teacher-centered instruction with a pedagogy that puts students at the center of learning through inquiry-oriented activities that require students to solve logic- and evidence-based problems (NRC, 1996). Unfortunately, none of these initiatives provide a specific mechanism for teaching students how to take control of their learning.

White and Gunstone (1989) have asserted that conceptual change may best be realized by empowering students to take control of their learning through the development of metacognitive skills that involve planning, monitoring and evaluating their thinking. Research has shown that metacognition plays a significant role in enhancing science problem-solving skills at the elementary school (Swanson, 1990) and college levels (Cooper, 2007; Jonassen, 2000; Phelps, 1996; Rickey & Stacy, 2000; Swanson, 1990; Taconis, Ferguson-Hessler, & Broekkamp, 2001). These findings hold promise for the role metacognition may play in the high school chemistry classroom.
High school chemistry students may benefit from the acquisition of metacognitive skills due to the constructivist nature of learning this subject matter. Therefore, chemistry teachers need to better understand what types of teacher practices promote metacognition in students (Von Secker, 2002), and research that provides more information is important. The value of developing greater understanding about what types of instructional practices promote metacognition is exemplified by Herron (1996), who attributed lack of success on complex chemistry problems to poorly developed metacognitive skills. These skills would help chemistry students organize work, sequence tasks, and check results. The role of mediating instructional practices is critical for learning because, in their absence, the most useful chemistry concepts are not within reach (Herron, 1996).

Traditional didactic teaching practices involve telling students “correct” scientific ideas, with few opportunities and insufficient guidance to help students develop an understanding of the ideas. Many researchers have asserted that these traditional methods have been ineffective because they have paid insufficient attention to developing the metacognitive skills necessary for students to take more control when learning (Baird, Fensham, Gunstone, & White, 1991; Beeth, 1998; Flavell, 1979; Hennessey, 1999; Pintrich, 2002; Rickey & Stacy, 2000; White, 1992; White & Gunstone, 1989). Growing evidence suggests that metacognition is central to both conceptual change and enhanced problem-solving. Further, Rickey & Stacey (2000) have asserted that and it works in harmony with constructivist learning perspectives and guided-discovery types of instruction.

Of particular importance is the need for chemistry teachers to recognize the extent to which students understand chemistry concepts and to respond by implementing appropriate instruction. It is not enough to assume lesson completion, artifact generation, or activity-based
lessons result in conceptual understanding, establish schema that ensure durability and transfer, or improve students’ problem-solving skills (Davidowitz & Rollnick, 2003).

**Purpose of the Study**

The purposes of this study are to explore what, if any, public high school chemistry teacher practices may help explain students’ metacognitive skillfulness and to compare the observed teachers’ instructional methods with the stated promising practices in the literature. Specifically, this research study explores the following two questions:

1. In what ways, if any, do high school chemistry teacher practices help explain the metacognitive skillfulness of chemistry students?
2. How do observed high school chemistry teacher practices compare to methods exemplified in the literature as holding promise in the area of teaching for metacognition?

**Limitations**

Although a large number of public high schools offer chemistry in the upstate of South Carolina, the study was limited to nearby schools that would allow the researcher to make frequent site visits.

**Site and Participant Selection**

Chemistry classrooms at four public high schools, all located in the upstate of South Carolina, were the sites of interest in this study. Each school had comparable resources for teaching chemistry, including laboratory size and inventory. The participating teachers were certified public high school chemistry educators who were teaching students seeking science credit towards graduation. All were guided by the state-mandated chemistry curriculum standards and instructional time requirements.
Research Design

This study used a sequential explanatory mixed-method approach that focused on collecting, analyzing and combining quantitative and qualitative data to explain any changes that may occur in students’ metacognitive skills after exposure to specific teacher practices. Students’ metacognitive skill development was measured quantitatively using pre- and post-metacognitive activities inventory (MCA-I). The MCA-I is a self-report instrument used to access students’ perceptions of metacognitive skillfulness (Cooper, Sandi-Urena, Gatlin, Bhattacharyya & Stevens, submitted). Students’ actual metacognitive abilities were measured at the end of the study using Interactive Multimedia Exercises (IMMEX), an internet software system that has been extensively used in K-16 classrooms (Underdahl, 2002) and described thoroughly (Cooper, Cox, Nammouz, & Stevens, 2007; Stevens, Johnson, & Soller, 2005; Underdahl, Palacil-Cayetano, & Stevens, 2001) with respect to identifying students’ problem-solving strategies and metacognitive skillfulness (Stevens, Soller, Cooper, & Sprang, 2004).

Qualitative data related to teacher practices included documents and artifacts, such as observation notes, lesson plans, sample assessments and lab-related assignments. The qualitative field notes, documents, and artifacts relating to teacher practices were transcribed, typed, and organized for analysis. The evidence was reviewed thoroughly to determine whether any themes or patterns existed. The teacher practice analyses culminated in rich, thick descriptive narratives. The qualitative narratives describing teacher practices were used to address the second research question related to the comparison of observed high school chemistry teacher practices with methods exemplified in the literature as holding promise in the area of teaching for metacognition.
Validity

Internal validity was addressed to the greatest extent possible in this study by selecting and interviewing participants on multiple occasions and using multiple data sources over a sustained period of time. The teachers were observed over an eight-month period and no participants left the study or changed their teaching schedules. Care was taken in this study to appropriately design a methodology to collect suitable data to thoroughly answer the research questions. Before going into the field for observations, the researcher met the participants in their classrooms to discuss how observations would occur without interrupting the teachers’ routines and protocols.

External validity represents whether the results of a study hold true for other populations or whether a study may be replicated in comparable studies. The research will provide an image of what exists; leaving readers and researchers to judge if the cases are generative and, thereby, helpful in other comparable settings.

Significance of the Study

The study of teaching practices that may explain students’ metacognitive skillfulness could lead to new or additional insights related to teaching and learning metacognitive skills. The results of this study may expose current teacher practices that possibly impede or enhance students’ metacognitive skills. Furthermore, the findings may reveal a need to provide chemistry teachers with a specific mechanism to assist them in understanding how to help students take more control over their learning.

This study’s comparison of high school chemistry teachers’ practices to methods exemplified in the literature as holding promise in the area of teaching for metacognition will shed light on the similarities – or lack thereof - between actual teaching practices in
this area and those showcased in the literature. This information may provide rationale for improving pre-service teacher programs to include training in pedagogy that facilitates students’ attainment of metacognitive skillfulness. Further, if this is the case, teachers who are currently practicing may benefit from professional development that assists them in learning how to change practices to help students attain metacognitive skillfulness.
CHAPTER TWO
REVIEW OF THE LITERATURE

“Learning is an active, constructive, cumulative, and goal-oriented process that involves problem solving.” T. J. Shuell (1990, p. 532)

“The more teachers understand about how students learn, the more effective they will be in achieving high rates of successful performance in problem solving.”
D.S. Mason & D. F. Shell (1997, p. 906)

Metacognition

In one of the earliest definitions, Flavell (1979) characterized metacognition as knowledge concerning one's own cognitive processes or thinking about one's own thinking, with active monitoring, regulation, and orchestration of these processes. Over twenty years later, Kapa (2001) described metacognitive processes as “mental operations which direct cognitive functions of a person and support a learning conceptualization (p. 318).” Metacognition is learning how to learn, whereby students develop, monitor, and revise their own investigative strategies (Zion, Michalsky, & Mevarech, 2005). According to Pintrich (2002), metacognition relates to "students becoming more knowledgeable of and responsible for their own cognition and thinking (p. 219).”

Metacognition can be divided into two main categories, metacognitive knowledge and metacognitive skillfulness, as summarized in Figure 2.1 (Sandi-Urena, 2008). Metacognitive knowledge is divided into three subcategories: declarative, procedural, and conditional knowledge. Declarative knowledge refers to knowing about things, procedural knowledge refers to knowing how to do things, and conditional knowledge refers to knowing when and why things should be done. Conversely, regulation of cognition involves activities that help control one’s
thinking via planning, monitoring and evaluating while learning. Regulation of cognition, also termed “metacognitive skillfulness,” is the focus of this study.

![Diagram of metacognition]

*Figure 2.1. Subdivisions of Metacognition. The identified focus of this study circled.*

Planning occurs when students select appropriate strategies and allocate the necessary resources that affect performance. Examples of planning activities include predicting outcomes before beginning a problem, sequencing strategies to utilize, and selectively allocating attention or time before beginning a task. Monitoring occurs when students maintain awareness during a task, whereby self-testing occurs throughout the learning process. Evaluation refers to judging the product of one’s learning. Developing an understanding of ideas requires students to evaluate the feasibility of their current ideas and reconcile them with the data or information being presented. Before students can seek help or ask for explanations, they must first recognize that their understanding is incomplete. Table 2.1 summarizes the specific student actions associated with the processes of metacognitive skillfulness (Jacobs & Paris, 1987).
### Table 2.1

*Student Actions Related to Specific Metacognitive Skills*

<table>
<thead>
<tr>
<th>Metacognitive Skills</th>
<th>Action Taken by Student</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>• Determine goal of problem</td>
</tr>
<tr>
<td></td>
<td>• Access background information</td>
</tr>
<tr>
<td></td>
<td>• Allocate resources</td>
</tr>
<tr>
<td></td>
<td>• Budget time</td>
</tr>
<tr>
<td>Monitoring</td>
<td>• Self-testing</td>
</tr>
<tr>
<td></td>
<td>• Comprehension of task performance</td>
</tr>
<tr>
<td>Evaluating</td>
<td>• Appraise products</td>
</tr>
<tr>
<td></td>
<td>• Re-evaluate goals and conclusions</td>
</tr>
</tbody>
</table>

Schraw and Moshman (1995) reported significant improvements in learning when these regulatory skills and an understanding of how to use them are included as part of classroom instruction. If students lack insight into their own learning abilities, it is doubtful that they will be able to plan or self-regulate effectively. Therefore, the importance of helping students develop a repertoire of metacognitive strategies has a significance for learning (Bransford, Sherwood, Vye, & Rieser, 1986). Since studies suggest that the development of metacognitive skills begins early in life and develops throughout adolescence (Brown, 1987; Garner & Alexander, 1989), teaching practices that encourage high school students to hone these abilities hold promise.
Teaching for Metacognition

Recent theoretical frameworks designed to guide instruction (AAAS, 1990; NRC, 1996) are based on constructivist models whereby knowledge is created or constructed by the learner on the basis of certain inherent cognitive characteristics of the individual learner and in relation to existing frameworks of knowledge in memory (Bodner, 1986). Furthermore, the substantive complement between constructivism and metacognition is exemplified by the statement that learners are appropriately metacognitive if they undertake an informed, self-directed approach to recognizing, evaluating, and deciding whether to reconstruct existing ideas (Case & Gunstone, 2006). The implication then is that teaching and assessment need to be designed to elicit deep approaches to learning.

Teaching should mediate the learning environment, making the learning process efficient and effective. Lack of conceptual understanding is a common cause of failure in solving problems in chemistry. Because problem solving is the ultimate goal of chemistry (Herron, 1996), it is important that instructional practices improve problem-solving skills and facilitate conceptual change. Concern with the utilization of previously acquired knowledge has led to an emphasis on the concept of metacognitive processes.

Sandi-Urena, Cooper & Stevens (2010) illustrated the potential for enhanced student metacognition awareness through strategic instructional practices using prompt questions to promote reflection during the learning process. The study measured the effectiveness of collaborative intervention in promoting college general chemistry students’ awareness and use of metacognition. The treatment group experienced three phases of intervention, a collaborative activity, an individual piece and an individual
feedback component. The collaborative phase sought to elicit reflection through prompts and social interaction, while the individual phase sought to reinforce skills practiced during the collaborative phase. Finally, the feedback phase involved students reflecting on a summary of the responses of fellow students with the intent of having students reflect on the activity as a learning experience. Each component used prompt questions to guide and promote reflection about metacognitive skillfulness.

The study found that the treatment group showed a significant increase in metacognition awareness, an increased ability to solve non-algorithmic chemistry problems of higher difficulty and with higher percent correctness. The treatment group demonstrated a significant difference in the effect of collaborative metacognitive intervention on self-reported metacognitive use compared to the control group. Sandi-Urena et al. suggests that “meaningful, purposeful social interaction and the reflective prompting instantiated by the intervention act as promoters of metacognition development (p.1).” This study substantiates the value of exploring what, if any, high school chemistry teacher practices explain students’ metacognitive skillfulness.

Another valuable study that indicated significant changes in students’ metacognitive skillfulness as a result of a certain teaching practices is Cooper’s mixed method study regarding the effect of cooperative problem-based lab instruction on regulatory metacognition, problem solving skills and performance (Cooper, Sandi-Urena, Gatlin, Bhattacharyya, & Stevens, submitted). In this study the treatment group completed a lab project that required an extensive inquiry-based, “minds-on, hands-on” protocol on problem-solving skills and performance as well as on students’ regulatory
metacognition. The treatment group analyzed the problem, set goals, planned strategies, designed and implemented experiments, learned necessary lab techniques, discussed and evaluated processes and outcomes, and answered guiding and planning questions. At the end of the lab, project student teams came together in a session where each group used a poster presentation to communicate, explain, defend and justify their procedures, rationales, decisions and conclusions to their peers and teachers.

The Cooper study showed that the percentage of students using the highest metacognitive strategies in the treatment group more than doubled that of the control group. The implications provide value to the current study because inquiry-based teacher practices and the intense social interactions yielded a significant increase in the percentage of students demonstrating high metacognitive skills. Further, the study indicated that students were unfamiliar with the inquiry-based methods and became frustrated when faced with taking more responsibility rather than is required with following a series of steps in a rote verification experiment.

The Model-Observe-Reflect-Explain (MORE) Thinking Frame, was designed to “promote metacognition in a guided-discovery environment while encouraging students to explore chemistry concepts through authentic scientific inquiry (Rickey, 1999; Rickey & Stacey, 2000).” The MORE lab protocol is contradictory to a rote verification lab format where students follow step-by-step instructional procedures and is in direct contrast to the nature of the actual experiences of scientists (Rickey, 1999). During the MORE study, a comparison was made between a standard laboratory group and a MORE group. Students in the standard laboratory followed a traditional, verification experiment
format; they followed step-by-step procedures, recorded specific data, performed calculations and completed lab reports. The MORE group began with an overarching issue designed to inspire experimental questions within the broad topic given to them in the beginning of each lab module. Students had to design and test a model, make observations, reflect on their findings during and following the experiment, and explain their results. Students were guided by prompts during each module and were progressively placed in positions of greater responsibility through involvement in designing and carrying out their own experiments, presenting their results in both oral and written formats, and critiquing their peers’ experimental methods and analyses. MORE students developed significantly enhanced metacognitive abilities, understanding of fundamental chemistry ideas, and abilities to solve examination problems (Rickey, 1999; Rickey & Stacey, 2000). These findings suggest that inquiry-based, authentic scientific thinking processes hold promise for teacher practices that may influence students’ metacognitive skillfulness and inspire students to have a more intrinsic appreciation for the methods of science.

Zion et al., the designers of MINT (metacognitive-guided inquiry within asynchronous learning networked technology), also believed that students should be instructed and trained to learn in an inquiry-based, guided manner (2005). These researchers sought to assist students in developing their metacognitive skills by helping them reflect on their learning, monitor their performance, and revise their investigation strategies as needed. The MINT researchers stressed the importance of students communicating their thought processes and results to others in order to negotiate ideas
and construct new knowledge. During the MINT research, students received explicit metacognitive guidance during the process of inquiry tasks relating to microbiology. Students in the experimental group received two sets of metacognitive questions, including “metacognitive consciousness” and “executive questions” which they answered in journals. Metacognitive consciousness questions related to knowledge about setting goals and implementing problem-solving strategies. The executive questions, on the other hand, aimed to train students in regulating, controlling and evaluating the cognitive processes and results. These questions involved planning, monitoring, and evaluating, processes which relate directly to our study. Students had to describe their thoughts before they began solving the problem and explain how they decided on the order of their strategic steps. Monitoring questions guided students to describe how and when they assessed their activities throughout the solution process. Finally, evaluation questions guided students to describe how they improved their abilities during the inquiry and problem-solving processes.

Students in the MINT experimental group demonstrated significantly higher achievements related to designing experiments and drawing conclusions than did students in the control group. Since the MINT study is believed to be the first to focus on metacognitive guidance in enhancing both general and domain-specific knowledge simultaneously, it provides exciting prospects for researching the role guided inquiry using strategic questions would play in a variety of disciplines, including the chemistry classroom.
Blank (2000) studied a learning cycle model, termed the Metacognitive Learning Cycle (MLC), which emphasized strengthening students’ abilities to examine their science ideas. In this study, students in the treatment group made entries into concept journals which allowed the teacher to ascertain students’ knowledge and identify misconceptions. The journal entries were guided by question prompts about the intelligibility, plausibility, and fruitfulness of their science ideas. The findings of this study suggested that the MLC students restructured their understanding of the concepts to a greater extent and made greater use of their knowledge for a longer period of time than did the group who did not receive this type of instruction.

Another research study that proposed advantages of teaching for metacognition explored its integration with instructional practice involving fifth grade science students. Concerned with students’ ability to transfer science to new contexts, Georghiades (2006) implemented a study using 60 students where an experimental class was exposed to “metacognitive instances” during instruction. Four types of metacognitive activities, including classroom discussion, diaries, concept mapping, and annotated drawing, were applied regularly during instruction to emphasize reflective thinking. Collectively, these activities sought to engage students in learning in a more conscious and meaningful way by prompting them to reveal their ideas and help them reflect and monitor their understanding. Georghiadas’ findings indicated that the use of metacognitive thinking activities can promote conceptual understanding. The experimental group demonstrated a significantly higher level of cross-contextual use of their science conceptions than did
students in the control group. The study suggests that “metacognitive instances” may help students transfer information from classroom contexts to laboratory situations.

Project META (Metacognitive Enhancing Teaching Activities) was a three-year case study (Hennessey, 1999) involving grades 1 through 6 which investigated the role of appropriate and productive pedagogical practices in facilitating changes in metacognition through individual and group dialogue. META was framed on the constructivist belief that the active restructuring of conceptual understanding in light of new experiences is key to learning science. The Project incorporated the use of technology, poster presentations and conceptual models to encourage students to reflect upon their own thinking and knowledge claims. These mechanisms for reflection were designed to enable the teacher to intervene with appropriate, meaningful instruction (such as metaphors, analogies, laboratory activities, etc.) and challenge student thinking.

Hennessey’s study led to several important instructional implications regarding metacognition. First, instructional practices that encourage students to inspect and evaluate their mental constructs hold promise over those which simply ask students to recall facts about the physical world. Secondly, the task of developing knowledge should not be separated from the context of building conceptual understanding. Furthermore, Hennessey stated that strategic decisions largely relate to the educational context within which one works. Project META provided some exciting results which inspire additional research related helping secondary chemistry students connect learning tasks and conception development.
Another study (Kramarski, Mevarech, & Marsel, 2002) compared the effect of a metacognition component on seventh-grade mathematic students taught in a cooperative learning format. Ninety-one students participated in the study in which one group was exposed to both metacognitive instruction and cooperative learning (COOP+META) while the other was exposed to cooperative learning only (COOP). The groups were heterogeneous in terms of low, high, and medium achievers. Students receiving metacognitive instruction were trained to formulate and answer four types of self-addressed questions, relating to comprehension, connection, strategy, and reflection. The teachers modeled the use of metacognitive questions illustrated in Table 2.2 in their introductions, reviews, and small group discussions.
Table 2.2

Classification of Question types, Purpose, and Examples

<table>
<thead>
<tr>
<th>Question Type</th>
<th>Explanation of Question</th>
<th>Prescriptive Example Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehensive</td>
<td>Prompt students to reflect on the problem before solving it.</td>
<td>• What is the problem/task all about?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• What is the question?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• What are the meanings of the mathematical concepts?</td>
</tr>
<tr>
<td>Connection</td>
<td>Prompt students to focus on similarities and differences between the problem/task they</td>
<td>• How is the problem/task or set of problems/tasks different or similar to what you have</td>
</tr>
<tr>
<td></td>
<td>work on and the problem/task or set of problem/tasks that they already solved.</td>
<td>already solved? Explain.</td>
</tr>
<tr>
<td>Strategic</td>
<td>Prompt students to consider which strategies are appropriate for solving the given</td>
<td>• What strategy, tactic, or principle can be used in order to solve the problem or task?</td>
</tr>
<tr>
<td></td>
<td>problem/task and for what reasons.</td>
<td>• Why is this strategy, tactic, or principle most appropriate for solving the problem or task?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• How can I organize the information to solve the problem or task?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• How can the suggested plan be carried out?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Can I use another approach in solving it?</td>
</tr>
</tbody>
</table>
Following teacher introductions to the problem or task, students worked in small groups where they read the task aloud, tried to solve it, and explained to their peer groups the reasoning in their approach. Next, the group discussed the issue until an agreement was reached. Students were encouraged to discuss the task, consider different perspectives, and converse about possible solution strategies. After using metacognitive discourse during their small group discussions, students recorded their strategy once they reached agreement.

The solution process included understanding the problem, selecting appropriate strategies for its solution, reflecting on the result and deciding whether it makes sense. Low achievers read problems rapidly and only focused on parts of the tasks. Further, they did not see the task as a whole nor did they recognize multiple methods of finding a solution. High achievers, on the other hand, gave up easily when the appropriate algorithms were not readily available. Further, they had problems applying their knowledge to the authentic tasks at hand.

The results of the study indicated that the COOP+META group significantly outperformed the COOP group on both authentic and standard tasks. Metacognitive students reorganized and processed given information better than did the non-metacognitive students; they also justified their reasoning better. The results suggested that both low and high achievers benefited from metacognitive instruction. Although the study involved mathematics education, the researchers suggest that metacognitive instruction has the potential to enhance students’ abilities to solve problems in other disciplines. The findings provide promise regarding the possible benefits of
metacognitive instruction in the chemistry classroom due to the problem-solving inherent in the subject matter.

Collectively, the aforementioned research related to teaching for metacognition is consistent with the National Science Education Standards (NSES, 1996), which call for encouraging students to take more responsibility while learning science in a manner that is more consistent with real scientists. Metacognition has been shown to be particularly valuable to learning chemistry. Clearly, if teachers wish to facilitate permanent conceptual change and deep understanding, they should go beyond the popular teaching methods those that make use of easy-to-follow mathematical algorithms. In order for students to maximize conceptual understanding and problem-solving abilities, educators should incorporate teacher practices designed to strengthen students’ metacognitive skills by encouraging them to reflect on their ideas and monitor and evaluate them during the learning process.

Previous studies have provided the foundation upon which to explore what, if any, teacher practices explain high school chemistry students’ metacognitive skillfulness and to compare actual practices to promising practices. Further, they have laid the groundwork for a comparison of high school chemistry teacher practices to methods exemplified in the literature as holding promise in the area of teaching for metacognition.
CHAPTER THREE
RESEARCH DESIGN

This chapter describes the research design of this study that examines the extent to which high school chemistry teachers’ practices may explain metacognitive skillfulness in the chemistry students that they teach and how observed practices compare to promising practices described in the literature. The study’s use of a mixed-method approach seeks to address two questions.

Research Questions

As identified in Chapter 1, the research questions that inform this study are:

1. In what ways, if any, do high school chemistry teachers’ practices help explain the metacognitive skillfulness of chemistry students?

2. How do high school chemistry teachers’ practices compare to methods exemplified in the literature as holding promise in the area of teaching for metacognition?

Research Context

This study emerged from an interest in research being conducted by Sandí-Ureña (2008) at Clemson University who developed a Metacognitive Activities Inventory, MCA-I, to measure metacognitive skillfulness in chemistry students. The researcher recognized the potential shown in student performances that Sandi-Urena’s study linked to metacognitive skillfulness in chemistry at the collegiate level, and saw the prospective value of honing these skills at the high school chemistry level. The researcher recognized the possibilities that teaching for metacognition may have in assisting teachers contend with the national teaching initiatives (American Association for the Advancement of Science, AAAS, 1990; American Chemical
Society, ACS, 2008; National Research Council, NRC, 1996), which call for students to become more responsible for their learning and become better equipped to learn science in the same manner as scientists conduct their investigations. The researcher’s personal experiences as a chemistry teacher and interactions with other chemistry teachers informed her of the need for a mechanism to help both teachers and students transition from a teacher-centered, autocratic learning environment to a more student-centered setting.

Additional inspirations for this study also emerged from fellow graduate students’ work at Clemson University who worked under Dr. Melanie Cooper’s guidance, including Edward Case, Charles Cox, and Minory Nammouz, who had researched chemistry problem-solving (Case, 2004; Cox, 2006; Nammouz, 2005). These studies involved the use of Interactive Multimedia Exercises (IMMEX), an internet-based software program that has been used extensively to gather information relating to student performance and strategy use while solving chemistry problems (Cooper, Cox, Nammouz, Case, & Stevens, 2008).

As a veteran high school chemistry teacher the researcher understood the importance of students’ problem-solving skills in their mastery of chemistry. The researcher saw the opportunity to utilize both the MCA-I and IMMEX to study high school chemistry students’ metacognitive skillfulness and the possibility that teacher practices may help explain them.

Site Selection

Teacher practices were the primary focus of this study. The initial considerations when selecting sites included the school-level influences that may affect learning outcomes other than the focus of this research study. Aspects of the research sites that may affect learning outcomes include school composition, practice, and context (Opdenakker & Van Damme, 2007), with composition and context being the most directly related to learning science (Gabel, 1994). Therefore, in an attempt to select cases and to account for any differences that may exist at the
research sites, composition and context were important considerations for selection. School composition relates to student population, teaching teams, and school leaders, while school context relates to descriptive characteristics, and physical and material characteristics.

Site selection began with a review of potential schools that were listed in the school directory at the South Carolina Department of Education’s website. Due to logistical considerations and lack of research funding, sites had to be within a manageable driving distance to be accessible to the researcher. After generating a list of ten potentially suitable upstate South Carolina schools, emails were sent to the high school principals (Appendix A) describing the nature of the study and soliciting permission to speak with the chemistry teachers at the school. From the responses, four schools met the criteria necessary for participation:

1. Principal gave researcher approval to research at the school.
2. The Institutional Review Board Application (IRB) form was completed by the researcher (Appendix B).
3. Teachers returned all consent forms, including the teacher (Appendix C), student (Appendix D) and parental consent forms (Appendix E).

The schools, where the four participating certified high school chemistry teachers worked, utilized the same state chemistry curricula and chemistry students earned a science credit required for graduation. Similar prerequisites were taken by chemistry students including physical science and algebra. Throughout the study, pseudonyms were used for the school, teacher, and student names. School pseudonyms included Hawk, Oak, Hardy and Lasso high schools. Although the class periods at all schools lasted 90 minutes, Lasso and Oak met daily, Monday through Friday for one semester (4X4 block) and Hardy and Hawk met on alternating days for an academic year (A-B block).
The schools’ compositions were scrutinized relating to grade level, gender, ethnicity, and poverty index. A school’s poverty index takes into consideration the percentage of its students who are eligible for Medicaid services and the free and reduced lunch program. Schools with relatively large percentages in these categories have relatively high poverty indices. Table 3.1 summarizes the site descriptions relating to these characteristics.

Table 3.1

*Site Composition Attributes*

<table>
<thead>
<tr>
<th>Site Attributes</th>
<th>Hawk</th>
<th>Oak</th>
<th>Hardy</th>
<th>Lasso</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade Levels</td>
<td>9-12</td>
<td>9-12</td>
<td>9-12</td>
<td>9-12</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male %</td>
<td>50</td>
<td>52</td>
<td>49</td>
<td>54</td>
</tr>
<tr>
<td>Female %</td>
<td>50</td>
<td>48</td>
<td>51</td>
<td>46</td>
</tr>
<tr>
<td>Ethnicity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White %</td>
<td>89</td>
<td>62</td>
<td>82</td>
<td>61</td>
</tr>
<tr>
<td>African American %</td>
<td>7</td>
<td>32</td>
<td>14</td>
<td>35</td>
</tr>
<tr>
<td>Asian %</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Hispanic %</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Poverty Index</td>
<td>32.9</td>
<td>57.1</td>
<td>44.9</td>
<td>62.6</td>
</tr>
</tbody>
</table>

The schools involved in the study were geographically located in the upstate of South Carolina, as illustrated in Figure 3.1.
Figure 3.1. Map of South Carolina, including the Upstate Region where research sites were located.

All four schools were relatively similar with respect to size of student body, curricular offerings and facility attributes. School populations of Hawk, Oak, Hardy, and Lasso were 1642, 1461, 1654, and 1547, respectfully. All schools had similar chemistry curricular chemistry offerings, including advanced, honors, and college preparatory levels. The sites had comparable facilities, including ample laboratories and appropriate lab supplies.

Since a school’s report card is a detailed local and state-level evaluation, and its accreditation credentials are comprehensive measures of its effectiveness and quality, these factors were analyzed. With regards to the school report card, Hawk, Oak, Hardy, and Lasso received absolute indices of 3.6, 2.7, 3.6, and 2.8, respectfully, in 2007. Correspondingly, each school had an absolute rating of good or below average. These report card results are summarized
in Table 3.2. All schools in this study were accredited by Southern Association of Colleges and Schools (SACS), the regional body for the accreditation of schools in South Carolina and ten other states in the southeastern United States.

Table 3.2

*Selected Sites’ School 2007 Report Card Results*

<table>
<thead>
<tr>
<th>Rating</th>
<th>Hawk</th>
<th>Oak</th>
<th>Hardy</th>
<th>Lasso</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute Index</td>
<td>3.6</td>
<td>2.7</td>
<td>3.6</td>
<td>2.8</td>
</tr>
<tr>
<td>Absolute Rating</td>
<td>Good</td>
<td>Below Average</td>
<td>Good</td>
<td>Below Average</td>
</tr>
</tbody>
</table>

**Cases**

Four chemistry teachers were the cases within this study. All participants were certified, public high school chemistry teachers who had obtained the appropriate education to teach chemistry. The four teacher participants were observed bi-monthly, during the 2007-2008 school year from August through May. Each teacher was located in different schools and in different school districts, eliminating the possible influence of a district-wide mandated teacher practice methodology or philosophy permeating all cases.

**Teacher Participants**

Three of the participating teachers had Master’s degrees and one had a Ph.D. All taught a range of levels of chemistry, including college preparatory, honors, and Advanced Placement (AP). A summary of the shared participants’ qualifications is represented in Table 3.3.
Table 3.3

Shared Participant Teacher Qualifications

<table>
<thead>
<tr>
<th>Cultural Backdrop</th>
<th>Upstate or “Upcountry” of South Carolina</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setting</td>
<td>Public high school, grades 9 -12, located within a local district, bound by the laws of the State of South Carolina.</td>
</tr>
</tbody>
</table>
| Certification and Education | • Master’s or Ph.D. degree.  
• Professional certificate.  
• 30 hours of specialized preparation, 18 included lab hours in chemistry.  
• Passing score on State Board exam in content area. |
| Curricular Guide | South Carolina State Standards |
| Instruction Time | 90 minute classes |

Table 3.4 uses assigned pseudonyms to summarize the differences among participants that included gender, years of teaching experience; age and educational degree. All teachers were Caucasian.

Table 3.4

Teacher Participant Comparison

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Gender</th>
<th>Age</th>
<th>Years Teaching</th>
<th>Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laura</td>
<td>Female</td>
<td>25</td>
<td>2</td>
<td>M.A.</td>
</tr>
<tr>
<td>Suzy</td>
<td>Female</td>
<td>48</td>
<td>15</td>
<td>M.A.</td>
</tr>
<tr>
<td>Ted</td>
<td>Male</td>
<td>29</td>
<td>4</td>
<td>M.A.</td>
</tr>
<tr>
<td>Dr. Wise</td>
<td>Male</td>
<td>65</td>
<td>35</td>
<td>Ph.D.</td>
</tr>
</tbody>
</table>
None of the participants acknowledged any previous familiarity with metacognition. Further, the researcher refrained from discussing the concept during the study in order to observe their natural teaching tendencies. Finally, the teachers were not monetarily compensated.

**Student Participants**

Only the students who returned the necessary personal and parental consent forms were allowed to participate. Identification codes were assigned to each participant to ensure confidentiality. Student demographics were noted in Table 2. All of the students were taking chemistry for graduation credit and all had taken similar state-required prerequisites in math and science. The age of participants ranged from 16 to 18 years old. All students had been issued state-adopted textbooks.

**Methodology**

A mixed-method approach was used for this study that focused on collecting, analyzing, and mixing both quantitative and qualitative data in a coherent manner (Creswell, 2003). According to Creswell and Plano (2007), “Its central premise is that the use of quantitative and qualitative approaches, in combination, provides a better understanding of research problems than either approach alone” (p. 8-9).

The mixed-method approach has been debated since the 1960s regarding the usefulness of combining quantitative and qualitative research methodologies in the same study (Creswell, 2003). While some scholars remain deeply rooted in distinguishing the value of quantitative versus qualitative research methods, other scholars advocate views of these methods that are complementary. Creswell (2003) states that qualitative results can be used to support or explain quantitative results and vice versa. Since 1988, mixed method has had a more systematic use of both strands and is considered a distinct methodology. The formation of an international
community using this approach has emerged, engaging and elaborating the method in journals, at conferences, and in books. In addition, specific language for discussing it has emerged, including names, terms, and diagrams of designs. Specific procedures for “mixing” have been developed, including designs and mixed-methods questions (Creswell, 2003). While mixed-method research has developed as a valuable and respectable research method, it has its advantages and disadvantages.

An advantage of a using mixed-method study through combining the two approaches sharpens our understanding of the research findings by using one approach to support or explain the other. For example, rejecting a null hypothesis relating to teacher practices may be clarified by using thick, rich qualitative data from open-ended interviews or observations of those teachers. Creswell (2003) emphasizes the value in using qualitative results to explain quantitative results. For example, in this study, the researcher’s goal is to explain quantitative measures of students’ metacognition using the qualitative appraisal of teacher practices. According to Creswell, the use of both quantitative and qualitative approaches in combination allows researchers to gain a deeper understanding of the research problems than either method alone. While advantages of using mixed-methods exist, this design is not without its disadvantages.

According to Creswell (2003), the mixed-method researcher has to be knowledgeable in both qualitative and quantitative designs. More time and effort is required on the part of the researcher. Another concern of Collins, Onwuegbuzie, and Jiao (2006) is sampling size. In quantitative research the larger the number of participants, the more reliable the findings will be. On the other hand, it is often not feasible to use a large sample size while conducting qualitative research due to the need to analyze data in more depth. In addition, some research questions do not lend themselves well to mixed-methods and the approaches can be philosophically at odds. While these concerns are acknowledged, based on the research questions of this study and the
goals of the researcher, a mixed-method approach is deemed most suitable to explain how teacher practices may explain student metacognition.

**Mixed-Method Design**

This study utilized a mixed-method approach with a sequential explanatory design, where the quantitative phase preceded the qualitative phase, to explore what, if any, high school teachers’ practices may help explain the metacognitive skillfulness of their students. The qualitative aspect of the study also compared these teachers’ practices to promising methods relating to teaching for metacognition in chemistry classrooms described in the literature. A comprehensive summary of the research design is illustrated in Figure 3.2
Mixed-method: Sequential Explanatory Design

Student Metacognition

Quantitative Data Collection
- Pre MCA-I
- IMMEX

Quantitative Data Collection
- Post MCA-I

Qualitative Data Collection

Qualitative Data Analysis
- mean comparison, (paired sample t-test)
- IMMEX strategy descriptor (Low, Intermediate, High)

Qualitative Data Collection
- Observations
- Interviews, questionnaire
- Document Analysis

Qualitative Data Collection
- Narratives
- Strategies - Questioning
- Activities

Teacher Practices

Site Selection of Schools

Case Selection of teachers

Integration at Interpretation

Figure 3.2. Mixed-Method, Sequential Explanatory Design (J Creswell, 2003).
In the quantitative phase, two instruments were used across method and time to measure students’ metacognitive skillfulness: MCA-I and IMMEX. For the qualitative phase, a multi-site case study was implemented with a variety of data sources, including observations, interviews, questionnaires, and document analyses. The quantitative and qualitative phases are described in greater detail in the sections that follow.

**Quantitative Phase**

**Instrument Descriptions**

Metacognitive skillfulness was measured with the two different instruments, the Metacognitive Activities Instrument (MCA-I) and Interactive MultiMedia Exercises (IMMEX). Both instruments have been established as valid and reliable instruments for the purpose of measuring metacognitive skillfulness (Sandi-Urena, 2008; Stevens, Johnson, & Soller, 2005). Each instrument will be described in greater detail in the sections that follow.

**Metacognitive Activities Inventory (MCA-I)**

The Metacognitive Activities Inventory, or MCA-I, is a robust, reliable, 28-item self-report instrument developed by Cooper and Sandi-Urena (2008) that assesses students’ metacognitive skillfulness when solving chemistry problems. Use of MCA-I as a diagnostic tool in deciding appropriate interventions makes it a valuable asset to chemistry teachers who want to alter their teaching practices in order to develop students’ problem-solving skills using metacognition (Cooper & Sandi-Urena, 2009). Table 3.5 details the MCA-I instrument utilized in this study.
Table 3.5

*Metacognitive Activities Inventory, MCA-I*

<table>
<thead>
<tr>
<th>Item</th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I read the statement of a problem carefully to fully understand it and determine what the goal is.</td>
</tr>
<tr>
<td>2</td>
<td>When I do assigned problems, I try to learn more about the concepts so that I can apply this knowledge to test problems.</td>
</tr>
<tr>
<td>3</td>
<td>I sort the information in the statement and determine what is relevant.</td>
</tr>
<tr>
<td>4</td>
<td>Once a result is obtained, I check to see that it agrees with what I expected.</td>
</tr>
<tr>
<td>5</td>
<td>I try to relate unfamiliar problems with previous situations or problems solved.</td>
</tr>
<tr>
<td>6</td>
<td>I try to determine the form in which the answer or product will be expressed.</td>
</tr>
<tr>
<td>7</td>
<td>If I do not know exactly how to solve a problem, I immediately try to guess the answer.</td>
</tr>
<tr>
<td>8</td>
<td>I start solving problems without having to read all the details of the statement.</td>
</tr>
<tr>
<td>9</td>
<td>If a problem involves several calculations, I make those calculations separately and check the results after each individual calculations.</td>
</tr>
<tr>
<td>10</td>
<td>I do not check that the answer makes sense.</td>
</tr>
<tr>
<td>11</td>
<td>I clearly identify the goal of the problem (what I’m solving for or the concept to be defined) before attempting a solution.</td>
</tr>
<tr>
<td>12</td>
<td>I spend little time on problems I am not sure I can solve.</td>
</tr>
<tr>
<td>13</td>
<td>(**Verification Item) Please mark E for this option.</td>
</tr>
<tr>
<td>14</td>
<td>I consider what information needed might not be given in the statement of the problem.</td>
</tr>
<tr>
<td>15</td>
<td>I try to double-check everything: my understanding of the problem, calculations, units, etc.</td>
</tr>
<tr>
<td>16</td>
<td>I spend little time on problem for which I do not already have a set of solving rules or that I have not been taught before.</td>
</tr>
<tr>
<td>17</td>
<td>I use graphic organizers (diagrams, flow-charts, sketched pictures) to better understand problems.</td>
</tr>
<tr>
<td>18</td>
<td>I experience moments of insight or creativity while solving problems.</td>
</tr>
<tr>
<td>19</td>
<td>I jot down things I know that might help me solve a problem before attempting a solution.</td>
</tr>
<tr>
<td>20</td>
<td>When I solve problems, I skip thinking of concepts before attempting a solution.</td>
</tr>
<tr>
<td>21</td>
<td>Once I know how to solve a type of problem, I put no more time in understanding the concepts involved.</td>
</tr>
<tr>
<td>22</td>
<td>I find important relations among the quantities, factors, or concepts involved before trying a solution.</td>
</tr>
<tr>
<td>23</td>
<td>I make sure that my solution actually answers the question.</td>
</tr>
</tbody>
</table>
Metacognitive Activities Inventory, MCA-I (continued)

<table>
<thead>
<tr>
<th>Item</th>
<th>Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>I plan how to solve a problem before I actually start solving it (even if it is a brief mental plan).</td>
</tr>
<tr>
<td>25</td>
<td>I reflect upon things I know that are important to a problem.</td>
</tr>
<tr>
<td>26</td>
<td>I analyze the steps of my plan and the appropriateness of each step.</td>
</tr>
<tr>
<td>27</td>
<td>I attempt to break down the problem to find a good starting point.</td>
</tr>
<tr>
<td>28</td>
<td>When practicing, if a problem takes several attempts and I cannot get it right, I get someone to do it for me and I try to memorize the procedure.</td>
</tr>
</tbody>
</table>

The MCA-I is designed to be administered and analyzed quickly and easily at any time during an instructional cycle, to any size student population. Administration of the MCA-I usually takes about 15 minutes and has respondents select their choices based on their level of agreement with the statements. Each instrument item is based on a five-point Likert scale (1 for strongly disagree through 5 for strongly agree). The resulting score is a percentage of the maximum possible points attainable, where the higher the score, the more self-reported metacognitive the student (Cooper et al., 2008; Sandi-Urena, 2008).

To circumvent issues of robustness of a single instrument measure (particularly a self-report instrument) and ensure the strength of the MCA-I, this study also used IMMEX, a measure of actual metacognitive skillfulness. The across method and time assessment of metacognitive skillfulness in chemistry problem solving ensures the reliability and validity of reported results. The MCA-I is designed to measure the behaviors associated with metacognitive skillfulness, including planning, monitoring, and evaluating components of the regulation of cognition. IMMEX, on the other hand, records the actual strategies utilized by students while solving chemistry problems. Taken together, MCA-I and IMMEX represent what students report they do and what they actually do metacognitively during problem solving.
The metacognitive regulatory skills of planning, monitoring, and evaluating are assessed using themed questions. For the purpose of addressing the research questions of this study, planning refers to actions taken by the student *before* attempting to solve the problem. Such actions include determining the goal of the problem, identifying information relevant to the problem, and planning how to solve the problem. According to Schraw and Moshman (1995), planning involves selection of appropriate strategies, allocation of resources, goal setting, activating relevant background information and budgeting time. Schraw and Moshman (1995) go on to define monitoring as “self-testing skills necessary to control learning” (p. 4) and “on-line awareness of comprehension and task performance” (p. 4). The MCA-I items that assess monitoring relate to actions taken *during* problem solving. Several examples ask students about analyzing, relating, or applying knowledge to solve the problem. Other questions assessing monitoring behaviors relate to sorting, organizing, or mapping information. Evaluation, according to Schraw and Moshman (1995), includes behaviors relating to appraising the products and regulatory processes of one’s learning, such as re-evaluating goals and conclusions.

The MCA-I assesses the evaluation component of student metacognition through items which address checking results or determining whether the result or solution makes sense: actions taken *after* problem solving. Table 3.6 categorizes the manner in which the MCA-I items related to students’ planning, monitoring, or evaluation for the purposes of this study.
Table 3.6

*MCA-I Item Analysis for Metacognitive Skills of Planning, Monitoring, and Evaluation*

<table>
<thead>
<tr>
<th>MCA-I Items</th>
<th>Metacognitive Skill/Action Taken by Student</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 6, 7, 8, 11, 12, 14, 16, 24, 25, 26, 27</td>
<td><strong>Planning</strong>: Actions taken before problem solving. Includes goal setting, allocate resources, access background information and budget time.</td>
</tr>
<tr>
<td>2, 3, 5, 17, 18, 19, 20, 21, 22, 28</td>
<td><strong>Monitoring</strong>: Actions taken during problem solving. Includes self-testing and comprehension of task performance.</td>
</tr>
<tr>
<td>4, 9, 10, 15, 23</td>
<td><strong>Evaluation</strong>: Actions taken after problem solving. Includes appraising products and re-evaluating goals and conclusions.</td>
</tr>
</tbody>
</table>

**Interactive MultiMedia Exercises, IMMEX**

IMMEX is an internet software system that has been extensively used in K-16 classrooms (Underdahl, 2002) and described thoroughly (Stevens et al., 2005; Underdahl et al., 2001) with respect to identifying students’ problem-solving strategies and how students’ strategies change over time with repeated practice (Steven et al., 2004). IMMEX presents many real-life problems in a wide range of subject areas, each having multiple cases or clones, and each requiring new strategies for the final solution. This study uses the IMMEX problem Hazmat; therefore, all
references to IMMEX in this paper relate exclusively to the Hazmat problem. IMMEX presents students with a problem scenario via a prologue, which includes embedded information and resources from which students may frame the question/identify the problem and begin developing hypotheses. Figure 3.3 illustrates the Hazmat prolog.

![Figure 3.3. A Prolog Statement for Hazmat.](image)

Each IMMEX problem has a “problem space” that includes data variables structured as menu item and links of resources that can be selected in any sequence. The resources are provided in the problem space, which students may access in order to solve the problem, and include a library, stockroom inventory, and physical and chemical tests (Stevens et al., 2001). The resources for the Hazmat problem are provided in Appendix F.

As illustrated in Figure 4, the Hazmat prolog presents students with the scenario that an earthquake has hit the school and a chemical has spilled in the chemistry lab. The objective is to utilize the resources to collect information in order to determine the identity of the spilled
chemical. Upon completion of the decision-making process, the student submits the name of the chemical they believe to have spilled in the scenario. IMMEX immediately informs the student if he or she is correct or incorrect, and the program also provides a stepwise list of viewed items and time spent on each. The feedback screen, illustrated in Figure 3.4, provides students the opportunity to reflect on the decisions and strategies implemented and, ideally, encourages them to strive for improvement in future cases (Cox, 2006). It is also important to note that during the process of testing and decision-making, IMMEX utilizes a point system whereby students are allotted a certain amount of points in the beginning and have to “pay” to complete tests. The purpose of the costs to test is to encourage students to be more conscious of their choices and corresponding actions.

![Figure 3.4. Immediate Feedback for the Proposed Solution.](image-url)
In addition to the immediate feedback screen at the end of the solution process, an epilog, illustrated in Figure 3.5, summarizes the important aspects of the problem.

The purpose of the immediate feedback and epilog is to allow students to evaluate their decision-making processes and solution strategies, which is the final step of the problem solving process. In addition, the feedback and epilog provides students the opportunity to reflect on the strategies and, therefore, become more aware of their own thinking, which is a vital component of metacognition (Gredler, 2001).

The IMMEX software is able to capture the strategies used by each student and a characterization of the student’s metacognitive skillfulness may be inferred through strategy descriptors or (metacognitive) states (Cox, 2006; Stevens et al., 2005). The categories of IMMEX strategy descriptors or “states” utilized in this study included high, intermediate, and low, modeled after Sandi-Urena (2008). The student who is using IMMEX is not aware that this is
happening and is performing the problem-solving process without any directive supervision, which presumably creates a more comfortable and natural problem-solving setting. The automated nature of IMMEX also removes researcher bias (Sandi-Urena, 2008).

As students navigate through the problem space, an HTML tracking feature of IMMEX identifies the items selected, the order they are viewed, the number of times each item is viewed and reviewed, as well as the time the problem solver spends on each item (Cox, 2006). The summation of the decisions students made while solving the problem are accumulated in a strategic performance map, which is illustrated in Figure 3.6.

Figure 3.6. Strategic Performance Map.
Figure 3.7 illustrates the probability of students moving away from a particular state, called “probability of transition” (Sandi-Urena, 2008). According to Stevens et al., (2004) during initial performances, students use prolific strategies to explore most of the available information that is relevant in the problem space. However, after only one performance, students tend to change their problem-solving strategies and stabilize after about five performances, after which little or no variation occurs in problem-solving strategies.

Based on thousands of IMMEX cases solved by students using the chemistry Hazmat problem (Cox, 2006), the states that students settle in after about five cases enable the inference of metacognitive strategies. State 1 represents students who use little consideration of background information and who do not run any of the chemical tests believed by experts to be necessary to
solve the problem. Instead, State 1 students move to furnish an answer very quickly. This type of student has a 99 percent probability of remaining in this state without advancing to another state, even though the student received feedback on the inaccuracies of his or her responses. This strategy type, State 1, is considered the lowest metacognitive skillfulness because these students are weak in all of the areas related to regulation of cognition: planning, monitoring, and evaluating (Sandi-Urena, 2008).

On the opposite extreme is State 5, where strategy use is effective and efficient, with students consulting background information and using selectively few, yet relevant, items. State 5 students are 95 percent likely to remain in this state. Students who are not in States 1 or 5 vary in the approaches they use to solve the problem. State 2 students use background information and tests and are considered “intermediate” in metacognitive use. State 4 students use many tests with little consideration of background information and are also considered intermediate in metacognitive use. State 3 students use the problem space prolifically and are considered low in metacognitive skillfulness. Table 3.7 (Sandi-Urena, 2008) summarizes the metacognitive state descriptions (strategy descriptors) for the Hazmat problem set.

Table 3.7

<table>
<thead>
<tr>
<th>State</th>
<th>Description</th>
<th>Metacognitive Strategy Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Few items used; quick to propose a solution</td>
<td>Limited</td>
</tr>
<tr>
<td>2</td>
<td>Equal use of background information and test items</td>
<td>Intermediate</td>
</tr>
<tr>
<td>3</td>
<td>Prolific use of problem space</td>
<td>Limited</td>
</tr>
<tr>
<td>4</td>
<td>Little use of background information, yet many test items accessed</td>
<td>Intermediate</td>
</tr>
<tr>
<td>5</td>
<td>Effective and efficient use of relevant items</td>
<td>High</td>
</tr>
</tbody>
</table>
**Quantitative Data Collection**

Data collection was completed for students’ metacognition using a pre-MCA-I in August at the beginning of the school year and a post-MCA-I the following May. The MCA-I was mailed from the researcher to the teacher to give to students as a hard copy with an optical reader scantron response sheet provided to record the answers. Teachers administered the MCA-I using a very specific script of directions that were provided by the researcher. The researcher picked up the pre-MCA-I on the first observation visit. The criteria for acceptance of the MCA-I response sheets was modeled after the developers of this instrument (Cooper & Sandi-Urena, 2008). Any of the MCA-I response sheets that had the following characteristics were not used: verification question answered incorrectly, damaged scantrons, identification code unable to be matched, multiple responses to a single item, or bubbled beyond 28. The only data utilized was from students who had appropriately completed both the pre- and post-MCA-I. The teacher required students to perform at least five cases in May of the school year. IMMEX was not given at the beginning of the school year because metacognitive growth was not the focus. IMMEX was utilized in order to characterize the metacognitive conditions of students at the end of exposure to teacher practices.

**Quantitative Data Analysis**

Paired sample t-tests were used to determine whether students’ self-report of metacognitive abilities significantly changed between pre- and post-MCA-I scores. In order to characterize students’ actual metacognitive state at the end of the study, a distribution for IMMEX scores were categorized in terms of the three metacognitive strategy descriptors, limited, intermediate, or high as previously described in Table 3.7.
Qualitative Phase

Teacher practices may vary from classroom to classroom, despite similar certification, education, and standards that may characterize or guide each teacher. For this reason, the qualitative phase of this mixed-method study utilizes a multi-site case study to examine teacher practices.

A case study is an exploration of a case over an extended period of time through detailed, in-depth data collection involving multiple sources of information that is rich in context. Addressing the research questions through a multi-site case study as part of the qualitative aspect of the mixed-method design allows the researcher to enter the field without manipulating it, thus allowing the environment being observed to define itself continuously throughout the study. In case studies, the researcher explores programs, individuals, or processes in depth. The cases are bounded by time and activity, with researchers collecting data over a sustained period of time. A goal of this study was to explore, in an in-depth manner the teachers and the practices they utilized.

According to Freebody (2003), the purpose of using a case study is to gain insight with a thorough documentation of the setting in order to ultimately impact practice. Freebody (2003) stated the following regarding education-related case studies:

In education, Case Study has enjoyed considerable prominence as a research methodology for some decades. One reason for this is researchers’ frustration at the apparent lack of impact of more traditional forms of research on daily educational practice, and, conversely, educators’ frustration at the apparent ‘non-translatability’ of many research findings. (p. 81)
According to Creswell (2003) and LeCompte & Schensul (1999b), using a multi-site case study is a way to enhance the validity of the researcher’s conclusions, in addition to triangulating data to avoid bias and to ensure validity of inferences. Multiple means of data collection were used to enhance the researcher’s ability to represent each case and the corresponding comparative or differential inferences in an authentic manner.

The paradigm on which this qualitative aspect of the mixed-method study is framed and strengthened is the constructivist perspective, which proposes that reality is socially constructed through interactions with one another over time in a social setting. Ideas are not fixed, and can be altered through dialogue over time, and the alterations can lead to new understanding or ways of acting. Shared meanings as expressed in common language, symbols, and other communication, describe both the cognitive and affective nature of culture according to constructivists. Constructs are situated in contextual characteristics, such as culture and other shared meanings, and influence how individuals think, believe, and present themselves. Constructivist approaches are inherently participatory because meaning can only be created through interaction. This belief places emphasis on the researcher participating in the lives of the research participants in order to observe social dialogue and interaction, or the process of creating ideas and meaning as it occurs. Data and findings are created and recreated as the research proceeds. Constructivists do not necessarily begin with or expect to produce results that commit to action, yet they seek to develop or produce a sense of shared understanding of a particular problem, as well as a set of shared norms that lead to specific directions for action (LeCompte & Schensul, 1999b). The constructivist paradigm was consistent with the goals and dynamics of this study of teacher practices.
Qualitative Data Collection

The qualitative multi-site case examination component of this mixed-method study required the researcher to enter the field -- the classrooms in which the participating chemistry teachers taught. In order to provide rich, thick, in-depth descriptions of each case, the researcher used multiple sources of data collection, including classroom observations, interviews, questionnaires, and document analysis. Detailed documentation of classroom observations occurred by developing abbreviations and codes so that all interactions could be written down. A standardized form, Teacher Observation Protocol: Inquiry-based Science Instruction (Appendix G) was used for every teacher’s observation to provide a consistent and familiar template. Clemson education faculty used the observation protocol form in their field work. Interview questions (Appendix H) were designed to investigate teacher beliefs about teaching strategies and to determine what teacher practices were most utilized and preferred. The interview was semi-structured in order to target certain information about teacher practices, but every opportunity to allow the teacher to expand their views beyond the questions was encouraged. All conversations were viewed as informal “interviews” because the researcher would ask certain questions during discussions or record any comments the teacher made during the conversation that were significant to teacher practices. A questionnaire was developed (Appendix I) to elucidate beliefs about teaching strategies and determine what teacher practices were preferred. From each teacher, documents such as lesson plans, lab assignments, various assessments, graded work, textbooks, and teacher websites were collected in order to gain more insight regarding teachers’ practices, planned strategies, or expected emphases. The variety of data sources helped the researcher better understand teachers’ strategies of questioning, activities, and any other emergent practices that would provide students the opportunity to plan, monitor, and evaluate during the learning process.
Table 3.8 is a summary of the qualitative instruments used in this study with regards to purpose, target, procedure, and content.
Table 3.8

**Summary of Qualitative Data Collection Component of the Mixed-Method Study**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Purpose</th>
<th>Target</th>
<th>Procedures</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classroom</td>
<td>Record teacher practices as they happen by category</td>
<td>Activities, conversations, interactions, events and sequences of behaviors between teachers and students, relating to planning, monitoring and evaluation</td>
<td>Detailed, written field notes: Record of informal interviews and conversations Maps of classroom Time notation of sequences and structures</td>
<td>Physical setting Actual teaching strategies implemented, including types and frequency of activities, questioning and feedback Interaction patterns Emotions</td>
</tr>
<tr>
<td>observations</td>
<td>Questioning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Activities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Feedback</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>*Note any additional actions that are relevant to study</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interviews</td>
<td>In depth knowledge and beliefs relating to teaching chemistry</td>
<td>Chemistry teacher participants</td>
<td>In-depth, formal, semi-structured Open-ended questions Informal conversations</td>
<td>Beliefs about teaching strategies. Preferences of strategies to implement Beliefs about strengths and weaknesses of certain practices</td>
</tr>
<tr>
<td></td>
<td>Personal teaching history</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Personal description of practices</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Document Analysis</td>
<td>Elicitation of themes or content relating to teacher practices</td>
<td>Lesson plans Lab assignments Teacher Web-site Textbooks Graded student work</td>
<td>Repeated observation Analytic categories Themed coding</td>
<td>Representation of actual written planned strategies Actual written feedback Emphasis after instruction, factual recall or deep questioning</td>
</tr>
<tr>
<td>Questionnaire</td>
<td>Determine beliefs and perceptions of teaching strategies, experience, and teaching philosophy</td>
<td>Chemistry teacher participants</td>
<td>Self-administered at teachers’ convenience with quantifiable answers to close-ended questions</td>
<td>Patterns Behaviors Tendencies</td>
</tr>
</tbody>
</table>
Qualitative Data Analysis

Each teacher’s documents were analyzed completely before undertaking the next teacher’s analysis. Each case analyses resulted from sets of identifiers that described features of the data (LeCompte & Schensul, 1999a). This strategy allowed the researcher to capture the richness of ideas that emerged relating to teacher practices representing promising practices in promoting students’ metacognitive skillfulness, including planning, monitoring and evaluating their ideas.

Recognition of new ideas during document analysis, which engage the researcher in re-reading the data and applying new themes, is essential until a “fully developed and well-supported interpretation emerges” (LeCompte & Schensul, 1999b). Review of all forms of documentation and the attempt to corroborate themes with evidence from different sources is triangulation, which strengthens the inferences made from data analysis (LeCompte & Schensul, 1999a, 1999b). Before data analysis began, the qualitative component’s focus was reviewed. The qualitative instruments were used to obtain rich, thick information that would expose each participant-teachers’ practices with respect to strategies of questioning, activities, and feedback. Any opportunity the teacher provided the students to plan, monitor, or evaluate their own ideas through the use of these strategies was considered relevant and important.

Classroom observations were the first qualitative data analyzed. The field notes were transcribed verbatim into a word document. Then, the transcribed version was reviewed and compared to the field document three times to ensure accuracy in these data. The transcribed version was then read to elicit themes and occurrences relating to the teacher utilizing strategies, including questioning, activities, and feedback. Each teacher’s observation documentation was analyzed completely, before reviewing another teacher. This was done in order to focus and seek
a thorough understanding of each teacher. Once themes and occurrences were identified and coded appropriately, a tally of each was made.

Teacher interviews were analyzed after a familiarity with the teacher’s practices was determined from the observation field note analysis. The face-to-face interview documentation was a strong way to supplement information obtained from teacher observations. Notes from the semi-structured interviews were transcribed verbatim and thoroughly reviewed to identify themes or instances relating to teacher practices regarding questioning, activities, and feedback. Teacher questionnaires which supported the actual classroom observations and interviews were analyzed to provide additional information about teacher practices.

Figure 3.8 shows a complete summary of both quantitative and qualitative data collection and analysis and the connection to the research study question.
Figure 3.8. Summary of Quantitative Data Collection and Qualitative Narrative Interpretative Analysis.
**Validity**

Internal validity was addressed in this study by recording detailed, rich field notes over a sustained observation period of eight months and triangulating these data with information from interviews, questionnaire, as documents such as laboratory reports. The extent to which conclusions effectively represent reality is a concern of researchers due to the complex nature of analyzing human behavior (LeCompte & Schensul, 1999c). One concern relating to internal validity includes selecting and interviewing participants, whereby researchers may expect certain answers or outcomes due to a study’s search for differences. The actual time required to paint an accurate portrait of the setting may take a long time. Another concern relating to internal validity is the appropriateness between the research questions and the research design. Care must be taken to appropriately design a methodology that allows the researcher to collect appropriate data to thoroughly answer the questions. Threats to internal validity include observer effects, where participants withhold information or lie due to the answers they may think the researcher wants to hear. Another threat includes parts of the population or setting that may be omitted from the study; for example, if the researcher can only observe certain classes the teacher is teaching, or the setting may not being stable over time, whereby participants may leave the study.

External validity represents whether the results of a study hold true for other populations. Threats to external validity include the use of concepts, instruments, or methods that are inappropriate for the group under study (selection effects) and describing concepts, instruments, methods, or results in such a way that prevent the study’s application to another setting or group (construct effects). Another concern of external validity is failure to document a researcher-participant relationship that affects the setting or results. In this study, concerns of external validity were addressed by rich, clear descriptions of the setting and events. The researcher made
every effort to create comfortable and nonthreatening opportunities for interactions to occur. In this study, the researcher and participants interacted only through email or in the school setting.

To address the observer effect, a collegial relationship was developed between the researcher and participant. Upon each visit, the researcher entered the environment in a non-threatening manner so the normal flow and routine of the setting would not be disrupted. Before actually going into the field for the official observations, the researcher arranged to meet the participants in their classrooms to discuss how observations would occur and express desire for all routines and protocol to go on uninterrupted. During these initial visits, every attempt was made to let the participant know that the researcher viewed herself as a peer. If time permitted before official observations began, the participant and teacher would have informal discussions about teaching, pedagogy, students’ efforts to learn chemistry, and other mutual teacher issues. No jargon was ever utilized while communicating to project an intimidating tone. The researcher and teachers communicated frequently through emails to continue discussions. Overall, the researcher developed respectful and trusting relationships with the four teachers, and all fully participated throughout the duration of the study.

**Ethical Issues**

The researcher met personally with each participant before research began. During the informal conversation between the researcher and teacher, a description of the research protocol was provided and any questions or concerns were addressed. Before the meeting, all research protocol was outlined in an email. Consent forms were provided. All teachers discussed the research with their students, had both parents and students sign consent forms. All consent forms were returned to the researcher before the first observation. The teacher-participants seemed comfortable with the research process and
the researcher coming into the classroom to observe teacher practices. The participants were told they could withdraw at any time, but all participants continued from the beginning until the end, with an uninhibited willingness to allow the researcher into their classrooms. In addition, each participant provided all necessary supplementary documents such as sample student work, lesson plans, and access to their teaching websites.
CHAPTER FOUR

RESULTS

Overview

This chapter will discuss the quantitative and qualitative results of this study. The MCA-I was used to measure students’ perceptions of their metacognitive skillfulness. A statistical comparison of pre- and post-MCA-I results was conducted in order to determine if a significant change in self-perception occurred over the course of the study. In addition, the IMMEX instrument was used to characterize students’ actual metacognitive performance. Narratives will be provided to describe the learning environment and teacher practices associated with each case. Each narrative section will include:

- the teacher’s self-reported teaching philosophy and practices;
- a description of the community;
- a description of the school;
- a description of the teacher’s classroom;
- an analysis of the teacher’s lesson plans;
- the context of the class before the witnessed lesson;
- observations from the witnessed lesson;
- the context of the class after the witnessed lesson; and
- an interpretive summary.
The interpretive summaries will elucidate what, if any, teacher practices explain students’ metacognitive skillfulness. After describing all four cases, a cumulative across-cases synopsis of emergent teacher practices will follow.
Laura – The Passionate Newcomer to Chemistry Teaching

Laura is a 25-year-old, energetic female with a bachelor’s degree in chemistry and a master’s of arts degree in teaching secondary education. She has two years of teaching experience, both of which were at Lasso High School.

Self-Reported Teaching Philosophy and Practices. Laura stated that she remembers interactions with excellent teachers who piqued her intellectual curiosity. She enjoyed one such professor’s chemistry demonstrations so much that she incorporates a “demo-day” each week into her classes at Lasso. She described other, relatively ineffective teachers from her past as “dull, lifeless, and difficult to relate to” who also inspire her. As a result of her experiences with a chemistry teacher who did not adequately prepare her, Laura vowed “that [her] students would be taught as much as possible before they left [her] class.” To that end, Laura established a chemistry II class at Lasso High because she felt the students needed “to go even deeper into the concepts” than time allowed in just one chemistry course.

Laura’s teaching philosophy centered on her view of chemistry as a “central science that integrates history, math, literacy, and foreign language.” Teaching chemistry excited Laura, who enjoys the challenges of explaining difficult topics such as nuclear chemistry and gas behavior, and the pleasure of watching students who get “that spark in their eyes” upon understanding the material. Laura considered chemistry naturally appealing to students because it allows them to work with chemicals, fire, and sometimes (controlled) explosions while learning.
Laura stated that she assigns pre-laboratory questions which she discusses with her students prior to experiments. Further, she pointed out that she models the problem-solving process and involves students by asking probing questions. Specifically, Laura indicated that she encourages students to first read a problem thoroughly in order to understand it and identify its goal. Then, Laura stated that she asks students guiding questions to help them identify important information and decide on appropriate problem-solving strategies.

Laura stated that she views lab activities as prime opportunities to teach students because of the cognitive and procedural planning inherent therein. She indicated that she helps students plan for each lab by promoting discussion related to the particular experiment and requiring students to develop hypotheses for each lab by relating the classroom concept to the lab activity. In addition to providing students these opportunities to plan, Laura pointed out that she also employs strategies that enable students to monitor while learning.

Laura stated that she assists students in monitoring their understanding of concepts, chosen strategies, and progress by circulating around the lab and asking questions to help students reconcile their ideas with their observations. For example, Laura said that she may ask, “Is the data you’re getting what you expected?” In addition, Laura pointed out that her students record data, reflect on findings to answer post-lab questions, and write lab reports using a rubric designed to steer them through the reflective process.
In efforts to encourage monitoring while problem solving, Laura indicated that she integrates multiple concepts in problems and varies the wording therein to provide unfamiliar types of problems related to concepts. During the process of problem solving, Laura pointed out that she stresses the importance of taking adequate time to thoroughly read and understand the problem before choosing appropriate solution strategies. Laura also stated that she requires students to show all work when solving problems by writing the step-wise details as they progress. Further, she indicated that she encourages students to evaluate the reasonability of their results.

**Lasso community.** Lasso is a rural community in the upstate of South Carolina that has evolved around textile mills. The locals and their offspring clocked in and out of the windowless walls of the mills for generations, forming a reciprocal dependency. The community provided a skilled workforce, and the mills provided employment. Although the security of predictable employment in the textile and manufacturing economy is in decline, Lasso’s local Chamber of Commerce describes the new economy as one grounded in “a large national retail chain, corporate bank headquarters and ‘mom-and-pop’ operations that have been sustained for generations.” The endurance of local businesses like Thomas Tires, Jane’s Flower Shop, and Lasso Furniture illustrates the loyalty and pride the community has for its members.

This proud community celebrates the annual “Squealin’ on the Square” barbeque cook-off and Christmas Parade, in addition to several seasonal events, such as the Farmer’s Market on the Square and the Lasso School District Arts Day. During the school year, athletic events at Lasso High School are a main attraction. The community’s
support for Lasso High is immense because it is the only high school serving the community. Lasso High is as central to the community as the mills once were. Lasso High’s mission statement illustrates its connection to the people in the area.

**Nature of Lasso High School.** Lasso’s school mission simply, but effectively, articulates that its goal to “develop productive citizens” for society. This occurs in the school’s safe environment, through an academic and work-based curriculum that prepares students to work in the local community or pursue higher education.

Lasso’s rich academic curriculum is complemented by broad extracurricular offerings, providing the student population of roughly 1,500 with an array of club organizations and sports teams from which to choose. The school website and building bulletin boards announce events, such as SAT prep courses, Beta and International Club meetings, the Homework Center hours; and a Chorus Concert. One common theme promoted in all organizations is community service, illustrating Lasso’s caring spirit. Lasso’s school facilities are immaculately clean, technologically updated, and neatly painted in school colors. The 30-year old school building is structurally organized with subject area “pods” surrounding a central cafeteria, whereby students move down different hallways to subject-specific classrooms.

As part of an overall rich curriculum, a variety of science courses were offered, including college prep, honors, and advanced levels in biology, chemistry, and physics. Special science opportunities included an annual science fair, a science club, and various forensics activities. Consistent with the school’s climate that seemed to promote student achievement, the science department’s classrooms were well stocked and organized.
Science posters, science instrumentation, and student work filled the walls, and students appeared to be engaged as I looked into the classrooms. While on campus, I had lunch with several Lasso science faculty members and witnessed lively, collaborative discussions filled with shared ideas about teaching. They seemed genuinely concerned with student learning.

**Laura’s classroom.** As I walked down the blank, cinderblock hallway leading to Laura’s classroom, I began to smile as colorful student posters about molecular geometry and chemical bonding welcomed me into a classroom where learning seemed to be about *experiencing* chemistry. Although the classroom was clean and well-organized, faint chemical odors lingered from recent labs, indicative of students engaging in chemistry.

The classroom inspired the chemistry senses – it smelled, looked, and felt like chemistry, creating a climate conducive for learning. The teaching area had nine rows of desks arranged in a horseshoe shape around the teacher’s podium which allowed Laura to easily engage with students. Her podium was equipped with a computer linked to a projector that allowed students to view PowerPoint presentations and other media on a 3’ x 5’ screen during instruction. The classroom setup enabled a transition from instruction to lab activities with only a few steps.

The lab area was adequately equipped with eight pedestals, each of which had a sink, a gas outlet, and several drawers of labware. Chemicals and glassware were stored conveniently in an adjacent prep room. Before each lab, the necessary materials were placed on a cart and moved in and out of the prep room for easy access during class and a safe, secure return at the end of lab.
Analysis of Laura’s lesson plans. Lasso High’s administration required teachers to use a standard weekly lesson plan template that identified each day’s lesson objectives; South Carolina standards; and the procedures, assessments, and modalities. Objectives were stated briefly as tasks to accomplish and state chemistry standards were cited numerically. Figure 4.1 illustrates a representative example of Laura’s lesson plans.
Figure 4.1. Laura’s Sample Lesson Plan. Shows brevity of planning in (a) objectives, (b) state standards, (c) procedures, (d) assessment and (e) rate/modalities.

The overly-simple template does not encourage thoughtful lesson planning. The task-like objectives were not stated as cognitive outcomes, and the one-word procedures did not detail how chosen activities would be used to elicit learning. Assessments identified the instrument to measure student learning, but did not describe how cognitive outcomes would be known. The state chemistry standards were numbered and the objectives were written with words or phrases such as “discuss polarity,” “determine shapes,” “quiz,” or “review.” They were presented as a list of tasks to accomplish rather than cognitive outcomes to achieve. Procedure choices included “lecture,” “lab,” “group work,” “worksheet/practice,” “reflection,” and “journal.” Assessment options were also checked and included abbreviated choices such as “TO” (teacher observations), “quiz,”
“test,” “project,” and “WO” (work out problems). Finally, the plan template required teachers to select the modalities related to the lesson, including tactile, visual, auditory, and kinesthetic. Lasso’s administration did not require an elaboration on objectives, standards, procedures, assessments and modalities. Therefore, Laura’s degree of critical thought devoted to the planning process is uncertain.

Laura’s observed lesson. Laura’s rapport with her students was evident in their mutual early morning greetings. Her students respected her routines and daily expectations. Laura’s lessons began promptly; most of the students were seated, settled, and had placed necessary materials on their desk before the tardy bell rang. Laura began the observed class by describing the previous day’s lab and writing the corresponding chemical equation on the board:

\[ 2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO} \]

Rather than asking her students to reflect on the chemical makeup of their product, Laura said, “Yesterday, you made MgO. You made an ionic compound. Today, we will continue to explore compounds by describing chemical bonding.” I anticipated that Laura would use an introductory method of asking concept-specific review questions, to encourage all students to connect previous knowledge with the current lesson, perhaps by requiring them to provide written responses.

Laura’s previous lesson had related to writing chemical formulas for ionic compounds, so I anticipated that she would ask probing questions that use this concept to segue to the upcoming lesson on molecular compounds. Possible questions that would have required critical reflection on previous knowledge include the following:

- What do the chemical formulas you wrote for homework really represent?
• Why do atoms combine in a variety of ways to form compounds?
• What evidence do you have to support the type of compound you prepared?

Instead, Laura asked relatively mundane questions and only a couple of her students engaged in the conversation, as demonstrated by the following dialogue:

Jody: Could you explain how to write chemical formulas again for ionic compounds?
Laura: (Wrote Cu⁺F⁻ on the board.) Is this a binary compound?
Jody: Yes
Laura: Is Cu a transition metal?
Sam: Yes
Laura: You “criss-cross” the charges.
(Laura finished the process of criss-crossing the charge).
Sam: How do you know the charges?
Laura: Don’t guess, look it up. (Telling students to refer to a reference sheet that listed ions and corresponding charges.)
Laura: Criss-cross the charges.
(Laura wrote a second example on the board, Sn²⁺PO₄³⁻, then finished the criss-crossing process, Sn₃(PO₄)₂.)
Jody: (Referring to the example) Where does the charge go?

Laura did not ask probing, guiding questions that would have required students to think deeply about the involved concepts. Instead, she simply helped them develop a method through which they could get the correct answers to their problems.
Laura proceeded to administer the daily quiz, which she viewed as necessary to force students to prepare for to active engagement in class. Following the quiz, approximately 25 minutes into the 90-minute lesson, Laura described the upcoming lesson’s objectives, which sounded more like tasks than conceptual learning goals.

Laura introduced the “goals” of the lesson by stating what and how students would cover the concepts associated with their lesson which was a follow-up to a PowerPoint presentation that distinguished ionic, covalent, and metallic chemical bonding.

Laura: Today you will describe three types of chemical bonding - metallic, ionic, and covalent. You will be “peer teaching”. You read, write, and tell. Find as much information as possible about chemical bonding in the textbook. Use the text as reference to write down the characteristics of ionic, covalent, and metallic bonding. Use peer collaboration to generate a green flash card for bonding, which you can continue to use as a study tool. Paraphrase, shorten it, and write in your own words. It is easier to talk about when you put it in your own words. Separate into groups of three and start the “peer teaching” activity.

Invitations for students to mentally engage and plan were negated in light of the prescriptive directions and the realization that the textbook was the sole resource. Laura did not encourage her students to reflect on their previous knowledge. An alternate method Laura could have used would have required students to work individually, without resources, to list all characteristics of each type of chemical bonding in a column
called “what I know now.” A second column could have been “what I learned during the activity,” and a third column “what is similar and different.” This approach would have required all students to reflect on previous material and monitor learning during and after the activity. Instead, Laura’s students moved into groups and began the activity without having critically evaluated their knowledge.

When students began the activity, Laura removed herself to her nearby desk to work on other tasks. Laura’s student groups actively shared content just as Laura had intended for roughly five minutes. However, after that point, roughly three of five groups seemed to stammer to simply recite book definitions. Within 15 instructional minutes, most groups communicated rather listlessly as they sought answers in order to complete their assigned tasks. The following dialogue illustrates the enthusiastic beginning, sputtering monotonous recitation phase, and fizzling enervated ending. Students did not seem to deeply monitor their conceptual understanding during the peer teaching activity, but rather appeared to focus on the extent to which the tasks had been completed. Without sustained teacher guidance, Laura’s students floundered as the following dialogue indicates:

Group 1 (G1)/Patesha: Sea of electrons in metallic bonding!
G1/Sally: (Immediately as Patesha’s comment ended) Shared electrons in covalent bonding!
G1/John: Electron transfer in ionic bonding.
G1/Patesha: (With enthusiasm) Metals lose electrons and nonmetals gain.
Group 2 (G2)/James: Protons do not equal electrons so we get a charged ion.

G2/Beth: I’ve got metals tend to be positively charged and nonmetals tend to be negatively charged.

Students’ up-tempo responses soon slowed to a mundane recitation from the textbook, while others answered the questions alone. Students did not seem to search for connections or contradictions to previous knowledge; they just searched for answers in the textbook. The following conversations exemplify the dwindling effort and lack of monitoring among group members:

Group 3 (G3)/Brandon: I know how to read it, I just don’t know how to put it into words.

G3/Bill: (In a whisper) Ionic bonds are electrically neutral, joined by transferring electrons.

G3/Megan: (Recited finding from the textbook) Put in parentheses, high melting point, boiling point, attraction of cation for delocalized electrons; good conductors, malleable.

Group 4 (G4)/Bev: (Reading from the textbook) Groups of electrically neutral, joined by transferring electrons.

G4/Adam: Valence electrons in metals form a sea of electrons.

After 30 minutes without interacting with the class, Laura said, “You should have different examples for each type of bonding, at least three. Wrap up and y’all (sic) did a great job staying on task; although I was not looking for copying session but a telling,
teaching to each other. When you explain to each other, you learn more from teaching than just reading. You should quiz yourself, compare and contrast types of bonding.”

If Laura had continuously moved around during the activity, she could have helped students’ monitor their comprehension by asking them probing, strategic questions that would require them to reveal their level of understanding. Her students did not seem to critically monitor knowledge, but instead, appeared to find answers directly from their textbook and monitor their progress by the extent to which they had completed the activity’s tasks. At the end of the session, Laura passed out a worksheet requiring students to define terms related to ionic bonding.

**Context after Laura’s classroom lesson.** Laura followed the witnessed lesson with a “hard water and soft water” lab to illustrate a real world application of chemical bonding chosen because many of her students’ homes utilized well water which is often associated with “hard water.” This lab experiment culminated a repertoire of lessons that provided multiple representations of concepts that cumulatively defined chemical bonding.

**Context before Laura’s lab lesson.** Before introducing the aspirin synthesis lab, Laura used a PowerPoint presentation to cover the key terms and concepts related to stoichiometry including theoretical and percent yield calculations using balanced chemical equations. The aspirin synthesis lab provided students with a valuable opportunity to clarify their understanding of these concepts. After reviewing her documents related to the lab and observing Laura teach several classroom lessons, I was looking forward to observing Laura’s level of interaction with her students. I was
particularly interested in the extent to which she guided them through the experiment’s procedural and conceptual components. I hoped that she would encourage students to reflect on their previous knowledge, monitor process and progress, and evaluate the reasonability of their results.

**Laura’s lab lesson.** Laura promptly began the lesson by describing how students would collect the aspirin they had produced during the previous class period. Laura did not ask students questions that required them to reflect on the process of synthesizing their product and started the session by stating the following:

Laura: Filter paper is on the desk. If it doesn’t fit, use the scissors to cut it to fit. You need to cut it not fold it. Weigh the paper after you cut it. Weigh the watch glass and paper together with stuff on it. If I don’t weigh the paper before, how would I know the mass [of what is on it]? Particles may pass through [the filter paper], so be careful. Start at number eleven [Referring to the lab procedure sheet that students followed during lab].

Her prescriptive teaching style caused students to miss opportunities to engage in planning. If she had asked strategic questions, her students could have been better able to relate the previous day’s lab experiences to current lesson’s filtration. For example, Laura could have asked questions such as the following:

- What did you do in lab yesterday and why did you do it?
- What is the appropriate next step today?
- How will you effectively collect laboratory data today?
- What actions taken today provide the data necessary to determine percent yield?
Instead of encouraging students to devise a suitable strategy for isolating their products using appropriate equipment, Laura organized students into groups of four and told them to move to the lab area and begin at number eleven on their prescriptive lab procedure sheet.

Laura moved in and out of the prep room beside the lab area, but she did not circulate among the students. Four of the five groups seemed uncertain about what to do and, instead of discussing a strategic plan of action, fumbled aimlessly for roughly five minutes and seemed to wait for someone in the group to take charge. Although the following dialogue represents one group’s lack of strategic planning, four of the five groups shared this type of beginning:

James: Do any of y’all (sic) know what to do?
Amanda: Don’t have a clue.
Todd: I think you hook the hose up to something. (Starts to try to assemble the tubing to the funnel and the fellow group members giggle as he struggles to figure out how hook the tubes up.)
Adam: What do we do once it is hooked up?
James: (Looks around the room to see what other groups are doing.) They turned on their faucet.

Laura did not engage with students during lab and missed opportunities to ask guiding questions that would have compelled students to relate lab experiences to concepts they had discussed in class. Most of the groups struggled to complete the lab, and did not seem to track their own comprehension of the underlying concepts on which the lab was
intended. One group proceeded, coherently led by Jack, who took charge while his group members passively looked on. The confused groups sent members over to ask Jack what to do. The students walked over and watched Jack, then gleefully returned to their own stations to mimic what he had done. None of the students in the class appeared to critically reflect on previous knowledge and its relevance to the actions taken in lab. Monitoring the conceptual underpinning of process and progress appeared to be replaced by accomplishing the tasks outlined on the lab procedure sheet. The following students’ dialogue was typical of four out of five groups and illustrates an uncertainty of underlying concepts and a focus on the relatively mindless completion of tasks.

When Tom returned to his group, he looked at the filtration set-up Sarah had assembled and turned on the water. Almost immediately, the group noticed the flask filling up with a cloudy white solution. The following conversation illustrates one group’s dialogue at this point:

Dan: Oh, look it’s working.
Sarah: Yes, look it’s got a bunch of white stuff in it.
Cathy: When do we know when to stop?
Tom: Turn off the faucet when water is not in the funnel.

It was apparent that the students did not understand the goal of trapping the solid on the filter paper. If this group had comprehended the concept and were monitoring the accuracy of their performance, they would have immediately stopped filtering upon noticing “the white stuff” in the flask. They would have recognized that an error had occurred and that they were losing some of their product in the filtration process. They
would have understood that this problem would decrease their actual and percent yields of aspirin. Unfortunately, their level of monitoring the filtration process simply entailed watching for the funnel to be void of water.

After about 25 minutes of leaving the students unguided, Laura appeared from the prep room and announced, “Leave your funnel set up where it is. We need for the aspirin to dry before we weigh it. Clean up before you leave your lab station.” Students cleaned the lab area and stuffed the lab sheets into their notebooks.

The lab ended without students critically assessing their results as related to the original goal. Laura may have planned to have students evaluate their results during the next class period when they used their data to calculate percent yield of the aspirin, but it was apparent from students’ uncertainty that guiding questions and strategic feedback would have benefited them as they collected their synthesized product.

**Context after Laura’s lab lesson.** Laura’s students were required to write a laboratory report following their aspirin synthesis. She said her typical procedures do not include oral presentations where students share their findings with peers. However, she indicated that she does provide students the opportunity to ask her questions and get clarification on concepts before writing the lab report.

**Interpretive Summary.** The results of the MCA-I assessment instrument indicated that neither of Laura’s classes changed their self-perception regarding metacognitive skillfulness at the p=0.05 level during the course of the study. As shown in Table 4.1, this was true for both her honors and chemistry II levels.
Table 4.1

*Summary of Laura’s Students’ Pre- and Post-MCA-I Results*

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Pre MCA-I Mean</th>
<th>Post MCA-I Mean</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honors</td>
<td>19</td>
<td>68.16</td>
<td>70.68</td>
<td>.08</td>
</tr>
<tr>
<td>Chemistry II</td>
<td>22</td>
<td>67.70</td>
<td>66.89</td>
<td>.62</td>
</tr>
</tbody>
</table>

Further, Table 4.2 and Figure 4.2 illustrate that Laura’s students in both levels were predominantly identified as intermediate according to the IMMEX instrument.

Table 4.2

*Summary of Laura’s Students’ IMMEX Results Shown by Level*

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Low</th>
<th>Intermediate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honors</td>
<td>5</td>
<td>26.3</td>
<td>73.7</td>
<td>0.0</td>
</tr>
<tr>
<td>Chemistry II</td>
<td>19</td>
<td>10.5</td>
<td>84.2</td>
<td>5.3</td>
</tr>
</tbody>
</table>
Figure 4.2. Comparison of Laura’s Students’ IMMEX Results Shown by Level.

As a result of observing Laura’s interactions with students and the documents related to her teaching philosophy and lesson planning, the following potentially problematic teacher-practice themes emerged:

- an emphasis on mathematical algorithms at expense of adequate coverage of important chemistry concepts;
- an abundant use of step-wise, prescriptive, rote verification experiments rather than activities that may have cognitively involved students to a greater degree;
- an inadequate use of proactive, probing questions during instruction; and
- an absence of detailed and sophisticated instructional planning.

Limitations on Laura’s students’ metacognitive skill development likely began with her brevity in lesson planning. She failed to embed strategic questions which would have encouraged students to confront, justify, and explain their conceptions. Her teaching
routine appeared to seldom challenge students to cognitively engage in the learning process and make connections between prior knowledge and current conceptual lessons. Her teaching methods seemed to involve students in a passive routine with a focus on task accomplishment. Laura’s questions did not probe students’ understanding and did not assist students in revealing their perceptions. During lessons about chemistry concepts that involved mathematics, Laura told students how the math underpinned the chemistry, but students seemed satisfied with successfully determining answers even though they lacked a thorough understanding of the related chemistry concepts.

While Laura used an abundant number of labs to support classroom instruction, they were primarily rote verification experiments that provided little interactive guidance. This approach did not encourage students to reflect deeply on connecting classroom concepts with the corresponding experiments. Perhaps as a result, her students seemed unable to unify daily lesson objectives with supporting lab experiences.

Laura’s genuine interest in teaching chemistry was evident throughout the research process. Her philosophy that students should become confident and independent may have influenced her decision to allow them to accomplish activities relatively unguided. Unfortunately, her lack of guidance seemed to cause students to miss valuable opportunities to relate prior knowledge to new situations and assess their understanding. Further, her teaching practices might explain why none of her classes of students self-reported higher metacognitive skillfulness at the p=0.05 level and why only 0.0% of her honors students and 5.3% of her chemistry II students demonstrated high metacognitive
skillfulness at the end of her course.
Dr. Wise – The Veteran of Chemistry Teaching

Dr. Wise has bachelor’s degree in chemistry, a master’s of science and Ph.D. in nutrition. He has 37-years of teaching experience, the last two of which are at Hawk High School, where he is the school’s most highly educated and experienced teacher. Wise holds National Board Certification in teaching science, and has been a career-long member of all relevant professional teaching organizations. He has been named “Teacher of the Year” over 10 times during his career and has received over $20,000 in grants.

**Self-Reported Teaching Philosophy and Practices.** Dr. Wise stated that he begins his teaching days early and ends them late because he strives to really make a difference in students’ lives. Dr. Wise pointed out that he wants his students to beyond learning chemistry and take a deep approach to learning. He asserted that he wants each lesson to help his students maneuver the complexities of learning chemistry.

On his website, Dr. Wise explained his desire to teach life skills using math and science as his tool, stating that he uses “math and science to teach things like respect for others, organizational skills, how to think and apply what is learned in different situations, and finally, belief in one’s self and ability to learn chemistry.” Dr. Wise went on to acknowledge the importance of students taking responsibility for their learning through the following statement:

The truth is that the student decides on the grade they wish to receive. They know what is required to earn that grade and study accordingly. I provide the opportunity for them to demonstrate their effort and report that effort as a grade.
Dr. Wise described a parent conference he once held in the school’s auditorium. Since many parents had expressed concerns regarding his stringent teaching demands, he brought the group together to share with them his goal of bringing out students’ individual best performance through the high, but fair expectations he refuses to lower. He indicated that he pointed out that he has faith in his students’ abilities even when they lack self-confidence. Dr. Wise told the parents that his teaching methods and the nature of chemistry require students “to think at a deeper level, to draw pictures and not just memorize, but to master these concepts.”

Dr. Wise indicated that he believes it is important to provide opportunities for students to demonstrate their understanding of chemistry concepts through classroom discussions, homework assignments, and lab experiences. He said, “To understand and master the material requires a lot of practice which we call homework.” For his Honors chemistry classes, he lets students know that they will do “several thousand homework problems.” Dr. Wise reported that homework and laboratory experiences are central to his teaching methods.

In his syllabi, Dr. Wise explains that students will “mix a lot of chemicals and work with some exciting reactions,” referring to the conservative prediction of at least 25 labs he uses each school year. He impresses upon his students that it is important to “understand why the reactions occur to better understand what is happening.” Dr. Wise indicated that his students complete homework and participate in pre-laboratory discussions in order to prepare for their labs. He pointed out that he helps them monitor and evaluate their knowledge by asking them probing questions during experiments.
Further, he indicated that he requires written lab reports to help students evaluate their understanding of the related chemistry concepts. He stated that he assigns two projects to encourage students to “do science” as scientists where they establish a problem, research the literature, make hypotheses, design experiments, collect and analyze data, and use their evidence to draw conclusions. Further, he pointed out that he requires students to present their findings to peers or enter their projects in a science fair.

**Hawk community.** My initial experience in Hawk community was a decade ago when I interviewed for a chemistry teaching position which I held from 1998-2000. During my first visit to Hawk High, Joe, the principal and a long-time resident of the Hawk community in upstate South Carolina, reflected fondly on his beloved community. If Joe’s descriptions were an oil painting, long strokes of rich green paint would show beautiful flowing hills of pastures, dotted with black and white dots as livestock. Joe would not leave out the sweaty workers in their straw hats, toiling in the fields, some on tractors and some on foot. Red would color the barns with yellow hay spilling out of the second floor door. The prideful, picturesque reflections Joe had of Hawk community soon turned gray as he hinted that the younger generation who inherited the land had “sold out” to developers who were anxious to put subdivisions in the place where cows once roamed. Joe seemed frustrated that the ancestors’ “back-breaking” hard work on the farmland seemed to have been forgotten by the heirs in their quest for quick monetary gains.

Real-estate developments had altered the picture of Hawk, which is now a bedroom community with an economy centered on residents who commute about 25
minutes to a nearby city for work. The long green strokes now paint holes on the golf course, with lines of dots to denote the houses in subdivisions. Red paints the new stop lights necessary to handle the traffic, and yellow outlines the new wider highway lanes. Turning at Hawk School Road, you will find trailer homes in one direction and expansive homes in the other. Regardless of the type of home in which Hawk members reside or whether they are from generations of locals or transplants from the city, they seem to share a cohesive spirit and enthusiasm for Hawk High. In this scenic community, all of the curvy country roads seem to lead to Hawk High.

**Nature of Hawk High School.** Hawk High is centrally situated in the community of Hawk, on Hawk School Road, and next to Hawk Middle and Hawk Elementary schools. Like the growing bedroom community, the Hawk High student body has expanded in size. Portable classrooms are now required to supplement the school’s instructional space. Incoming freshman, however, are able to enjoy a new wing in the Hawk High’s original building. When classes are out, the 1,642 students seem like ants, lining the entrance walkway, and swelling out of the commons area that is surrounded by an auditorium, gym, and cafeteria. Two academic hallways extend from the commons area and are separated by a small library and computer room that the entire student body shares.

Despite the discomfort of limited space and an out-dated facility, Hawk is one of the top high schools in the state, honored as “Palmetto’s Finest.” The prestigious award was earned through the school’s exemplary efforts in student achievement, faculty training, program goals, teaching quality, office practices, and community involvement.
The faculty, 64 percent of whom hold advanced degrees, have a warm family-like rapport with their students. Hawk High offers a wide range of extracurricular activities, including athletic teams and nearly 20 clubs, including the Navy ROTC, Beta Club, and Drama Club. One club that has special meaning and touches the entire community is Students Against Destructive Decisions (SADD). During the past decade, Hawk High has lost an unusually high number of students to traffic accidents. As a former teacher at Hawk High, I have witnessed first-hand how the Hawk community unites in the face of such crises. The people in this community have an infectious, passion for Hawk High.

**Dr. Wise’s classroom.** I knew exactly where to go the first time I observed Dr. Wise because a decade earlier I taught chemistry at Hawk High in the classroom next door. Dr. Wise’s room was one of three science classrooms that surrounded a common teacher work area. Upon walking in, I saw that a sea of desks filled the space between the lab counters that lined both sides of the room. I was amazed by the boxes of supplies and materials that covered the countertops on all surfaces except for the lab spaces where students worked. The classroom was no longer the dank room I remembered; now it was a pleasant space that touched every chemistry sensation. Chemical odors filled the air, balances, burettes, and beakers blanketed work stations, and molecular models colored the ceiling. Just like college labs, chemicals and other common supplies were located on a “side shelf” at an accessible location for all students near Dr. Wise’s desks. The classroom had certainly transformed during Dr. Wise’s tenure.

Dr. Wise’s area of the classroom included his personal and instructor desks, which stretched across the front of the classroom and faced four rows with nine desks...
deep. A mountain of books and papers covered both desks, but were not high enough to hide the SMART Board that was connected to his computer. He used the electronic presentation board for incorporating PowerPoint presentations, Internet resources and animations into his classes. Despite the clutter, Dr. Wise seemed familiar with the classroom which seemed almost like his cocoon. Next to his chair, a large aquarium hummed and added comfort and a bit of peace to bustling school days.

**Analysis of lesson plans.** Reviewing Dr. Wise’s lesson plans was convenient because Hawk High administration encourages teachers to make lesson plans and other teacher resources available for students and parents on the school’s website. Figure 12 is a representative sample of Dr. Wise’s lesson plan format for all of his classes.

---

**Lesson Plans For January**

_Honor’s Chemistry_

_Chapters to UnCover:_

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Chapter 14 Mixtures and Solutions</td>
</tr>
<tr>
<td></td>
<td>Chapter 18 Acids and Bases</td>
</tr>
</tbody>
</table>

_Labs To Be Experienced Hands On:_

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
<td>14. Verifying Graham’s Law - The Velocity Of Gases</td>
</tr>
<tr>
<td></td>
<td>15. Verifying Boyle’s Law - PV = Constant with the CBL</td>
</tr>
<tr>
<td></td>
<td>16. Verifying Charles Law ( \frac{V}{T} ) = Constant - Finding Absolute Zero</td>
</tr>
<tr>
<td></td>
<td>17. Finding Solubility of Lead (II) Iodide – <strong>if time permits</strong></td>
</tr>
<tr>
<td></td>
<td>18. Standardization of Stock 1.0 M Sodium Hydroxide Solution</td>
</tr>
<tr>
<td></td>
<td>19. Standardization of Stock 1.0 M Hydrochloric Acid Solution</td>
</tr>
</tbody>
</table>

---

*Figure 4.3.* Dr. Wise’s Sample Lesson Plan. Shows brevity of planning in (a) chapter numbers and titles and (b) accompanying labs.
Dr. Wise’s lesson plans were essentially a list of textbook chapters, chemistry topics, and corresponding labs. Student-oriented, learning-based, and explicit and assessable statements of intended cognitive outcomes were absent from them. Dr. Wise seemed to rely on his vast years of experience to inform his practice, but his absence of contemporary teaching practices may have limited his students’ ability to fully master metacognitive skills.

**Context before Dr. Wise’s witnessed lab lesson.** Dr. Wise had given students a handout at the end of the previous class to be completed as homework, most likely to help them prepare for lab. It provided a mathematical chemistry concept guide and practice calculations similar to those involved in the lab activity, a standardization experiment that involved an acid-base titration. Students were to use stoichiometric coefficients, representations of the number of moles of each species in balanced chemical equations, to establish quantitative relationships. Further, they were to set up mole ratios and use these in the determination of unknown concentrations (in units of Molarity, moles solute/liter of solution) from volumes of solutions reacting in a titration.

The homework handout included the procedure for the upcoming lab. It called for students to prepare an aqueous solution of sodium hydroxide (base) and standardize it using potassium acid phthalate (HPAP) in triplicate titration trials using phenolphthalein, an indicator that turns pink in the presence of excess base.

**Dr. Wise’s witnessed lab lesson.** Students meandered into the crowded chemistry classroom. Students bumped into each other as they attempted to settle into their desks while situting their book bags. When class was scheduled to begin, Dr. Wise was at the
front of the class, but only about one-fourth of his 20 students had taken out appropriate materials. The others lethargically sat with empty desktops.

Dr. Wise began the lesson by referring to the homework handout. A few students eagerly pulled their papers from their book bags, but most still seemed relatively disinterested. Even though it was clear that very few students had completed their homework, Dr. Wise’s patient efforts to use the assignment to familiarize his students with the lab concepts persisted, as illustrated in the following dialogue:

Dr. Wise: (To the class) What is molarity?

Ann: (Sarcastically under her breath, but audible) Who knows?

Larry: Mass

Dr. Wise: No; (Then, moved to the board and wrote the \( M = \frac{n}{V} \)… a statement relating molarity (M), moles (n) and volume (V)).

Dr. Wise: If I have 1000 milliliters, how many liters do I have?

(No response, so Dr. Wise goes on.)

Dr. Wise: What is the density of water?

Larry: (Wanting to rectify his first attempt at the earlier question) one!

Dr. Wise: Good Larry, (then asked the class) How do I find moles of water?

Jill: 18 grams

Dr. Wise: Why?

Tara: (Cynically under her breath, but audible) Sounds like a good number to me.
Jill: Add the masses of elements.

Dr. Wise: We know mass is 1000 grams for 1000 milliliters – that is why.

Dr. Wise: How do we know molar mass of sodium hydroxide?

Betty: (Cynically) I don’t know.

Bill: Add element masses together.

Ann: What is “big M”?

Gary: (Ann’s neighbor quickly responded to her) Molarity, it was in your homework!

Gary’s frustration with the lack of effort and inability of his peers to answer questions was echoed by Dr. Wise who said, “You only had five problems for homework. It is hard to change your mindset (referring to his apparent familiarity after six months with students’ unwillingness to do homework). You need to do your homework. It takes time, but when you go to college, I want you to be prepared.” Dr. Wise remained focused on trying to ready students for the lab.

Dr. Wise seemed to recognize the difficulty of managing math and chemistry concepts simultaneously, and he persistently tried to help students become comfortable with both concepts before starting the lab. He went to the board, rearranged and wrote the mathematical formula for determining the number of moles of a solute from a solution’s molarity and volume (moles = M · V). Then, he wrote the following sample problem on the board: “If molarity is 0.500 M and volume is 20 liters, how many moles is this?” Dr. Wise seemed perturbed that he had to use valuable class time to cover material that should have been completed as homework. Clearly, he had intended to spend more time
engaging students in the hands-on activities he had planned for the day. Nonetheless, Dr. Wise continued the dialogue with his students, asking questions in attempts to help students gain an understanding of the fundamental concepts associated with the lesson:

Dr. Wise: How many moles of NaOH are needed to prepare a 0.500 molar solution with a 20 liter volume?

Brandon: 10 moles

Dr. Wise: How many grams NaOH do I need to get for 10 moles?

Sam: 400 g

Dr. Wise: Why? (There was a pause and no students answered) Last time I checked 10 times 40 equals 400.

Dr. Wise seemed pleased that he got two consecutive student responses to his questions. Just as he moved on to begin a demonstration of the method of titration, Ann asked, “How did you get 10 moles?” Patiently, Dr. Wise changed his course back to the SMART Board and pulled up a 3’ x 5’ image of a graphing calculator and proceeded to show the entire method of calculating moles step by step, even though the steps had been covered in the pre-lab homework and he had just meticulously explained the mathematical process moments before. Without seeming annoyed, Dr. Wise continued the review, focusing on the chemistry concepts from the homework handout that he had expected students to complete before coming to class. The following dialogue illustrates both the students’ continued lethargy and Dr. Wise’s persistent effort to involve students by asking questions:
Dr. Wise: What standard are we going to use? (After no students responded, Dr. Wise continued.) The answer is on your homework sheet, number two. (Still no students answered). Does everyone see mole equal mole?

Betty: (Continued her sarcasm) No, I’m not on that page.

Dr. Wise: Joann, why do we know that sodium hydroxide is a solid?

Joann: I don’t know.

Dr. Wise: (held up the pre-lab homework handout and pointed to number one to emphasize the consistency between the homework and the pre-lab review). It says you need “grams” (an inference that solid quantities have to be massed).

Jill, Gary, and Brandon: (Affirmed Dr. Wise almost simultaneously by exclaiming) “grams.”

Dr. Wise had intended to help students monitor their understanding before lab in order to give the lab experiences more meaning than just being a thoughtless, mechanical exercise. Unfortunately, the students did not seem to understand the value of the homework in helping them plan for lab. Rather than asking probing questions, Dr. Wise continued by simply writing the balanced equation on the board straight from the homework sheet. While he continued asking questions, most students were either unable or unwilling to participate. Only about five students were alert and seemed anxious to understand.
After using the first 30 minutes of class to essentially complete the pre-lab homework assignment, Dr. Wise was able to resume the demonstration that was interrupted earlier. With great detail, he continued his practice of asking questions as he explained how to use a burette, the chemistry apparatus central to obtaining volume data during the lab. In the culminating minutes before students moved to the lab work areas, Dr. Wise used a graphing calculator projected on the SMART Board to demonstrate the calculations with three additional example problems. Despite Dr. Wise’s obvious efforts to prepare students and engage them in the learning process, only a few students seemed to have properly completed the pre-lab homework handout and appeared to be cognitively motivated. Unfortunately, their progress was likely stifled because the other students’ lack of preparation resulted in the use of half of the 90-minute class for a pre-lab review. I wondered if the relatively passive students would become more motivated when the groups were required to collect experimental data.

The lab activity began with students moving to the lab work areas along both side walls. Similar to college lab protocol, Dr. Wise kept most chemicals on a designated “side shelf” with each lab station appropriately stocked with labware. This arrangement was helpful because movement in the lab-classroom combination was highly impaired by the number of student desks that filled the area between the lab work stations. Students gathered in groups of three, each with a lab procedure sheet. I moved around the room to get a feel for the students’ ability to perform the lab in lieu of their lack of homework completion and their disinterested nature during the pre-lab discussion. The students were first required to prepare two chemical solutions. Then, they placed a designated amount
of HPAP into a flask, added a chemical indicator and titrated with their sodium hydroxide solution until the solution turned a very light pink. Students seemed to try to decide what to do first by reading the procedure sheet and looking around at other groups’ actions.

Students seemed to understand how to follow the procedure steps and delegate tasks. Each group had members who retrieved the chemicals and others who measured. All groups worked with a similar pace. The following dialogue is representative of all groups:

Cody: (To Dr. Wise) I need the stuff (referring to a chemical located at the “side shelf”).

Dr. Wise: Tell me the name of “the stuff.”

Cody: (thought for a second) Sodium hydroxide

Dr. Wise: Good; where do we keep the chemicals?

Cody: On the table near your desk.

Dr. Wise: Right.

Joe and Lindy, Cody’s partners, were at the lab area measuring water for the two solutions. Cody returned from the “side shelf” with the chemicals and massed them. Then Joe and Lindy prepared the solutions. Continuing their mission to complete one task at a time, the group turned their attention to transferring their sodium hydroxide solution to the burette. Cody’s group continued with the following dialogue that illustrates their students’ overall lack of attention to the important concepts related to the laboratory experiment:

Cody: Where is the funnel?
Joe: In the drawer.

Lindy: Let’s take it (the burette) down and add the stuff.

Joe: (Grabbed the stand holding the burette and lowered it) Ok, y’all (sic) add the stuff.

Cody: (Put the funnel in the burette opening) Ok, go ahead.

Joe: You’ve got to hold it to let air out.

Lindy, Joe, and Cody transferred the sodium hydroxide solution to the burette and added several drops of the indicator to a flask with the HPAP. They seemed to go through the steps outlined in the prescribed procedure in a mindless fashion. The key part of the lab approached where students added the basic solution from the burette until the solution in the flask turned a very light pink color. The level of understanding of the chemistry concept provided in the lab handout seemed to fade as the following dialogue indicates:

Cody: Ok, which one is it we’re supposed to put in the flask?

Lindy: I think the sodium hydroxide.

Joe: No, I don’t think so because the indicator is in there and that (sodium hydroxide) is what makes it turn pink.

Lindy: Ok, then how much of the acid do we add to the flask?

Joe: (Reading from the procedure sheet) For this part we add 100 milliliters.

Cody: (Reaching for a graduated cylinder and getting water). I’ll get that.

Lindy: What do we do next?

Joe: We’ve got to add the other stuff until the color changes.
The versed ability of all student groups to read and follow the procedure was evident in the manner in which they accomplished the tasks. The extent to which students sought understanding of the underlying concepts remained in question. Students were approaching the critical point in this part of the lab where their understanding would become apparent in the degree of pink color they accepted as the signal that the neutralization reaction was complete. The following dialogue and actions of Cody, Joe, and Lindy were typical of most student groups:

Cody: Who’s going to add the stuff?
Lindy: It doesn’t matter to me.
Joe: I’ll add it (as he takes the flask and moves it under the burette containing the sodium hydroxide).
Cody: How much is it going to take?
Lindy: I don’t know.
Joe: What does the sheet say?
Lindy: Around 30.

Joe added the sodium hydroxide from the burette rapidly and the solution turned suddenly a deep pink color and he stopped. Lindy, Cody, and Joe seemed pleased that what they had heard would happen actually did - their mixture turned pink. Dr. Wise had been keeping a keen eye on all groups, moving around constantly while answering students’ questions. Dr. Wise noticed the deep pink color and moved over to discuss the results. Dr. Wise asked, “Is that the color we talked about expecting?” Cody, Joe, and Lindy looked at each other as if one hoped the other would answer and get them off the
hook. The following dialogue exemplified the type of questioning Dr. Wise had used with other groups:

Dr. Wise: Ok, let’s think about what you did. What chemicals did you mix?

Joe: sodium hydroxide and the HPAP acid

Dr. Wise: Did you know the mass of the HPAP?

Lindy: Yes

Dr. Wise: Cody, can you get moles from mass?

Cody: Yes

Dr. Wise: What else did you measure?

Lindy: Volume

Dr. Wise: What can you get from moles and volume?

Joe: Molarity

Dr. Wise: What did you do next in the lab after you prepared your acid?

Lindy: Added the other stuff.

Joe: The sodium hydroxide

Dr. Wise: What have we learned that relates chemical quantities?

Joe: Chemical equations?

Dr. Wise: Yes, but what about them.

Joe: They have to be balanced.

Dr. Wise: Then, how do you use them?

Lindy: The numbers
Dr. Wise: The coefficients and what do they mean?

Lindy: Ratios

Dr. Wise: What kind?

Joe: Moles

Dr. Wise: Ok, if you know moles of one can you get moles of the other?

Cody: Yes?

Dr. Wise: And if you find moles and volume can you get Molarity?

Joe: Yes, I got it (sounding as if he had enough information to move forward)

Dr. Wise: Then what does the pink color show?

Joe: The reaction is complete because the base turns the indicator pink.

Dr. Wise: So is the dark pink just the right end of the reaction (speaking of timing)?

Joe: No, it should be lighter.

Dr. Wise: How can you fix the color?

Joe: Well on the next trial, since we have to do three, we can add slower when we see the pink start showing up.

Dr. Wise seemed satisfied that Joe knew enough to address the color issue and could share the details with Cody and Lindy who were hesitant to engage in the discourse. As Dr. Wise walked away he reminded the class, “Be sure to complete three trials before you finish.” Students continued to work, but some seemed more fluent with the lab process than others. All groups seemed familiar with following step-wise lab procedures, even
though they worked at various paces. When about five minutes remained in the class, Dr. Wise said, “If you didn’t finish three trials, you can finish them the next time. Be sure to put your lab sheets in a safe place. You’ll need them next time.”

**Context after witnessed lab lesson.** Dr. Wise followed the lab lesson with lab report assignment using a prescriptive rubric. The required lab report format did not encourage students to thoughtfully connect lab experiences with prior chemistry concepts discussed during class. Instead, it allowed students to simply copy the objective, list of materials, and procedural steps given by the instructor. They recorded their data and plugged it into the provided algorithms. The results section did not require deep analysis, as illustrated by comments such as “pink color formed.” A clearer understanding of the concepts would have allowed students to use lab evidence to *explain* the color change in relation to the quantitative data and the stoichiometric coefficients from the balanced chemical equation.

**Interpretive Summary.** The results of the MCA-I assessment instrument indicated that none of Dr. Wise’s classes changed their self-perception regarding metacognitive skillfulness at the p=0.05 level during the course of the study. As shown in Table 4.3, this was true for all three of his levels: college preparatory, honors, and advanced placement.
Table 4.3

*Summary of Dr. Wise’s Students’ Pre- and Post-MCA-I Results*

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Pre MCA-I Mean</th>
<th>Post MCA-I Mean</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>College Preparatory</td>
<td>15</td>
<td>74.71</td>
<td>75.09</td>
<td>0.86</td>
</tr>
<tr>
<td>Honors</td>
<td>53</td>
<td>75.67</td>
<td>77.04</td>
<td>0.08</td>
</tr>
<tr>
<td>Advanced Placement</td>
<td>8</td>
<td>80.63</td>
<td>79.91</td>
<td>0.72</td>
</tr>
</tbody>
</table>

Further, Table 4.4 and Figure 4.4 illustrate that Dr. Wise’s students in all levels were predominantly identified as intermediate according to the IMMEX instrument.

Table 4.4

*Summary of Dr. Wise’s Students’ IMMEX Results Shown by Level*

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Low</th>
<th>Intermediate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>College Preparatory</td>
<td>11</td>
<td>9.1</td>
<td>81.8</td>
<td>9.1</td>
</tr>
<tr>
<td>Honors</td>
<td>44</td>
<td>20.5</td>
<td>77.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Advanced Placement</td>
<td>4</td>
<td>25.0</td>
<td>75.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
An interesting result is the college preparatory level of high metacognitive skillfulness in comparison to Dr. Wise’s other chemistry levels. Further, the percentage of low metacognitive skillfulness is highest in Dr. Wise’s Advanced Placement chemistry class, students who are supposedly the most knowledgeable chemistry students. Further study would be needed to explore these differences.

As a result of observing Dr. Wise’s interactions with students and the documents related to his teaching philosophy, planning and methods, the following teacher-practice themes emerged:

- an emphasis on mathematical algorithms at expense of adequate coverage of important chemistry concepts;

Figure 4.4. Comparison of Dr. Wise’s Students’ IMMEX Results Shown by Level
• an abundant use of step-wise, prescriptive, rote verification experiments rather than activities that may have cognitively involved students to a greater degree; and

• an absence of detailed and sophisticated lesson planning.

Dr. Wise’s lesson plans did not detail how instructional practices would achieve cognitive outcomes and did not describe how assessments would measure students’ conceptual understanding. His seeming reliance on his long, distinguished career for lesson planning may have resulted in a lack of recognition that newer teaching strategies might be more effective in engaging students in the learning process. Through more thoughtful planning, Dr. Wise could have likely been enlightened to new teaching methods that hold promise in the area of metacognitive skill development.

Even with Dr. Wise’s use of an abundant number of supporting labs, his students did not seem to connect the chemistry concepts covered during class with the lab activities. Rather, students seemed to view lab procedures as tasks to accomplish, and they equated collecting data with lab success. Additionally, students’ failure to complete homework assignments and their relatively low level of engagement in during class activities also contributed to their inability to demonstrate high metacognitive skillfulness.

Dr. Wise’s long-established teaching methods that involve lecture and procedure-driven labs appeared to reinforce passivity among students who perceive learning as tasks to complete. His students’ demeanor during observations seemed to illustrate an attitude centered on putting forth the minimum effort necessary to get through the class. They
appeared to approach learning as a chore and seemed to be unaware of the importance of planning, monitoring, and evaluating their understanding of the chemistry concepts. The traditional teacher routine may fail to help students make connections that are essential in learning the cumulative, interwoven layers of chemistry concepts.

The findings of Dr. Wise’s case suggest that traditional teacher practices must be reconsidered if the goal is to assist students in becoming more metacognitive. In order for students to learn science authentically and to take more responsibility for their own learning, they must be equipped with metacognitive skills that facilitate this type of learning. Teacher practices must elicit deep reflection and provide students with opportunities to defend and rationalize their decisions. Learning situations should require students to confront their ideas and evaluate their understanding of concepts.

Dr. Wise’s devotion to his students was evident throughout the research process. His high expectations and desire to encourage students’ individual best may have influenced him to rely on the teaching practices that he felt had been effective for nearly 40 years. Unfortunately, his lack of incorporation of more effective teaching methods likely caused his students to miss valuable opportunities to relate prior knowledge to new situations and assess their understanding. Further, his teaching practices might explain why none of his classes of students self-reported higher metacognitive skillfulness at the \( p=0.05 \) level and why no more than 10% of the students in any of his classes demonstrated high metacognitive skillfulness. Two noteworthy and seemingly related trends emerged. The percentage of students demonstrating high metacognitive
skillfulness decreased with increasing level of course difficulty while the percentage of students categorized as having low skillfulness increased.
Suzy – The Former Chemist and Semi-Veteran Chemistry Teacher

Suzy is a former analytical industrial chemist with a bachelor’s degree in chemistry and a master’s degree in teaching. She had been teaching high school chemistry for ten years, the last nine of which were at Hardy High School.

Self-Reported Teaching Philosophy and Practices. Suzy stated that she was inspired to go into teaching while moonlighting as a part time lab assistant at a local technical school. Suzy said that she “realized I really helped people by tutoring them” and that she found the students to be so appreciative that she decided to “[teach chemistry] full time because it felt so rewarding.”

Suzy pointed out that she wants to maintain a relaxed learning environment for her students, but that she often finds this difficult due to the pressures associated with covering all of the materials required by the state’s high school chemistry standards. She described herself as a “laid-back hippie” who likes to spend several minutes before, during, or after lessons chatting with students about school-related activities or their personal interests. Further, she said that she provides snack breaks for students on a fairly regular basis.

Suzy’s indicated that she enjoys teaching chemistry and wants her students to enjoy learning it. She said she believes it is important to build students’ self-confidence in order for them to truly take pleasure in their academic pursuits. Realizing that chemistry is a relatively difficult subject, she tries to reduce students’ anxiety by encouraging them to develop systematic, step-wise strategies and graphic organizers to solve problems.
Suzy stated that she is unable to incorporate demonstrations into her lessons because, with all of the additional responsibilities associated with teaching, she simply does not have time to prepare them. She pointed out that she is relatively unfamiliar with the inquiry-based learning process and, therefore, lacks the confidence to implement these methods in her classes. Further, she indicated that she felt that her students lack the content knowledge and previous experience that would be necessary for this type of teaching and learning to be successful.

Suzy stated that she believes it is important for students to connect chemistry concepts through homework assignments, classroom discussions, and lab experiments. She indicated that she incorporates an abundance of mathematically-based chemistry questions into her lessons and models problem-solving strategies with her students. She pointed out that she places a strong emphasis on students fully understanding and determining the goal of a problem before proceeding to solve it. Suzy stated that she helps students sort information given in a problem and determine its relevance and that she emphasizes the importance of developing a plan to solve problems. Further, she pointed out that she assists students in evaluating their understanding of concepts by modeling the process of checking the reasonability of results.

Suzy stated that she views lab activities as prime opportunities to give meaning to the mathematically-based chemistry problems solved during class. Suzy suggested that she believes that by using their data collected in lab, students are likely to make connections with chemistry problems discussed in class. Suzy pointed out that she provides students with step-wise procedure guides which she feels will help students
monitor their lab progress. She indicated that she feels that lab experiences provide students with opportunities to reconcile the ideas they test with their data and ascertain the reasonableness of their results. Further, she stated that she believes that written lab reports help students evaluate their understanding of the related chemistry concepts.

**Hardy community.** Hardy is located within an hour of several major cities and a major university. The community is in an economic transition as a result of a decline in the manufacturing jobs that were once the cornerstone of employment. The local Chamber of Commerce website indicates that 23 percent of the population remains in manufacturing jobs, with another 21 percent serving in the education, health, and social services professions. Many citizens commute to work at the major university in the vicinity and in the nearby urban area, which not only provides employment but also offers resources to local industries. Hardy High along with three other community high schools serves the Hardy community.

**Hardy High School.** Hardy High is situated in an upstate South Carolina city. The school’s mission statement highlights the benefits of home and community involvement and emphasizes the value of cultural diversity. This is evident in the abundant variety of clubs and organizations the school sponsors, including three foreign language clubs, Model United Nations and Youth in Government. Hardy feels like a safe and caring environment that aims to help students cultivate their full potential through challenging and innovative educational programs.

**Suzy’s class and lab room.** The small classroom seemed like a sea of desks just far enough apart for students to squeeze down the row to their seats. Suzy’s personal desk
was cluttered with an accumulation of artifacts from a decade of teaching and assorted stacks of graded and ungraded papers. It was located on the side of the classroom near the door, with her instructional cart rolled to the front, facing six straight rows, five desks deep. Her instructional cart had a laptop computer that was connected to a SMART Board. After just two observations, I realized how frequently Suzy used it to show PowerPoint presentations and solve chemistry problems to highlight important concepts.

Suzy’s lab room was located across the hall from her classroom and seemed well stocked. The design included an instructor’s desk at the front of the room with circular islands spread throughout, each equipped with gas outlets and water faucets. Lab equipment and chemicals were located on shelves along the wall, with specific labware and chemicals for the lessons placed conveniently on carts.

**Analysis of Suzy’s lesson plans.** Figure 4.5 illustrates the Hardy High administration’s required weekly lesson plan. The brief plan only identifies the week number, course, chemistry topic, class work, homework, and assessments. The lesson plans are representative of typical lesson plans utilized by Suzy.
**Figure 4.5.** Suzy’s Sample Lesson Plans. Shows brevity of planning in (a) classwork, (b) homework and (c) assessments.

Suzy’s lesson plans were neither student-oriented nor learning-based, and they lacked explicit and assessable statements of intended cognitive outcomes. Each day’s lessons seemed like tasks to accomplish. For example, Suzy included statements such as “perform a Ka lab,” “calculations for lab,” “review problems,” “practice old AP problems,” and “complete all problems.” Proactively planned questions that would have provided students with opportunities to plan, monitor and evaluate their understanding of the material were absent in the lesson plans. Subsequently, absence of purposeful
planning may have hindered Suzy from having new insight into creative ways to help students pursue chemistry concepts more deeply.

**Context before witnessed lesson.** Students followed Suzy’s chemistry topic introduction by completing homework problems from the textbook. It seemed routine for Suzy to review the previous night’s homework at the beginning of each day’s class before moving to new concepts. Preceding the observed lesson, Suzy had assigned acid-base chemistry problems to help students prepare for the upcoming lesson.

**Analysis of witnessed lesson.** As I walked into Suzy’s advanced placement (AP) chemistry class, 15 students hurried to retrieve materials and calculators from their book bags. Suzy moved from her desk to the instructional laptop at the front of the room. As Suzy walked across the room she told students, “Today you will do the problems you had for homework on the board and then explain them.” I was keenly interested in listening to students talk about the chemistry concepts and hearing if Suzy asked probing questions and provided feedback. I was attentive to identify the opportunities students would have to develop metacognitive skills during the learning experience. The lesson began when Suzy asked Joe and Cindy to go first.

While Joe and Cindy were writing their problems on the SMART Board, four students talked about unrelated social topics, two watched the students at the board, and seven others appeared inattentive. Students’ selection of the correct notebook where the homework was located seemed to be students’ focus; any deliberate reflection on previous chemistry knowledge appeared absent. I anticipated whether the students’ would explain the problems they were working at the board in a mathematically-oriented or
conceptually-based manner. Suzy reminded the class to “pay attention to the explanations” and Joe began explaining part (a) of the first problem. He pointed to the mathematical formula that he used to complete the problem and the following ensued:

   Joe: This is a base but I don’t know its name. Add water, put ‘x2’ over one. Plug into formula, straightforward.

   Bev: Is 9.3 good for that?

   Joe: No

Suzy looked on and did not ask questions or clarify the name of the base or why Bev’s answer of 9.3 was not correct. Joe proceeded to explain part (b) of the problem as follows:

   Joe: Last one was a strong acid, gonna (sic) dissociate. (Pointing to a weak acid formula on the board) This one will do nothing, it is weak. Find $K_a$

   because this is a weak acid. Do your stuff.

“Do your stuff” as I interpreted from several observations, meant to do the math associated with the problem. With no input from Suzy and no questions from the class, Joe continued to explain part (c) of the problem.

   Joe: Dissociation of water, plug in formula, memorize that stuff.

   Cindy: pH of water is always 7

Joe got Suzy’s attention to ask a question and I hoped to hear the chemistry concepts emerge in the discussion. However, the emphasis continued to be on getting mathematical answers, as exemplified by the following dialogue between Joe and Suzy:

   Joe: When is the “H-H” [Henderson-Hasselback] equation used?
Suzy: When you have a weak acid and salt.

No chemistry concepts were detailed and Cindy began explaining the second problem that related to weak acid-salt solutions and pH determinations.

Cindy: Now we are mixing the equations. Salt automatically dissociates.

The major species are… (trailed off and did not finish sentence). Just use the “H-H” equation.

When Cindy used the phrase “mixing equations”, she was referring to using various mathematical formulas from previous topics to get the answer. I hoped Suzy would interject the underlying chemistry concepts of mixing a weak acid and salt. I anticipated strategic questions or feedback that allowed students to monitor, make connections, or detect conflicts with their understanding. No one responded so Suzy said, “Are you ready to present, Ben and Meg?”

Ben and Meg went to the board while two other students worked with Suzy at her desk. Of the other remaining students in the class, two worked at their desks on the same problem that Ben and Meg were working on the board; all other students were having conversations unrelated to chemistry. At this point in the lesson, monitoring involved checking to see if the answers matched the answer key and verifying what mathematical formula to use. Due to the lack of emphasis on chemistry concepts, students were not encouraged to monitor or evaluate their conceptual understanding.

The lesson continued in the same manner, with student pairs going to the board and others talking about topics unrelated to chemistry. When “explanations” were presented to the class, Suzy and her students used mathematical phrases such as “plug
and chug” and “just do the math,” or “solve for x.” That part of the lesson ended when Suzy said, “Ok, let’s go on, we’ve run out of time. We’re going on to thermo [chemistry].”

**Context after the lesson.** Suzy’s next lesson was a lab that extended the problems performed in class related to acid-base titration and determination of the dissociation constant, $K_a$, for a weak acid. Suzy asked students to read the procedure sheet in order to help them plan and prepare for lab.

**Context before witnessed lab lesson.** After observing the mathematical emphasis during the classroom lessons, I anticipated the ability in which students would be able to apply the mathematical chemistry concepts to the lab experience. The acid-base titration lab should unify the problems solved during class with the data collected during lab.

**Analysis of witnessed lab lesson.** Pre-lab planning consisted of Suzy telling students about lab safety, describing lab techniques, and prescribing the step-wise procedures to follow. Suzy began the pre-lab activity by making the following statement which, unfortunately, provided students with the result of they should obtain in the quantitative analysis experiment, the percentage by mass of acetic acid in vinegar:

First you place the container on the balance and press tare. Then you pour vinegar in the container and record the mass. Then you transfer the vinegar to the E. flask. Vinegar is five percent acetic acid. That is what you’re trying to find.

After Suzy’s comments, she sat at the front of the class and began grading papers while students looked over the procedure sheet in order to decide what to do first. Each group
had a student who read the procedure steps and delegated tasks to others. The following
dialogue is representative of the interactions between group members, their questions to
Suzy and the task completion-themed approach among students:

Tom: (to Suzy) Do we use distilled water?

Suzy: Yes.

Tom: (To his lab partner, referring to the stir bar spinning at a very high
rate). It’s turning pink, slow down.

Suzy: (Who heard Tom comment to his lab partner) The stir bar should
not go so fast that it splashes, that would affect accuracy.

Jan: (Referring to the expected volume used to reach endpoint) How many
milliliters will it take?

Suzy: About 30mL.

Sam: (To Suzy, referring to pouring a solution into the very small opening
of the burette) Is there a better way to do this?

Suzy: Yes, you can use a beaker.

A deliberate effort by students to understand the lab’s conceptual goals, select
appropriate strategies and allocate corresponding resources seemed absent. Students
explicitly followed the directions on the procedure sheet and asked Suzy to clarify when
they were uncertain about tasks. I had hoped Suzy would use the lab opportunity to use
strategic, probing questions that forced the student to think critically and make decisions
related to an appropriate plan of action. Instead, most students robotically retrieved
materials and implemented the lab as dictated by the procedure sheet; their actions were
void of any attempt to connect the previous class’s acid-base textbook problems to the concepts exposed during lab.

During the lab, monitoring and reflection took the form of assessing what procedure number had just been completed and what step was next. When Jan asked Suzy how many milliliters will it take to finish, I hoped Suzy would seize the opportunity to use a series of strategic, guiding questions that would force Jan to make connections with the concept on which the lab was based. Suzy could have encouraged Jan to relate the approximate concentration of acetic acid in vinegar quantitatively to the volume of base used in the titration and arrive at an answer to her question. Instead, however, Suzy simply answered, “about 30 milliliters,” and provided information the students should have obtained as they conducted the lab.

I observed the remainder of the lab anticipating a time when Suzy would strategically question students to elicit conceptual connections or recognize conceptual conflicts to clarify. However, students continued until their three titration trials were completed and Suzy graded papers until the class period ended.

**Context after the witnessed lab.** During the class that followed the lab, I had hoped Suzy would urge students to reflect on the activity and its goals and critically evaluate the reasonability of their data and results. Suzy began the class by asking if anyone had questions and the ensuing dialogue seemed to illustrate that at least one student did not understand the lab’s goals and, therefore, probably could not have appropriately monitored or evaluated her decisions during the lab.

Suzy: Does anyone have questions about the lab?
Ann: I don’t know what to do with the second part of the lab (Referring to how to use the data in calculations.).

Suzy: Ok, let’s do it, five minutes and then we have to move on.

(Suzy illustrated the lab apparatus used in lab and wrote two mathematical ratios needed for the calculations on the board.)

Suzy: Use five milliliters of vinegar, part over whole.

Ann: How do we know acetic acid is in vinegar?

Suzy: That is why you did the lab titration…to get the mass of acetic acid.

Suzy: What does percent mean? (No one responded and Suzy continued with a jargon-loaded response.) At equivalence point, moles acid equals moles base. We need grams acetic acid. If we have moles of acetic acid, we are home free. We convert moles to grams. If we know moles base, we know moles acid – you standardize it. Can I get moles from volume and molarity?

Ted: Yes, but make sure you convert milliliters to liters.

Suzy: We know moles of acetic acid, so now we know mass of acetic acid.

Now let’s move on to polyprotic acids.

(Suzy wrote the current day’s objectives on the board and read over each one.)

I was disappointed that the student who apparently did not still know that vinegar contains acetic acid did not get more scaffolded feedback. It appeared to me that this student may have received Suzy’s answer as gobbledygook and remained confused. Suzy
told the students before the lab that they were verifying that vinegar is five percent acetic acid. Unfortunately, Suzy’s students seemed unable to unify concepts discussed in class and lab and they equated lab completion and artifact collection with success.

Suzy’s sense of urgency about content coverage was observed during each visit. In the semi-structured interview and informal conversations, Suzy spoke of “lack of time” to use more guided inquiry. However, in the questionnaire and semi-structured interview, Suzy described a more extensive approach to offering students opportunities to plan, monitor, and evaluate than was observed during visits. Suzy’s self-described teacher practices that promote planning for labs included:

- talking about the purpose and chemistry of the lab;
- giving students the lab [procedure] sheet the day before the lab;
- having students writing up the purpose and theory of the lab; and
- asking students to study the lab.

Suzy also explained that she assessed students’ prior knowledge through pencil and paper problems before labs and emphasized the importance of developing a plan for solving a problem. Suzy was extensive when she self-reported on the opportunities she provided students to monitor during lessons, in order to reflect on their process, progress, and comprehension. Suzy described the teacher practices she utilized to encourage students’ monitoring of their conceptual understanding, including:

- questioning students during lab in order to probe their conceptual understanding;
- circulating during lab to monitor and check for understanding; and
- requiring students make a written record of data during the lab.
In addition to stating that she employed teaching practices that encourage students’ to monitor, Suzy self-reported in the questionnaire and interview that she utilizes strategic practices to encourage students to evaluate and make sense of their results. Suzy emphasized that she models the behavior of intentionally checking the reasonableness of results when working problems in class. Further, Suzy described several teacher strategies she uses to encourage students to evaluate their conceptual understanding of the material, including:

- encouraging students to discuss what they learned in the lab;
- requiring students to reflect on results and their implications in order to develop more questions;
- requiring formal, written lab report on which specific feedback is provided; and
- providing students opportunities to compare and contrast results with peers.

Suzy’s expectations of students with regards to planning, monitoring, and evaluating conceptual understanding were detailed in the formal and informal conversations, the semi-structured interview, and the questionnaire. Her observed teaching practices, however, based on seven, 90-minute classroom visits, were in sharp contrast to her self-reported methods.

Interpretive Summary. The results of the MCA-I assessment instrument indicated none of Suzy’s classes changed their self-perception regarding metacognitive skillfulness at the p=0.05 level during the course of the study. As shown in Table 4.5, this was true for both her honors and advanced placement levels.
Table 4.5

*Summary of Suzy’s Students’ Pre- and Post-MCA-I Results*

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Pre MCA-I Mean</th>
<th>Post MCA-I Mean</th>
<th>p - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honors</td>
<td>48</td>
<td>72.11</td>
<td>73.72</td>
<td>0.19</td>
</tr>
<tr>
<td>Advanced Placement</td>
<td>16</td>
<td>73.80</td>
<td>73.79</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Further, Table 4.6 and Figure 4.6 illustrate that Suzy’s students in both levels were predominantly identified as intermediate according to the IMMEX instrument.

Table 4.6

*Summary of Suzy’s Students’ IMMEX Results Shown by Level*

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Low</th>
<th>Intermediate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honors</td>
<td>15</td>
<td>26.7</td>
<td>73.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Advanced Placement</td>
<td>9</td>
<td>11.1</td>
<td>55.6</td>
<td>33.3</td>
</tr>
</tbody>
</table>
As a result of observing Suzy’s interactions with students and the documents related to her teaching philosophy, planning and methods, the following potentially problematic teacher-practice themes emerged:

- an emphasis on mathematical algorithms at expense of adequate coverage of important chemistry concepts;
- an abundant use of step-wise, prescriptive, rote verification experiments rather than activities that may have cognitively involved students to a greater degree;
- an absence of detailed and sophisticated lesson planning; and
- an inadequate use of proactive, probing questions during instruction.

Suzy’s lesson plans were not well developed, and an underlying emphasis on mathematical algorithms permeated all observed lessons. By focusing on math and content coverage, Suzy seemed to miss opportunities to ask strategic, probing questions and provide guiding feedback. Suzy and her students seemed to find arriving at

Figure 4.6. Comparison of Suzy’s Students’ IMMEX Results Shown by Level
mathematical *answers* to chemistry problems less stressful and more appealing than
discussing the difficult concepts related to them. Furthermore, her students seemed to
have little-to-no need to apply previous knowledge of current chemistry concepts to the
lab activity. Suzy’s teaching practices seemed to reinforce students’ tendencies to take a
task-oriented approach and avoid deep reflection on previous knowledge and its value to
understanding the related concepts.

Suzy’s enthusiasm for teaching chemistry was evident throughout the research
process, and she still seemed to view it as a rewarding career. Suzy seemed to find it
difficult to reconcile her natural tendency to favor a low-pressure environment and
unhurried pace in her classroom with the urgency to cover the extensive content dictated
by the state standards. The pressure to cover content seemed to cause her to
overemphasize mathematical algorithms at the expense of engaging students with
chemistry concepts at an appropriate depth. This may have caused her students to miss
valuable opportunities to relate prior chemistry knowledge to new situations and evaluate
their understanding. Further, her teaching practices might explain why neither of her
classes of students self-reported higher metacognitive skillfulness at the p=0.05 level and
why no more than one-third of the students in either of her classes demonstrated high
metacognitive skillfulness.
Ted – The Chemistry Teacher Practitioner

Ted is in his late twenties and holds a bachelor’s degree in chemistry and a master’s degree in divinity. His teaching career started when he served as a teaching assistant at a nearby university while he was enrolled in a chemistry Ph.D. program. Ted’s growing family caused him to leave his three-year appointment at the university to come to Oak High School where he has taught chemistry for two years.

Self-Reported Teaching Philosophy and Practices. Ted stated that he begins his syllabi by stating that he will do “anything to help a student who is trying to learn and almost anything to motivate a student to want to learn.” Ted pointed out that he makes himself available to his students by offering two hours of tutorial time after school every Tuesday and Thursday. Ted pointed out that as a teacher, he plays a vital role in facilitating students as they learn chemistry, since the subject is made difficult by the many complex and abstract concepts involved. Further, he asserted that he is dedicated to helping his students in an exciting, engaging and enjoyable environment.

He indicated that he incorporates contemporary chemistry practices he was exposed to while working under the direction of a nationally-renowned chemical educator. Despite his relatively brief teaching career, Ted stated that he makes the plethora of teaching resources including lesson plans and chemistry tutorials he has accumulated available to his students on his website. Further, he pointed out that he has an extensive variety of laboratory texts which he uses to tailor experiments in his efforts to maximize the conceptual understanding of his students. He indicated that he views
both the pre- and post-laboratory sessions as vital to helping student connect their experiences with the concepts discussed during class.

Ted stated that he helps student plan for each lab thorough pre-laboratory discussions in which he encourages students to clarify the goal of the experiment and connect prior knowledge to the current activity. Ted pointed out that he creates opportunities for students to describe their current understanding of the lab concepts prior to conducting the experiment through written pre-lab questions. Further, Ted’s indicated that he regularly uses microscopic images and animations to supplement the chemistry concept being covered in class and lab. He indicated on the questionnaire that he employs relatively few explicit opportunities for students to monitor while learning. Ted pointed out that he seeks to engage his students in extensive post-laboratory discussion prior to their writing lab reports using a rubric designed to steer them through the reflective process.

During the process of problem solving, Ted stated that he stresses the importance of students fully understanding the goal of a problem and determining the relevance of information provided before choosing an appropriate solution strategy. He also indicated that he requires students to show all work when solving problems by writing the step-wise details as they progress. Ted also indicated that he encourages students to evaluate the reasonability of their results after they solve problems or obtain laboratory findings.

**Oak community.** Oak is a sparsely populated, unincorporated suburban “commuter community.” Many of the community’s 4,000 citizens work in the urbanized regions of upstate South Carolina located about 30 minutes from Oak. The rural
community is comprised of winding country roads, extended open fields and small abandoned farm houses hugged by forests. As a result of suburban spread, subdivisions filled with modest-sized homes are sprinkled among the old farm homes and fields. After several miles of country roads, Oak High appears as an expansive, new and contemporary school facility.

**Nature of Oak High School.** The Oak High School facility is situated on 69 acres of land and spans 250,000 square feet. Oak High’s website describes the building as “large expanses of brick and abundant natural light used in combination with precast concrete that create a warm, welcoming appearance.” As I drove down the extended, curving driveway towards Oak’s entrance, the two-story building welcomed visitors with its wide, spacious entry, lined with benches. The school’s entry was an expansive atrium with enormous palm trees reaching upward from the first floor to the second, toward the sunlight pouring in the second floor glass skylights. The front office had a cordial office staff who greeted me. The long hallway leading towards Ted’s chemistry classroom was wide, spacious, and lined with neat intermittently-spaced bulletin boards. Displayed student work enhanced the orderly and clean hallways. During class transitions, students moved without excessive noise and when classes were in session, the classrooms were abuzz with activity as I glanced through windows and opened doors.

**Ted’s classroom.** Ted’s combination classroom-laboratory was arranged with the student desks at the front and the laboratory area at the back. The extremely well organized laboratory area seemed to be thoroughly stocked with necessary lab materials and resources in the cabinets that lined one side of the classroom. The three lab counters
were spacious and nicely accommodated with gas outlets and water faucets. Ted’s clean and clutter-free desk was located at the front of the classroom and was equipped with a SMART Board and projector that enabled him to use PowerPoint presentations that regularly embedded Internet links to show images and animations that illustrated abstract chemical concepts. The impeccable cleanliness of Ted’s teaching environment made me wonder if Ted’s instructional practices were as organized and meticulous.

**Analysis of Ted’s lesson plans.** Figure 4.7 is a representative example of Ted’s lesson plans.
Figure 4.7. Ted’s Sample Lesson Plan showing (a) the state standard, (b) the over-arching unit question, (c) the daily essential topic questions and (d) the daily bell-ringer activities.

Ted’s lesson plans began with the specific state chemistry standard on which the week’s lessons were based, followed by an overarching unit question. Each day’s lesson
was framed around an “essential question” and initiated by a “bell ringer” activity, a thought-provoking question designed to focus students’ attention on the topic and encourage students to integrate concepts from previous classes. Ted’s plans seem to indicate that his teaching routine includes topic instruction followed by guided practice with an integration of demonstrations and laboratory activities to support the chemistry concepts. Ted’s “essential topic questions” replaced learning objectives typically present in lesson plans. Assessable statements of intended learning outcomes were not identified and the lesson plans did not indicate teaching strategies that would utilize proactive, strategic questioning during any aspects of instruction. The manner in which each “agenda” item would facilitate deeply reflective thoughts and help students monitor and evaluate their understanding of chemistry concepts was unclear.

**Context before Ted’s witnessed lesson.** Ted had given a pre-lab homework assignment to help students prepare for the session by identifying the lab goal, comparing and contrasting the underlying lab concepts, and interpreting periodic table trends that may explain the lab results. Ted’s pre-lab homework questions suggested that he would use probing, conceptually-based questions. His approach did not seem prescriptive at this point in the lesson and the wording of the pre-lab assignment suggested a teaching style that included probing questions to encourage students to think deeply about important aspects of the lab such as:

- the goal of the activity;
- the relationship between an atom’s number of valence electrons and its group number;
relationships between periodic table trends and valence electrons.

The witnessed lesson would provide a more thorough description of Ted’s teacher practices.

**Ted’s witnessed lesson.** Ted exchanged mutually enthusiastic greetings with his students as they entered his class, and then promptly began the lesson by reminding students of the Thursday afternoon tutoring sessions. Before introducing the daily lesson, Ted provided feedback relating to the concerns he noted from the previous class period’s test. All 22 students had the appropriate material on their desks and seemed to listen attentively. Ted started by using probing questions that required students to reflect on previous knowledge and potentially induce cognitive conflict. Ted wrote the formula for density on the board (\(d = \frac{m}{v}\), where \(d\) is density, \(m\) is mass and \(v\) is volume.) Then, interestingly, he wrote a student’s *incorrect* formula (\(2.7g/mL \times g = g^2/mL\)) on the board. The following dialogue seemed to illustrate Ted’s use of strategic questioning to elicit reflective thinking and possibly initiate cognitive conflict:

Ted: You have to think. What is the problem (referring to the example)?

Adam: You can’t have gram squared and density’s unit should be g/mL.

Ted: Right; in what other ways can the variables for density be related?

Gwen: If you calculate mass, you have to multiply density times volume.

Chris: And if you calculate volume, you have to divide mass by density.

Ted did not prescriptively answer the questions he asked, but allowed students time to consider the question and then respond. Ted continued nudging the students by drawing an unlabeled graph on the board and by asking students to consider an alternative method.
of determining density. Ted’s use of an unlabeled graph presented students with a new situation in which to apply the density concept. Ted continued his probing questions as illustrated in the following dialogue:

Ted: Consider the graph and the ratio for density?

Ann: Mass over volume.

Ted: So how might we assign the properties to our graph?

Gary: Mass on the x-axis and volume on the y-axis.

Ted: And how would you determine density from a graph?

Adam: Well, slope is change in x over y and density is mass over volume, so would slope be equal to density?

Ted: (Smiled, seemingly pleased with students’ thoughtful involvement)

Yes!

Ted’s asked strategic questions which required students to reflect on their knowledge of the concept of density to solve the calculation rather than providing them with a step-wise, mathematical algorithm that would not have promoted deep thought. After Ted discussed his concerns from the previous test, he reviewed the pre-lab homework questions relating to the conceptual goals of the lab. He utilized the same type of questioning he had earlier as illustrated in the following dialogue:

Ted: What have we been studying?

Glen: The periodic table

Ted: Be more specific.

Jenna: Different groups
Ted: And what about the different groups?
Jenna: How they are similar or different…trends.
Ted: What concept have we discussed that makes elements similar or different?
Joel: The atom
Ted: What do you mean?
Will: The valence electrons.
Ted: What might you expect in the lab?
Cindy: That elements may react differently?
Ted: Should all elements react differently?
Jenna: Well, maybe the different groups of elements will behave alike.
Ted: (Smiled and gestured toward the lab area) Lets go see!
The dialogue illustrates Ted’s keen questioning ability during teacher-guided discussions. I anticipated similar probing questions throughout the lab experience. Students moved purposefully to the back of the class for the lab and began by reviewing the lab procedure sheet, questioning each other about the process to make sure they agreed how to proceed. I anticipated the extent to which Ted’s questioning techniques would continue.

The high importance Ted had indicated he placed on engaging students in pre-lab planning was evident in the manner in which his students’ behaved during the lab. Students seemed familiar with using the procedure sheet to follow steps. The depth with which the students interacted seemed to indicate they knew that post-lab questions would
require an understanding of the lab experience and related concepts. The following
dialogue is representative of five of six lab groups:

Mel: It is sitting on top; do we need to mix it?
Sarah: Yes, (reaching for the test tube and inverting it) but you can see it is
still separated.
Mel: Would you say the solution on top is hexane? (Before anyone
answers he went on) I think it is because of its color.
Bob: Do we say hexane went to the bottom?
Sarah: (Held up the test tubes and compared test tube three with the results
of test tubes one and two) Would you say this mixed?
Bob: Let’s redo this to see what happens.

Students seemed to have developed a habit of monitoring their decisions by
discussing issues among group members. When students asked Ted a question, he usually
responded with a question as he moved around the lab area. Ted did not engage students
using proactive questions; he only responded when students asked questions. Ted’s
continuous movement around the lab allowed him to gauge students’ understanding of
how to progress in the lab. On one occasion, when Ted thought one student was copying
another’s work, Ted emphatically said, “You have to discuss each question.” Five of his
six groups maintained interactive dialogue. Although students were following the step-
wise procedure on the lab sheet, they seemed to try to make sense of the related
chemistry concepts. At the end of the lab clean up, students moved back to their desks
and lab groups gathered to answer their post-lab questions. I was anxious to see if students could unify their experiences with the concepts they had discussed in class.

As students answered the post-lab questions, they verbalized their answers with their group members for several minutes, but then seemed to begin to answer the questions individually. As Ted moved around the classroom during post-lab student work, he did not ask proactive questions. He only responded when students asked him a question. For example, Jane remarked to Tim, “All mixtures with group 17 elements formed a powder.” Tim said, “Well, ah, that’s a trend.” Ted could have intervened to more deeply probe the dialogue between the students that seemed to connect to the original lab goals to the results. Instead, Ted concluded the lesson by reminding the students that the written lab reports were due in one week and that the lab rubric should be followed. The lab ended without a class-wide peer review of results in which groups questioned each other, compared and justified their findings with the evidence they collected.

**Context after Ted’s witnessed lesson.** During the next class period Ted reminded students of the lab report deadline and continued the concept of valence electrons and chemical bonding. No further discussion occurred relating to the lab.

**Interpretive Summary.** The results of the MCA-I assessment instrument indicated that the students in Ted’s honors-level class did not change their self-perception regarding metacognitive skillfulness at the p=0.05 level during the course of the study, as shown in Table 4.7.
Table 4.7

*Summary of Ted’s Students’ Pre- and Post-MCA-I Results*

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Pre MCA-I Mean</th>
<th>Post MCA-I Mean</th>
<th>p - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honors</td>
<td>47</td>
<td>71.52</td>
<td>71.78</td>
<td>0.84</td>
</tr>
</tbody>
</table>

Further, Table 4.8 and Figure 4.8 illustrate that Ted’s honors chemistry students in were predominantly identified as intermediate according to the IMMEX instrument.

Table 4.8

*Summary of Ted’s Students’ IMMEX Results Shown by Level*

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Low</th>
<th>Intermediate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honors</td>
<td>35</td>
<td>8.6</td>
<td>82.9</td>
<td>8.6</td>
</tr>
</tbody>
</table>
As a result of observing Ted’s interactions with students and the documents related to his teaching philosophy, planning and methods, the following potentially problematic teacher-practice emerged:

- an abundant use of step-wise, prescriptive, rote verification experiments.

Ted’s teaching routine involved teacher-led instruction followed by student practice. He used rote verification experiments where students were guided by a procedure sheet, and during lab, his use of proactive strategic, questions during instruction seemed limited.

Ted’s instruction of mathematics-based problem-solving strategies seemed to cognitively engage students to a substantial level. This was illustrated during the laboratory discussion related to density. Ted seemed to interest his students by teaching chemistry as an emerging story with embedded “hooks” to stimulated students’ curiosity.
and inspire them to remain engaged in lessons. During each classroom observation, his students appeared to be attentive and mentally engaged, as indicated by the number of students who were willing to ask and answer questions, as well as edit the questions they had completed for homework.

Ted’s incorporation of contemporary teaching methods including the use of computer animations to connect microscopic to macroscopic chemistry concepts was evident throughout the research process. He also had a savvy way of asking questions during the teacher-led discussions. However, his lack of proactive questioning and students monitoring during the lab process may have caused his students to inadequately connect classroom concepts to lab. These shortcomings might explain in part why his students did not self-report higher metacognitive skillfulness at the p=0.05 level and why fewer than 10% of his students demonstrated high metacognitive skillfulness.

It is important to note that during the school year after I observed Ted and his students, I made a follow-up visit. At that time, Ted informed me that due to several administrative decisions that infringed upon his time outside of class instruction, he had stopped requiring lab reports and began using multiple choice assessments more. Ted stated that it was not feasible for him to give assignments that required thorough reading and specific feedback on his part because he simply lacked the time. It seemed that Ted’s efforts to challenge each student and inspire their curiosity had succumbed to the time constraints imposed by Oak High’s administration.
Cumulative Interpretive Summary

The results of the MCA-I evaluative tool indicated that none of the instructors’ students showed a significant change at the $p=0.05$ level at any of the instructional levels (college preparatory, honors, chemistry II advanced placement) studied. Further, the intermediate IMMEX strategy descriptor was the predominate state for all levels. At least two-thirds of the students demonstrated this level of metacognitive skillfulness at the end of the study with one exception. In one teacher’s advanced placement class, just over one-half of the students placed in the intermediate state. Further, one-third of the students in this class demonstrated high metacognitive skills. No other teacher had a group of students in which greater than 10% showed high metacognitive skills.

Three of the four teachers taught chemistry courses at different instructional levels. In two of these cases, as expected, students who were in the higher-level classes demonstrated high metacognitive skillfulness in larger percentages and low skillfulness in smaller percentage than did those who were in the lower-level classes. In the case of the other teacher, which involved college preparatory, honors, and advanced placement levels, a reverse trend was found. Surprisingly, the advanced placement class had the smallest percentages of high metacognitive skillfulness and the largest percentage of low skillfulness, while the college preparatory class demonstrated the largest percentage of high metacognitive skillfulness and the smallest percentages of low skillfulness.

As a result of observing the four teachers interactions with students and the documents related to their teaching philosophies and lesson plans, several potentially problematic teacher-practice themes emerged. These include incorporation of lesson
plans with inadequate details, use of prescriptive rote verification experiments, and inadequate use of probing questions and an over-emphasis on mathematical algorithms during instruction. These undesirable practices, summarized in Table 4.9, may have limited the students’ development of the important metacognitive skills of planning, monitoring and evaluating during their academic pursuits.

Table 4.9

<table>
<thead>
<tr>
<th>Teacher Practice</th>
<th>Laura</th>
<th>Dr. Wise</th>
<th>Suzy</th>
<th>Ted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abundant use of step-wise, prescriptive, rote verification experiments</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Over-emphasis on mathematical algorithms</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>Inadequate use of proactive, probing questions during instruction</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>Absence of detailed and sophisticated lesson planning</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
</tr>
</tbody>
</table>

Note. (✓) indicates that the teacher used the practice and (-) indicates that the teacher did not seem to use it.

Two of the instructors demonstrated all four of these undesirable teaching practices and one demonstrated the use of three. It is encouraging that one teacher was found to make use of only one of these practices. Unfortunately, three-fourths of the teachers were found to over-emphasize mathematical algorithms at the expense of adequate coverage of chemistry concepts. Further, all of them seemed to rely on the use
of step-wise, rote verification lab experiments that may have been relatively ineffective in helping students develop metacognitive skills, as compared to student-centered activities that encourage more planning, monitoring, and evaluation during the learning process.

The second research question compared the practices in the literature which hold promise in the area of teaching for metacognition to the practices observed in this study. The comparison of teacher practices which emerged from this study and those described in the promising practices is shown in Table 4.10. The observed teacher practices were found to be in sharp contrast to the related promising practice in the literature. The teachers’ small group activities not appear to require students to engage in a deeply cognitive manner or have students reflect, monitor and evaluate their conceptions. Further, the questioning practices of the observed teachers did not seem to consistently probe students’ understanding and require them to reveal, reconcile and justify their ideas. The teachers used an abundance of rote verification experiments where students followed step-wise procedures. This practice contradicts the promising inquiry-based practices that inherently utilize metacognitive skills. Further, the observed teachers’ requirement of written lab reports did not seem to elicit deep reflection among students and their use of small group activities did not require students’ to reflect on, explain and validate their ideas.
Table 4.10

Comparison of Promising Metacognitive Practices with Observed Teaching Practices

<table>
<thead>
<tr>
<th>Promising Metacognitive Teacher Practices</th>
<th>Aligned With Observed Practices?</th>
<th>Observed practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inquiry-based laboratory instruction</td>
<td>X</td>
<td>Use of rote verification experiments</td>
</tr>
<tr>
<td>Explicit metacognitive guidance,</td>
<td>X</td>
<td>Little use of strategic, probing questions</td>
</tr>
<tr>
<td>using prompt questions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Requirement of students to reveal and</td>
<td>X</td>
<td>Absence of requirement for students to deeply and</td>
</tr>
<tr>
<td>monitor thinking</td>
<td></td>
<td>deliberately reflect on ideas</td>
</tr>
<tr>
<td>Use of cooperative learning groups with</td>
<td>X</td>
<td>Use of group work to accomplish tasks using provided</td>
</tr>
<tr>
<td>a metacognitive component</td>
<td></td>
<td>stepwise directions</td>
</tr>
<tr>
<td>Explicit training to help students</td>
<td>X</td>
<td>Little-to-no training to help students develop</td>
</tr>
<tr>
<td>develop metacognitive skills</td>
<td></td>
<td>metacognitive skills</td>
</tr>
</tbody>
</table>

Note. A (√) indicates that observed practices align with promising practices and an (X) indicates that observed practices did not appear to align.

The teachers indicated that time constraints prevented them from planning and preparing more extensively. Further, they suggested that a lack of knowledge regarding the implementation of inquiry-based learning activities and unfamiliarity with teaching for metacognition stood in their way of moving away from their current practices. The teachers seemed to rely on the practices with which they were the most comfortable and, in all likelihood, felt to be the most time efficient mechanisms by which to cover the state standards’ extensive content.
CHAPTER FIVE

DISCUSSION

“When appreciation of metalearning [metacognition] pervades the teaching profession, the whole operation of schools will alter in ways that make it easier for students to reflect and learn with understanding.”


Conclusion

The focus of this study was to explore what, if any, high school chemistry teachers’ practices may explain students’ metacognitive skillfulness. In addition, the study sought to compare actual teachers’ practices to those exemplified in the literature as holding promise for teaching for metacognition.

The majority of the students in all four cases were categorized with the IMMEX intermediate metacognitive strategy descriptor state, suggesting that they possessed a limited ability to effectively unify prior knowledge and apply it to problem solving situations, such as laboratory experiences. This was found to be the case at all instructional levels, including college preparatory, honors, and advanced chemistry. Further, the MCA-I indicated that students’ self-perception of their metacognitive skillfulness did not change at the p=.05 level after exposure to their teachers’ practices in any of the cases, regardless of the instructional level.

The findings of the study represent four emergent teacher practices that may in part help explain students’ lack of development of metacognitive skillfulness including:

• an emphasis on mathematical algorithms at expense of adequate coverage of important chemistry concepts;

136
• an abundant use of step-wise, prescriptive, rote verification experiments rather than activities that may cognitively involve students to a greater degree;
• an inadequate use of proactive, probing questions during instruction; and
• an absence of detailed and sophisticated instructional planning.

The participating teachers did not make use of these potentially problematic practices to the same extent. While two of the teachers were found to routinely employ all four of these methods that potentially limit development of metacognitive skillfulness, one teacher revealed the use three of the practices and another used only one. The worrisome teaching practice exhibited in all cases was the incorporation of step-wise, prescriptive, rote verification experiments rather than activities that may have provided students with deeper opportunities to plan, monitor and evaluate to a greater degree during the learning process. Since the MCA-I results indicated no change in students’ perception of metacognitive skillfulness regardless of the teacher, potentially problematic teaching strategies may not have equal influence on the hindrance of metacognitive skill development. The findings of this study suggest that the routine use of rote verification experiments may play a relatively large role in impeding the development of these skills.

Students conducting the prescriptive, rote verification experiments seemed to work with a task-accomplishment mentality. These observations support Hodson’s (1990) assertion that this type of lab work is unproductive since it does not require students to work with a clearly thought-out purpose. Students’ dependence on their lab procedures’ step-by-step instructions seemed to inhibit the development of their metacognitive skillfulness. Further, students’ perception of planning seemed to be collecting necessary
lab materials, while monitoring appeared to be equated with determining which procedural steps had been carried out and evaluating seemed to be a critique of whether all necessary data had been collected.

Overall, the students in all cases seemed to be familiar with performing the laboratory tests dictated by their procedure sheets, but they seemed to lack the ability to connect the chemistry concepts from classroom discussions to the specific laboratory activities that were intended to support these concepts. The fact that the majority of the students demonstrated the IMMEX intermediate metacognitive strategy state rather than the high state in all cases most likely resulted from the teachers’ abundant use of prescriptive laboratories. The intermediate metacognitive strategy state seems fitting for most of the students based on the observed practices of their teachers. This middle-level strategy state represents students who either use background knowledge and lab tests equally or overcompensate for uncertainty with an abundant use of lab tests (Sandi-Urena, 2008).

Promising practices for teaching for metacognition include inquiry-based methods that inherently require students to plan, monitor and evaluate their conceptual understanding during the learning process (Sandi-Urena, 2010; Cooper et al., submitted; Rickey & Stacey, 2000). These practices make use of proactive strategic questioning to force students to reveal and reconcile their ideas. While the participating teachers indicated that they recognized the potential value of inquiry-based teaching strategies, all stated that they did not have enough time to develop the extensive lesson plans these methods require. Further, all pointed out that they lacked the necessary time to provide
orientations to help students learn how to engage in the inquiry process and to regularly engage students in peer discussion with evidence-based arguments. The pressure of covering all of the state’s required chemistry standards seemed to exacerbate these struggles and may explain in part why these teachers did not use inquiry-based teaching methods and probing questioning techniques which they may have perceived as relatively time inefficient. Further, the teachers have likely continued to rely on rote verification experiments in part because of their comfort and familiarity with these practices.

**Implications for School Administrators**

This study identified several teacher practices which may be relatively ineffective in developing students’ metacognitive skills. All of the participating teachers identified insufficient time as the main reason they did not incorporate inquiry-based activities that would have perhaps engaged students in a more meaningful, reflective learning experience. Administrators should give teachers more time to plan inquiry-based lessons and labs. As Hennessey (1999) pointed out, it takes a significant amount of time to have students meaningfully negotiate their ideas. Further administrators should provide teachers time to reflect on the effectiveness of their methods on students’ conceptual understanding. Moreover, administrators should provide teachers with professional development opportunities to educate them of the important role metacognitive skillfulness plays in developing conceptual understanding.

As indicated by Rickey & Stacey (2000), teachers need to understand the merit of metacognitive skills in helping students unify concepts discussed during class with labs intended to reinforce them. An increased awareness of the value of metacognitive
skillfulness would likely motivate teachers to move away from rote verification experiments in pursuit of those involving inquiry-based instruction. Equipping teachers with the knowledge and skills necessary to transition to inquiry-based instruction could also be facilitated through professional development.

**Implications for Chemistry Teachers**

The findings of this study suggest that teachers should assess the effectiveness of their teaching practices in strengthening their students’ metacognitive skills and their abilities to unify prior knowledge with laboratory activities. Current methods of assessment such as convergent tests and written lab reports may not provide adequate data with which to measure students’ metacognitive skill development and the extent to which they are able to connect their laboratory experiments with classroom concepts. Coupled with professional development related to the importance of metacognitive skillfulness, the results of these assessments may inspire teachers to reconsider the familiar practices on which they have relied for perhaps many years. Their implementation of promising practices would likely heighten students’ cross-contextual understanding of the key chemistry concepts while also strengthening their metacognitive skills.

Pre-service teachers should be trained to instinctively use promising practices such as inquiry-based methods and pro-active strategic questioning that requires students to plan, monitor, and evaluate their ideas during the learning process. Further, these teachers should be taught the necessary skills with which to develop evidence-based
assessment instruments to use in the analysis of their teaching effectiveness. Training should also encourage them to become lifelong learners who change their teaching practices as needed.

**Recommendations for Further Research**

The findings of this study open doors for future research that examines the effectiveness of teacher practices on students’ ability to apply knowledge across contexts in the sciences or other subjects. This study substantiates the need for more insight into teachers’ ability to assess the effectiveness of their practices.

More broadly, this study lays a foundation for future research regarding the role teacher practices play in increasing students’ metacognitive skillfulness and bringing about experiences that connect laboratory experiences with concepts discussed in the classroom. These findings hold promise for other disciplines of science such as physics and biology. Further, these revelations regarding the importance of teacher practices will likely have a positive impact on areas outside of the fields related to science.

**Limitations**

Due to the exploratory nature of this study, teacher-practice interventions were not implemented and the study acknowledged an inability to control all variables that may have influenced students’ metacognition. It was the goal of this study to use four case studies to illuminate teacher practices and possibly reveal issues of further interest to the research community and the field of chemistry education. This primary research study
provides information related to teacher practices that warrant further research regarding the ways in which to teach effectively for metacognition.
APPENDICES
Appendix A

Email to Schools for Site Selection

EMAIL TO SCHOOLS FOR SITE SELECTION

I am a doctoral student at Clemson University seeking participants in my dissertation study. I currently teach chemistry and biology full time at SC Governor's School for the Arts while working on my PhD at Clemson. I anticipate the opportunity to speak with you and your chemistry teacher in order to have your school participate in my study. After reading the description about my study below, I hope you will feel comfortable to let me communicate with you and/or your chemistry teacher in order to move forward with your school’s participation in my study.

Briefly, my study involves a 20 minute chemistry problem solving inventory survey and a student questionnaire to be given on one occasion and the same problem solving inventory survey to be given at the end of the instructional term. I cannot do anything without principal approval to speak with the chemistry teacher to see if he or she is interested in assisting me. Schools and participants names are never used; all data is coded to preserve anonymity. I would greatly appreciate the opportunity to work with your chemistry teacher and the chemistry students.

Participation involves the following steps:
1. Principal approval to speak with the chemistry teacher
2. I speak with the chemistry teacher. **If he/she agrees to participate...
3. Parent permission slips have to be signed. (I have all of this).
4. Students have to sign a consent to participate form.
5. Students complete the 2 surveys (chemistry problem solving and personal information - like age, gender, etc...)
6. Teachers return the bubble sheets used for the surveys in an envelope I've supplied.
7. 12 weeks later teachers give the same chemistry problem solving survey and mail that back to me.

If you approve of my speaking with your chemistry teacher, Clemson requires a "letter of support" signed by you. Below I will write a statement which you may copy and paste to a document you can sign and fax to me.

Please feel free to call me or email me if you have any questions.
Joni R. Jordan - cell phone 864-346-4693; home phone: 864-292-8946;
email: jjordan@segsh.state.sc.us

It would be a tremendous help to me if you all could participate. I greatly appreciate your consideration. The statement you may fax to me with your signature is below.

Thanks again for your consideration.

FAX NUMBER: 864-282-3755
Statement of Support:
I support Joni Jordan's request to speak to my chemistry teacher in order to possibly participate in her dissertation study. I understand that if we participate, names of schools and participants will be coded to retain anonymity. I understand the study involves the completion of 2 surveys, taking approximately 20 minutes total, with an additional survey given at the end of the instructional term.

Signature

Date:
Appendix B
Institutional Review Board Application

Research Application Form for Expedited and Full Review
http://www.clemson.edu/research/orcsite/indexcomply.htm

IRB use only: Proposal Number: Date Stamp: 
☐ Approved ☐ Full Committee ☒ New ☐ Revised Revision date: 
Expiration date: ____________________ 
Signature of IRB Chair/Designee Date: ____________________

I. Review Status. ☒ Expedited ☐ Full Committee ☒ New ☐ Revised Revision date:

II. Research title. (If a grant application exists, include the exact title listed there. You may use a subtitle after the grant application title to denote a specific research protocol.)

How do high school chemistry teachers’ practices explain students’ metacognition?*** (Edited later in study)

III. Principal Investigator. The PI must be a member of the Clemson faculty or staff. You cannot be the PI if this is your thesis or dissertation. The PI must have completed IRB-approved human research protections training.

Name:** Jeff Marshall (Original Chair) Status: ☒ Faculty 
☐ Staff 
Mailing Address: 418G Tillman Hall Clemson, SC 29634-0175
School of Education ☒864-656-2059 ☐ manha9@clemson.edu 
Department Telephone ☐ E-Mail Address 

IV. Co-investigators. Co-investigators must have completed IRB-approved human research protections training. If necessary, list additional co-investigators on additional sheets.

Name: Joni R. Jordan Status: ☐ Faculty ☐ Staff 
☒ Graduate Student ☐ Undergraduate Student 
☐ Other. Please specify. 
Mailing Address: 104 Wappoo Lane Taylors, SC 29687-4150
Graduate School of Education ☒864-292-8946 ☐ jordan@scetsah.state.sc.us 
Department Telephone ☐ E-Mail Address 
Name: ☐ Status: ☐ Faculty ☐ Staff
☒ Graduate Student ☐ Undergraduate Student 
☐ Other. Please specify. 
Mailing Address: 

Department Telephone ☐ E-Mail Address 

Page 1 of 8
V. Anticipated Dates of Research. Please note, human subjects research includes analysis of data.
Anticipated start date (cannot be prior to IRB approval; may state “upon IRB approval”): August 27, 2007.
Anticipated completion date: December 1, 2007

VI. Agreement and Statement of Assurance by the Principal Investigator.
I have reviewed this research protocol and the consent form, if applicable. I have also evaluated the scientific merit and potential value of the proposed research study, as well as the plan for protecting human participants. I have read the Terms of the Assurance held by Clemson University (http://www.hhs.gov/ohpe/humansubjects/assurance/fiar.htm) and commit to abiding by the provisions of the Assurance and the determinations of the IRB. I request approval of this research study by the IRB of Clemson University.
I understand that failure to adhere to any of these guidelines may result in immediate termination of the research. I also understand that approval of this research study is contingent upon my agreement to:
1. Report to the IRB any adverse events or research-related injuries that occur;
2. Submit in writing for IRB approval any proposed revisions or amendments to this research study;
3. Submit timely continuing review reports of this research as requested by the IRB; and
4. Notify the IRB upon termination of this research study.

_________________________________  ____________________________
Signature of Principal Investigator                      Date

VII. Statement of Assurance by Department Chair (or supervisor if PI is Department Chair).
I have reviewed this research protocol and the consent form, if applicable. I verify this proposed research study has received approval in accordance with department procedures. I have evaluated the plan for protecting human participants. I have read the Terms of the Assurance held by Clemson University (http://www.hhs.gov/ohpe/humansubjects/assurance/fiar.htm) and commit to abiding by the provisions of the Assurance and the determinations of the IRB. I request approval of this research study by the IRB of Clemson University.

_________________________________  ____________________________
Signature of Department Chair                      Date

VIII. Conflict of Interest Statement.
Could the results of the study provide an actual or potential financial gain to you, a member of your family, or any of the co-investigators, or give the appearance of a potential conflict of interest?
☐ NO.
☐ Yes. I agree to disclose any actual or potential conflict of interest prior to IRB action on this study.

_________________________________  ____________________________
Signature of Principal Investigator                      Date

Page 2 of 8
IX. Research Team. (All personnel/students responsible for study design, obtaining consent, and data collection. Members of the research team must have completed IRB-approved human research protections training.)

List members of the research team other than the individuals listed on the first page. If necessary, list additional research team members on additional sheets.

<table>
<thead>
<tr>
<th>Names</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joni R. Jordan</td>
<td>Faculty</td>
</tr>
<tr>
<td></td>
<td>Graduate Student</td>
</tr>
<tr>
<td></td>
<td>Undergraduate Student</td>
</tr>
<tr>
<td></td>
<td>Other, Please specify.</td>
</tr>
</tbody>
</table>

X. Research Team Roles.

Describe the role of each member of the research team, indicating which research activities will be carried out by each particular member. Team members may be grouped into categories. Individuals are “engaged” in human subjects research and are, therefore, members of the research team, when they (i) intervene or interact with living individuals for research purposes; or (ii) obtain individually identifiable private information for research purposes. Federal guidance on what constitutes engagement in human subjects research may be found at http://www.hhs.gov/ohrp/humansubjects/assurance-engage.htm.

Description: All research activities will be carried out by Joni Jordan.
1. Students fill in a scantron (bubble sheet) to respond to a metacognitive (problem solving) inventory survey. This survey will be given on two occasions, approximately 14 weeks apart.
2. Teachers fill in a survey to respond to a series of questions relating to teaching practices utilized in the classroom.
3. Teachers will be interviewed.
4. Teachers will be observed a minimum of two class periods.

XI. Other IRB Approvals.

Has this research study been presented to any other IRB? ☐ Yes  ☒ No  ☐ Pending

Where? ______

If yes, what was their decision?  ☐ Approved  ☐ Disapproved

Please attach a copy of any prior actions

XII. Study Locations and Recruitment Method.

☐ Clemson University  ☒ School System  High schools agreeing to participate throughout South Carolina
☐ Other—specify location ______

Describe how research participants will be recruited in the study. How will you contact them? Attach a copy of any material you will use to recruit participants (e.g., advertisements, flyers, telephone scripts, verbal recruitment, cover letters, or follow-up reminders). Will the participants be recruited through schools, employers, or community organizations? Are you required to obtain permission to gain access to people or to access data that are not publicly available? If yes, provide a letter of support from the person authorized to give you access to the participants or to the data.

Description: South Carolina school districts and principals will be contacted for approval to communicate with the chemistry teachers at their school. Chemistry teachers will be contacted via email, telephone and/or written letter requesting participation of their chemistry students. The chemistry students will be asked to participate by their classroom teacher.

☐ Letter(s) of support not required.
☐ Letter(s) of support attached.
☒ Letter(s) of support pending and will be provided when obtained.

XIII. Study Population. (Groups specifically targeted for study)

Describe the participants you plan to recruit and the criteria used in the selection process. Indicate whether the participants are 18 years of age or older. Indicate the approximate number of participants to be recruited. Indicate if there are any special inclusion or exclusion criteria.

Description: High School students who are likely under the age of 18, who are currently enrolled in chemistry. An attempt will be made to obtain 300 participants.

Age range of participants: 15-18
Projected number of participants: 300

☐ Employees ☒ Students ☒ Minors (under 18) *
☐ Pregnant women * ☐ Prisoners * ☐ Educationally/economically disadvantaged *
☐ Other—specify: ______

*State necessity for using this type of participant. The study involves high school chemistry and therefore high school chemistry students' participation is needed.

XIV. Funding Source. (Include a copy of the grant proposal if the study is funded or is part of a proposal for funding.)

☒ Not funded
☐ Submitted for external funding ☐ Externally funded

Funding agency, if applicable (Do not use initials alone): ______

☐ Submitted for internal funding ☐ Internally funded
☐ Support provided by Creative Inquiry Initiative
Other internal funder, if applicable (Do not use initials alone): _____

XV. Study Purpose. Provide a brief description of the purpose of the study in non-technical terms.

Description: The study seeks to obtain a sample of scores from high school students on a metacognitive (problem solving) inventory survey. The metacognitive inventory is currently being researched and given at Clemson University to freshman chemistry students. No current baseline exist for this inventory related to high school students. Teaching practices will examined to determine the extent to which any influence the metacognitive scores; in addition, item analysis of the metacognitive survey will be analyzed to determine if any specific components of metacognition are influenced by teacher practices.

XVI. Informed Consent. Templates: [http://www.clemson.edu/research/orcSite/orcIRB_Consent.htm](http://www.clemson.edu/research/orcSite/orcIRB_Consent.htm)

Will the title on the consent documents differ from that on the research application? □ Yes ☒ No If yes, title to be used on consent documents: _____

Are you seeking waiver of consent? □ Yes □ No If yes, attach justification.

☐ waiver of all required elements of consent ☐ waiver of some required elements of consent
[http://www.clemson.edu/research/orcSite/IRBforms/doc/justification.doc](http://www.clemson.edu/research/orcSite/IRBforms/doc/justification.doc)

☑ waiver of documentation of consent (signature)
[http://www.clemson.edu/research/orcSite/IRBforms/doc/WaiverOfConsent.doc](http://www.clemson.edu/research/orcSite/IRBforms/doc/WaiverOfConsent.doc)

Who will obtain the participant’s consent? □ Principal Investigator ☒ Co-Investigator ☐ Research Assistants ☐ Contracted/Hired Data Collection Firm: _____ □ Other: _____

XVII. Participant Remuneration.

Will participants receive monetary remuneration? □ Yes ☒ No

Amount: $_____ Payment Schedule: _____

Will participants receive incentive gifts? □ Yes ☒ No

Type: _____ Value: $_____ Award schedule: _____

XVIII. Procedures.

Describe the means you will use to obtain the data and the type of data to be collected. Describe all procedures in which participants will participate. If data collection instruments will be used, indicate the time necessary to complete them, the frequency of administration, and the setting in which they will be administered, such as by phone, mail, or in person. If follow-up data collection may occur, please describe this. Include copies of surveys and interview questions. Please note if procedures are new (experimental) or established. If survey or interview questions have not been fully developed, provide information on the types of questions to be asked. Please note: finalized survey or interview instruments will need to be reviewed and approved as amendments, before implementation.
Description: Student participants will complete a metacognitive (problem solving) inventory survey and teachers will complete a survey relating to teaching practices. In addition, teachers will be interviewed and observed. The metacognitive inventory survey will be given again approximately 14 weeks later. The time required for the metacognitive inventory and the teacher survey is approximately 20 minutes. Teacher interviews will last approximately 45 minutes, while teacher observations will occur a minimum of two class periods.

XIX. Protection of Confidentiality.

Describe the measures you will take to protect the confidentiality of the information obtained. Investigators are required to protect the confidentiality of the information obtained during research, unless the participants explicitly agree to be identified and/or quoted. Will participants be identifiable either by name or through demographic data? If yes, how will you protect the identity of the participants and their responses, where will the data be stored and how will it be secured, who will have access to the data, and how will identifiers be maintained or destroyed after the study is completed? Please note: all research records must be maintained for at least three years following completion of the research study.

Description: The identification of participants will never be used. All surveys and will be numerically coded. I will assign numeric codes and pseudonyms to all schools and participants. No real names of schools or participants will ever be utilized by anyone other than Joni Jordan. I will code and encrypt the data on the transportable flash drive, all data will be stored, coded and encrypted on my home computer.

XX. Risk/benefit analysis.

Describe all potential risks and benefits for this study. Risks can include physical, psychological, social, legal or other risks connected with the proposed procedures. Benefits can include benefits to the participant or to society in general.

Description: Benefit comes from using the data to create interventions that may lead to improved metacognitive (problem solving) skills for students through effective teaching practices.

Describe the procedures to be used to protect against or minimize potential risks. Assess the likely effectiveness of these procedures.

Description: All surveys are numerically coded to avoid the use of names of participants. This enables participants to answer questions without the possibility of embarrassment.

Briefly state the risk/benefit ratio (this is a verbal description, not a numerical ratio).

Description: The potential for benefit is much greater than risk. Results from the study will provide the opportunity to enhance students' metacognitive skills. Due to the numerical coding and lack of association of answers to individuals, risk is minimum.

XXI. Expedited Review Checklist. To determine whether this study meets the federal requirements for expedited review [45 CFR 46.110], please complete the following checklist. This checklist will indicate if your study can be expedited, or if it must be presented to the full IRB for review.

Yes ☐ No ☒ Does this project include any procedures that present more than minimal risk to the participants? (A project is considered to present minimal risk if the probability and

Page 6 of 8
magnitudes of harm or discomfort anticipated in the research are not greater than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations.)

Note: The expedited review procedure may not be used if identification of the participants and/or their responses would reasonably place them at risk of criminal or civil liability or be damaging to their financial standing, employability, insurability or reputation, unless reasonable and appropriate protections will be implemented so that risks related to invasion of privacy and breach of confidentiality are no greater than minimal.

If your study presents no more than minimal risk to participants, your study may be eligible for expedited review. Please complete the following questions to determine whether the only involvement of human participants will be in one or more of the following categories.

Note: The activities listed below should not be deemed to be of minimal risk simply because they are included in the list. Inclusion in this list merely means that the activity is eligible for review through the expedited review procedure if the specific circumstances of the proposed research involve no more than minimal risk to human participants.

Yes ☐ No ☒ 1. Clinical studies of drugs and medical devices only when condition (a) or (b) is met:
   (a) Research on drugs for which an investigational new drug application is not required.
   Note: Research on marketed drugs that significantly increase the risks or decrease the acceptability of the risks associated with the use of the product is not eligible for expedited review.
   (b) Research on medical devices for which 1) an investigational device exemption application is not required or 2) the medical device is cleared or approved for marketing and the medical device is being used in accordance with its cleared/approved labeling.

Yes ☐ No ☒ 2. Collection of blood samples by finger stick, heel stick, ear stick, or venipuncture as follows:
   (a) From healthy, non-pregnant adults, who weigh at least 110 pounds. For these subjects, the amount drawn may not exceed 550 mL in an eight week period and collection may not occur more than two times per week; or
   (b) From other adults and children, considering the age, weight, and health of the subjects, the collection procedure, the amount of blood to be collected, and the frequency with which it will be collected. For these subjects, the amount may not exceed the lesser of 50 mL or 3 mL per kg in an eight-week period, and collection may not occur more than two times per week.

Yes ☐ No ☒ 3. Prospective collection of biological specimens for research purposes by non-invasive means.

Examples: (a) hair and nail clippings in a non-disfiguring manner; (b) deciduous teeth at time of exfoliation or if routine patient care indicates need for extraction; (c) permanent teeth if routine patient care indicates need for extraction; (d) excreta and external secretions (including sweat); (e) uncultured saliva collected either in an unstimulated fashion or stimulated by chewing gum base or xyn or by applying a dilute citric solution to the tongue; (f) placenta removed at delivery; (g) amniotic fluid obtained at the time of rupture of the membrane prior to or during labor; (h) supra- and subgingival dental plaque and calculus, provided the collection procedure is not more invasive than routine scaling of the teeth and the process is accomplished in accordance with accepted prophylactic techniques; (i)
mucosal and skin cells collected by buccal scraping or swab, skin swab, or mouth washings; (j) sputum collected after saline mist nebulization.

Yes [X] No [ ] 4. Collection of data through non-invasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.) Examples: (a) physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subject’s privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, Doppler blood flow and echocardiography, (e) moderate exercise, muscular strength testing, body composition assessment, and flexibility testing when appropriate given the age, weight, and health of the individual.

Yes [X] No [ ] 5. Research involving materials (data, documents, records, or specimens) that have been collected or will be collected solely for non-research purposes (such as medical treatment or diagnoses).

Yes [X] No [ ] 6. Collection of data from voice, video, digital, or image recordings made for research purposes.

Yes [X] No [ ] 7. Research on individual or group characteristics, behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior), or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

XXII. Checklist of documents accompanying this application.

☐ Grant proposal, if the study is funded or is part of a proposal for funding.
☒ Recruitment documents, if applicable.
☒ Letters of support, if applicable.
☒ Surveys, interview questions, tests, or data collection sheets, if applicable. If survey or interview questions have not been fully developed, provide information on the types of questions to be asked.
☒ Informed consent form or justification of request for waiver.

Submit this application by e-mail to Laura Moll, IRB Coordinator (lmoll@clemson.edu). One signed paper copy should also be sent to the Office of Research Compliance, 223 Bracken Hall, Clemson, SC 29634-5704. Should you have any questions, contact Laura Moll at 864-656-0469.
Appendix C

Teacher Consent Form

Teacher Consent - Information Concerning Participation in a Research Study
Clemson University

*How do high school chemistry teachers’ practices explain students’ metacognition?

Description of the research and your participation

You are being invited to participate in a research study conducted by Dr. Jeff Marshall*, a Clemson University professor and graduate student, Joni Jordan. The purpose of this research is to examine students’ self-reported approaches to chemistry problem solving and investigate possible teacher practices that may influence these approaches.

Your participation will involve completing a 28-question survey (which is the same as the students are completing) on one occasion. You will be asked to allow the researcher to observe at least two chemistry class periods, followed by a semi-structured interview. Finally, you will be asked to complete a teacher questionnaire inquiring about your teaching practices.

The amount of time required for your participation would be as follows:
- Metacognitive inventory (what students complete) – 20 minutes
- Classroom observations – minimum 2 class periods (same day preferred)
- Semi-structured interview – 30 – 45 minutes
- Teacher questionnaire – 20 minutes

During the classroom observation, no audio taping or videotaping will be done and no contact will be made with students.

Risks and discomforts

To minimize any risk of distraction during the observations, the researcher will sit quietly in a discrete location within the classroom. The researcher will maintain complete confidentiality with all information that is discussed and collected during the research process. No identities of any school, teacher or student will ever be used. The researcher will assign pseudonyms.

Potential benefits
The benefits from the research have great potential. Little research has been performed to try to “score” a student’s metacognitive skillfulness. Clemson University researchers have developed a metacognitive survey that, while in its initial stages of development, may enable teachers to efficiently and effectively “score” this student characteristic. My research contributes to research that already exists which examines teacher practices that are believed to influence students’ metacognitive skillfulness.

**Protection of confidentiality**

All information collected by the researcher will remain only with the researcher. All school, teacher and student identities will be coded to maintain confidentiality. The stored data will be encrypted on the mobile storage device and all data collected will be kept solely at the researcher’s home computer and will also be encrypted at that location. No identities of any school, teacher or student will ever be used. The researcher will assign pseudonyms.

**Voluntary participation**

Although your principal has given me permission to speak with you about participating, your participation in this research study is voluntary. You may choose not to participate and you may withdraw your consent to participate at any time.

**Contact information**

If you have any questions or concerns about this study or if any problems arise, please contact Jeff Marshall at Clemson University at 864-686-2059. If you have any questions or concerns about your rights as a research participant, please contact the Clemson University Institutional Review Board at 864.656.6460.

*The original research question before subsequent committee changes.

*Jeff Marshall was the original committee chair, replaced by Co-chairs, Dr. Bea Bailey and Dr. Melanie Cooper.
Appendix D

Student Assent Form

STUDENT ASSENT TO PARTICIPATE IN A RESEARCH STUDY

How do high school chemistry teachers’ practices explain students’ metacognition?

You are being invited to participate in a research study. Below you will find answers to some of the questions that you may have.

What is the purpose for the study?
- This study attempts to better understand students’ self-awareness of how they approach chemistry problem solving and teacher practices that may influence these approaches.

Why me?
- Since this study concerns high school chemistry, it is important to get high school chemistry students to participate.
- Your participation is completely voluntary and you will not be penalized if you choose not to participate.

What Will I Have to Do?
- You will be asked to complete a 28-question survey relating to chemistry problem solving (called “Students’ Activities in Problem Solving Survey”). The total time for completion is approximately 20 minutes. I may also observe your teacher teaching one day during your chemistry class.

Did My Parents Say It Was Okay?
- You can only participate with your parents’ permission.

Who Will Be Helped By This Research?
- Your participation will help teachers better understand student approaches to chemistry problem solving. The result could be the ability to help students improve their problem solving skills in chemistry.

What If I Want to Stop? Will I Get In Trouble?
- Participation is completely voluntary and you may choose to quit at any time with no penalty.
- The research in no way will be used to positively or negatively impact your grades, participation in programs, etc.

It is also important to remember that your school and individual identity will remain strictly confidential.

By signing below, I am saying that I have read this form and have asked any questions that I may have. All of my questions have been answered so that I understand what I am being asked to do. By signing, I am saying that I am willing and would like to participate in this study. I also have received a copy of this form to keep.

Signature of Child Student ___________________________ Date ___________________________

October 16, 2007
Appendix E

Parent Permission Form

Parental Permission Form for Participation of a Child in a Research Study
Clemson University

*How do high school chemistry teachers’ practices explain students’ metacognition?

Description of the research and your child’s participation

Your child has been invited to participate in a research study conducted by *Dr. Jeff Marshall, a Clemson University professor and graduate student, Joni Jordan. The purpose of this research is to examine students’ self-reported approaches to chemistry problem solving using a survey and examine possible teacher practices that may influence these approaches.

Your child’s participation will involve completing a 28-question survey on two different occasions spaced approximately 14 weeks apart.

The amount of time required for your child’s participation would be approximately 20 minutes for completion of each survey.

I may also observe the teacher teaching during your child’s chemistry class on one occasion. During this observation, no audiotaping or videotaping will be done and no contact will be made with students.

Risks and discomforts

There are no known risks associated with this research.

Potential benefits

The benefits that may result from this study include the ability to measure students’ problem solving strategies in order to provide intervention where improvement may be sought.

Protection of confidentiality

Numerical codes are assigned to all surveys. At no time will names ever be utilized.

In rare cases, a research study will be evaluated by an oversight agency, such as the Clemson University Institutional Review Board or the federal Office for Human
Research Protections that would require that we share the information we collect from your child. If this happens, the information would only be used to determine if we conducted this study properly and adequately protected your child’s rights as a participant.

**Voluntary participation**

Participation in this research study is voluntary. You may refuse to allow your child to participate or withdraw your child form the study at any time. Your child will not be penalized in any way should you decide not to allow your child to participate or should you withdraw your child from this study.

**Contact information**

If you have any questions or concerns about this study or if any problems arise, please contact *Jeff Marshall at Clemson University at 864-686-2059. If you have any questions or concerns about your child’s rights as a research participant, please contact the Clemson University Institutional Review Board at 864.656.6460.

**Consent**

I have read this parental permission form and have been given the opportunity to ask questions. I give my permission for my child to participate in this study.

Parent’s signature: ___________________________ Date: ______________

Child’s Name: ___________________________

*The original research question before subsequent changes in committee members.

*Dr. Jeff Marshall was the original committee chairperson, replaced by Co-chairs Dr. Bea Bailey and Dr. Melanie Cooper.
the entries acidity/alkalinity, electrical conductivity, and reaction with acid/base refer to the listed item when in aqueous solution

**alkaline earth metal salts**
- acidity/alkalinity: high to low depending on anion
- solubility in water: soluble
- electrical conductivity: high
- reaction with acids: no visible reaction
- reaction with bases: tend to form neutral solutions

**alkali metal salts**
- acidity/alkalinity: high
- solubility in water: soluble
- electrical conductivity: high
- reaction with acids: no visible reaction
- reaction with bases: tend to form neutral solutions

**ammonium salts**
- acidity/alkalinity: high
- solubility in water: soluble
- electrical conductivity: high
- reaction with acids: no visible reaction
- reaction with bases: depends on properties of anion
- pungent gas released
the solution turned blue-green

the solution turned blue-green
neutral in aqueous solution as shown by the litmus test
the flame test clearly indicated the presence of potassium
the test with silver nitrate confirmed the presence of chloride
the test with barium nitrate eliminated the remaining possible anions
the definitive clues were the litmus test, flame test, reaction with silver nitrate, and the lack of reactivity with other compounds
Appendix G

Teacher Observation Protocol

Teacher Observation Protocol
Inquiry-Based Science Instruction

Observation Date: ____________ Time start: ____________ Time end: ____________ Observer: ____________________

School: ____________________ District: ____________ Teacher: ____________________

1. Descriptive Information
   A. Teacher Descriptive Information:
      1. Teacher Gender: Male (M), Female (F)
      2. Teacher Ethnicity: White (W), Black (B), Hispanic or Latino (H), Other (O)
      3. Grade Level: ____________________
      4. Subject/Course: ____________________
      5. Highest degree: ____________________
      6. *Number of years of experience: ____________________

   B. Student/Class Descriptive Information
      1. Number of students in class: ____________
      2. Gender breakdown: Males _______ Females _______
      3. Ethnicity Breakdown: White _______ Black _______ Hispanic _______ Other _______

   C. Lesson Descriptive Information
      Working title for lesson:
      Objectives of lesson:

      Standards Addressed:

165
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15-20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30-35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35-40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40-45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45-50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50-55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55-60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60-65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>65-70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70-75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>75-80</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80-85</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>85-90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Activity codes

- TLac teacher l'd lecture w/discussion
- TLed teacher l'd lecture w/discussion
- TDis teacher l'd class discussion
- TDir teacher directions
- TDem teacher demo/demonstration
- TRev teacher l'd review
- THom teacher l'd review - homework
- TRin teacher l'd review - in-class assignment
- TngO open inquiry lab/investigation
- TngD directed inquiry lab/investigation
- TInt verification lab/investigation
- RPrj research project/ non-inquiry focused
- SRca student reading assigned material
- STex students work from textbook
- SWsh students complete worksheets
- SPsc student presentations
- Vide video/ film/DVD
- HAss homework/assessed
- HCol homework/collected
- FTrp out-of-class experience (field trip)
- ATsk administrative task
- Qntz quiz/test
- Intr interruption
- Othr other

### Organization Codes

- WC Who Class
- Smgp small group
- Lab students working individually or assignments

### Student Attention to Lesson

- LA low attention, 80% or more of the students off-task. Most students are obviously off-task - heads on desks, staring out of the window, chatting with neighbors, etc.
- MA medium attention, 50% of students are attending to or engaged in the lesson.
- HA high attention, 80% or more of the students are attending to or engaged in the lesson. Most students are engaged with the activity at hand - taking notes or looking at the teacher during lecture, writing on the worksheet, most students are volunteering ideas during a discussion, all students are engaged in small group discussions even without the presence of the teacher.

### Cognitive Codes

8 Other - eg. classroom disruption, no science in the lesson, administrative activity
1 Receipt of knowledge
2 Lower order (recall, remember, understand, basic problem solving)
3 Apply (demonstrate, modify, compare, advanced problem solving)
4 Analyze/ Evaluate (evidence, verify, analyze, judge, interpret)
5 Create/ and/ or Transfer

Use the following rating scale for sections II - V:

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>
II. Instructional Factors

| The teacher appeared confident in his/her ability to teach the lesson. |
| The teacher effectively managed student behavior. |
| The pace of the lesson was appropriate for the developmental needs of the students and the purposes of the lesson. |
| The teacher adjusted instruction based on students' level of understanding. |

III. Ecology and Climate

| * The teacher encouraged students to generate ideas, questions, conjectures, and/or propositions. |
| * The teacher encouraged active participation by ALL students. |
| * There was a climate of respect for students' ideas, questions, and contributions. |
| * Interactions reflected positive collaborative working relationship among students. |
| * Interactions reflected positive relationships between teacher and students. |
| * Intellectual rigor, constructive criticism, and challenge to justification were evident in the learning environment. |
## Questioning and Assessment

<table>
<thead>
<tr>
<th>Action</th>
<th>** Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>The teacher asked questions focused on factual recall</td>
<td></td>
</tr>
<tr>
<td>The teacher asked questions that foster conceptual understanding</td>
<td></td>
</tr>
<tr>
<td>The teacher engaged in active dialogue with students</td>
<td></td>
</tr>
<tr>
<td>The teacher encouraged students to ask questions of other students</td>
<td>peer critique</td>
</tr>
<tr>
<td>The teacher asked questions that stimulated higher level thinking</td>
<td>teacher questioning</td>
</tr>
<tr>
<td>The teacher encouraged students to explain their thought processes</td>
<td>teacher encourages students to explain thoughts</td>
</tr>
<tr>
<td>The teacher effectively guided students to reflect on their individual understanding</td>
<td>teacher as a guide/coach</td>
</tr>
<tr>
<td>The teacher provided appropriate oral feedback to student responses</td>
<td>oral feedback</td>
</tr>
<tr>
<td>The teacher provided appropriate written feedback to student responses</td>
<td>written feedback</td>
</tr>
<tr>
<td>The teacher adjusted instruction based on students' level of understanding</td>
<td></td>
</tr>
<tr>
<td>Teacher circulates during the lesson</td>
<td>teacher circulates</td>
</tr>
</tbody>
</table>

**STUDENTS...**

- Students are asked to develop a model (testable idea) to represent the concept being discussed.
- Students are asked what is the main goal of the experiment or activity. **recognizing main goal**
- Students asked meaningful questions of the teacher during the lesson.
- Students are asked to reconcile data with expectations or model. **reconcile data**
- Students are asked to relate lesson concepts to microscopic level understanding. **microscopic relationship to lesson**
- Students write a summary to explain their understanding.
- Students are asked to write a written report.
- Students are asked to give an oral report of activity.
- Students asked meaningful questions of their peers during the lesson. **peer critique**
- Students are encouraged to monitor their understanding during the lesson. **monitor progress**
I. Components of Inquiry

| Students demonstrated interest/motivation in the lesson. | S: |
| Teacher facilitated above: | T: |
| Students demonstrated curiosity throughout the lesson. | S: |
| Teacher facilitated above: | T: |
| Students used prior knowledge during the lesson. | S: |
| Teacher facilitated above: | T: |
| Students explored a scientific or mathematical question. | S: |
| Teacher facilitated above: | T: |
| Students used evidence to formulate conclusions. | S: |
| Teacher facilitated above: | T: |
| Students justified their conclusions. | S: |
| Teacher facilitated above: | T: |
| Students compared their conclusions/evidence to alternative explanations. | S: |
| Teacher facilitated above: | T: |
| Students effectively communicated ideas, findings, and conclusions. | S: |
| Teacher facilitated above: | T: |
| Students extended learning to new contexts (e.g., applied, transferred, generalized). | S: |
| Teacher facilitated above: | T: |

V. Analysis of Instruction

Rate the quality that each of the following was addressed (using 1-5 or N/A with 1 = extremely ineffective, 3 = somewhat effective, 5 = extremely effective—N/A is Not addressed):

- Engage (holistic for category)
  - Prior Knowledge
  - Misconceptions
  - Motivation/Interest
  - Develop Scientific Questioning

- Explore (holistic for category)
  - Predict
  - Design/Construct strategies
  - Test
  - Collect
  - Reason
  - Model

- Explain (holistic for category)
  - Interpret
  - Evidence
  - Communicate
  - Alt. Explanations/Strategies
  - Verify
  - Justify
  - Analyze

- Extend (holistic for category)
  - Apply
  - Elaborate
  - Transfer
  - Generalize
Quality of curriculum to encourage inquiry learning???

Quality of metacognitive reflection to encourage deeper thinking and learning???
### Appendix H

**Semi-Structured Interview Form**

#### Semi-Structured Interview Dialogue

"Talk about what type lab activities you do with your students."

<table>
<thead>
<tr>
<th>Question</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the source of your labs? (student designed or manuals?)</td>
<td>Would you say you use guided discovery, discovery, inquiry, lecture?</td>
</tr>
<tr>
<td>Do peers compare results? How? Within groups? Oral presentations?</td>
<td>Do students keep a written record of lab results?</td>
</tr>
<tr>
<td>Do they critique each other? (formally)</td>
<td></td>
</tr>
<tr>
<td>How do you remind students of the main objective or lab goals during the lab process? Before? During? After?</td>
<td>How do you encourage students to assess their own understanding during lab? Do you encourage them to ask “self” questions?</td>
</tr>
<tr>
<td>Before lab, how do you assess students’ understanding?</td>
<td>Do you encourage students to develop hypotheses or would you say you make more general predictions? Do you design labs that test an idea?</td>
</tr>
</tbody>
</table>

173
How do you put students in a position to relate data or lab events to concepts?

How do you coach or guide students?

Do you circulate during lab?

Do you give detailed, written feedback to each student?

What is the typical routine for students when you do labs?... what are their responsibilities throughout the process?

Problem solving teaching practices

Will you describe your instructional procedures for a typical stoichiometric problem?

How do you emphasize what the goal of the problem is?

Do you model reading the entire problem, developing a plan and eliciting all of the details given in the problem?
How do you use sequences of rules?

Do you allow students to use graphic organizers, “cheat cards” with formulas? Etc...

Do you relate current problems to past problems you’ve done?

Do you use a set, systematic process..break down the problem, reflect on “what I know”, make a plan, list the givens, decide on the formula (ALGORITHMIC)

Do you create new, novel problems that present students with new situations that use previously learned concepts?

....Do you encourage students to check your results as you go or at the end???
Appendix I

Teacher Questionnaire

Directions: Consider the actual instructional practices that you utilize in order to answer the following questions.

- Do not over-elaborate the meaning of the statements. Read the statements with regards to your perception of what opportunities you provide your students or actions that you encourage.
- If you do not understand an item, leave it blank.

Rate your responses with the following scale.

<table>
<thead>
<tr>
<th>Use the following rating scale:</th>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1  2  3  4  5  0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Teacher Practices

Part 1: Lab-related teacher practices

1. When conducting an experiment, you tend to follow a lab manual procedure associated with the textbook.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  2  3  4  5  0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. When conducting an experiment, you tend to use guided inquiry.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  2  3  4  5  0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. After a lab activity, you encourage your students to compare results with their peers.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  2  3  4  5  0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. You require students to record data and observations during lab activities.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  2  3  4  5  0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. You allow your students to use oral presentations to communicate their lab results.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  2  3  4  5  0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. You create opportunities for students to critique each other’s lab practices and results.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  2  3  4  5  0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. 7.
7. **Before** starting lab, you create situations where students ask themselves, “What is my main goal?”

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

8. While the lab activity is in progress, your design ways for students to ask themselves, “What is my current understanding?”

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

9. **During** the lab process, you encourage students to ask themselves, “What experimental questions can I pose with answers that will help me further understand the lab concepts?”

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

10. **Prior to the lab process**, you create opportunities for students to describe their current understanding of the lab concepts.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

11. **During the lab process**, you encourage students to ask themselves whether the hypothesis is consistent with what is occurring in lab?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

12. **During the lab process**, you design opportunities for students to make experimental predictions about experimental outcomes based on testable ideas.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

13. **During the lab process**, you encourage students to design, then carry out experiments.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
14. *During the lab process,* you encourage students to monitor the progress of their experiment.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

15. *During the lab process,* you continually encourage students to understand what is happening as it relates to the lab concept being investigated.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

16. *During the lab process,* you encourage students to consider implications of the data being collected.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

17. *During the lab process,* you create opportunities for students to integrate relevant science concepts.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

18. *During the lab process,* you encourage students to reconcile the idea being tested or developed with the experimental data.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

19. *During the lab process,* you encourage students to seek understanding of the observations at the microscopic perspective as it relates to atoms and molecules.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

20. *During the lab process,* you coach and question students to probe their understanding.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
21. *During the lab process,* you use embedded questions in the lab manual or other instructions, to prompt students to reflect.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

22. *During the lab,* you circulate throughout the lab.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

23. *After lab* you encourage students to continue to reflect by developing more questions, and by analyzing the implications of the results data through *written* reflections.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

24. You give written, specific feedback to these reflections to *INDIVIDUAL* students.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

25. You require students to write a coherent summary of their ideas for presentation to the class.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

26. You require students to write a coherent summary in the form of a written lab report.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

27. You create opportunities for students to receive and respond to criticism during an oral report.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
NON-LAB PROBLEM SOLVING INSTRUCTIONAL PRACTICES CONTINUED ON THE NEXT PAGE.

In class (non-lab) problem solving opportunities

1. When providing instruction to students on problem solving, you place emphasis on students' fully understanding and determining what the goal of the problem is?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

2. When teaching problem solving, you place emphasis on integrating the concepts on which the problem is based?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

3. When doing a sample problem for students (on the board or overhead), you sort the information in the problem and the relevant information is determined?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

4. When doing a sample problem for students (on the board or overhead), you overtly check the results to see if they make sense?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

5. When providing students problem solving opportunities (like on worksheets), you provide unfamiliar problems that actually use concepts from previous situations or problems solved?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

6. When doing a sample problem for students (on the board or overhead), you vary problems for a concept in order that the wording may be different or the situation surrounding the problem is different?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

7. You encourage students to guess?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
8. When doing a sample problem for students (on the board or overhead), you model reading the entire problem in order to elicit all details from the problem?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

9. When doing a sample problem for students (on the board or overhead), if the chemistry problem involves a mathematical calculation, you place emphasis on the algorithmic approach?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

10. When students confront problems with which they have difficulty, you encourage them to take a systematic approach (read the problem, determine what is given, find a formula, solve, etc...)

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

11. You teach/allow students to use formula sheets, graphic organizers, flow charts, note card or other tools that may assist them in following the sequence of steps needed to solve chemistry problems.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

12. When doing a sample problem for students (on the board or overhead), you model jotting down or listing information that the problem provides that is useful in solving the problem?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

13. You feel that students generally have such difficulty with the mathematical aspects of chemistry problems that the emphasis placed on the math detracts from eliciting the most meaning of the chemistry concept being studied.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

14. When doing a sample problem for students (on the board or overhead), you model and emphasize to students the importance of developing a plan for solving the problem?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>
References


