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Investigating the effectiveness of implementing the science writing heuristic on student performance in general chemistry

Jason Ray Poock
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Investigating the effectiveness of implementing the science writing heuristic on student performance in general chemistry

by

Jason Ray Poock

A dissertation submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major:  Chemistry

Program of Study Committee:
Thomas Greenbowe, Major Professor
Brian Hand
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Iowa State University
Ames, Iowa
2005

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Graduate College
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This is to certify that the doctoral dissertation of

Jason Ray Poock

has met the dissertation requirements of Iowa State University

Signature was redacted for privacy.

Major Professor

Signature was redacted for privacy.

For the Major Program
DEDICATION

This dissertation is dedicated to my family. To my wife LaDonna, my little girl Hannah, and soon to come baby Jacob, I love you.
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ACKNOWLEDGEMENTS

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CHAPTER 1. INTRODUCTION

The Science Writing Heuristic

This research has all been based on what is called the science writing heuristic (SWH), (Hand and Keys, 1999; Keys, Hand, Prain, and Collins, 1999; Rudd, Greenbowe, and Hand, 2001; Rudd, Greenbowe, Hand, and Legg, 2001; Hand and Prain, 2002). The first question that I always get is, “What is a heuristic?” A heuristic is a tool. It is a problem-solving device. In this case specifically, we use the science writing heuristic to organize how the laboratory classroom functions and how the students write their laboratory reports. So there are two aspects of the science writing heuristic. One is what happens during the laboratory experiments with respect to the classroom dynamic that is created and the other is the actual writing of laboratory reports. Both parts are used together as a tool for successful understanding of chemical concepts in the freshman laboratory.

It is hard to explain all that is involved in creating the classroom dynamic when using the science writing heuristic (Poock, Greenbowe, Burke, & Hand, 2004; Poock, Burke, Cantonwine, Greenbowe, & Hand, 2003). It goes back to constructivism; that knowledge is constructed in the mind of the learner (Bodner, 1986). The teacher in charge of the laboratory needs to frame the experiment in such a fashion that students are placed in the center of the learning process. It is like building a puzzle. The first thing that you need to do is build the frame. You have to find all the straight pieces, line them up, and put them together. This gives you a structure in which to work. This pictures the function of the teacher. It is not feasible to let the students pursue every avenue of exploration during a chemistry laboratory session. Also, the teacher has a chemical concept that he/she wishes to
impress upon the students. This is where the picture frame comes into use. If the teacher effectively creates a framework inside which the students can work, then the students can put the puzzle together, without going astray. The frame ensures that the students are exploring a concept that the teacher wants to cover. Yet, this structure still allows a degree of student control and initiative. Even though the frame of the puzzle has been put in place, the picture is not complete. The students need to put the puzzle together. After all, they are the learners. Within the framework, they can modify, change, and explore different aspects of the chemical system that the teacher has placed before them. The teacher builds the frame and the students put the puzzle together creating a classroom dynamic that involves both the teacher and the students.

With regard to teacher implementation of the SWH, a number of factors have been found useful in creating an effective classroom dynamic (Omar, 2004). One is to run the classroom using inquiry strategies to engage the students in an active learning process (Farrell, Moog, & Spencer, 1999). The three stages of the learning cycle (exploration, concept invention, and application) can be utilized to structure the laboratory session around a specific chemical concept that the teacher is trying to impress upon the students (Abraham, 1998).

Another is to let the students discuss their beginning questions at the start of class. After completing the assigned reading for the laboratory experiment, each student comes to the laboratory with a beginning question. The teacher needs to allow the students the opportunity and the time to discuss these questions with each other. The students can form groups and decide on a question they can write on the chalkboard at the front of the room. This sets the stage for the interactions that will take place during the laboratory. The teacher
can then use these beginning questions to set up the framework for the experiment or a series of experiments.

Once this framework is in place, the design of the experiment is finalized by the students in the laboratory. Even though the framework presented by the teaching assistant gives a direction to the laboratory experiment, a variety of details are left to be decided by the students. Specifics as to which variables will be investigated, the number of students investigating each variable, what ranges for those variables are experimentally feasible, and what, if any, replication is necessary are left to the students. This results in students taking ownership of the laboratory experiment and becoming more motivated. Greater student engagement and interest in the investigation leads to greater discussion of the concepts later in the session. Ideally, the entire class will be involved with contributing data for the experiments that are being investigated.

The students need to form teams and the various teams need to decide on what experimental data they will contribute to the class in a collaborative project (Shibley & Zimmaro, 2002). Since one team cannot possibly complete all the necessary experiments in the time required, it is necessary for different teams to contribute appropriately to the data set so that all experiments get completed. It is crucial that the teacher not interfere with this process. It seems to be a natural tendency for teachers to group students into teams and delegate what those teams will accomplish. The students need to take control of this step if the SWH is to be effectively utilized. It leads to further dialogue between the students later during the laboratory. They need to make decisions about what team they will be on and how that team is going to contribute to the class experiment. It was observed that when this component is missing from the implementation of the SWH, future dialogue and discussions
between the students about the chemical concepts involved in the laboratory did not transpire (Poock, Burke, Cantonwine, Greenbowe, & Hand, 2003).

Another hurdle that the students need to overcome, with the encouragement and prodding of the teacher, is in making use of the chalkboard. It was surprising how reluctant students were to write their experimental results on the chalkboard. Yet, it is vital that data from the experiment be available for the class to see, use, and analyze. It is also necessary for all the data to be on the chalkboard in order to proceed to the next step in implementing the SWH. That next step is having the teacher frame a class discussion about the experiment, the results, and the concepts that were covered during the laboratory session. These steps are under the guidance of the teacher and necessary for effective implementation of the SWH.

Yet, the teacher is not the only person that has control in the laboratory. The students are in control of their response to the teacher's direction, and that response determines how influential the SWH is in their learning. Even when the teacher effectively incorporates the SWH, the students may or may not respond in a positive manner. Ideally, the students "jump on the bandwagon" of what the teacher is trying to accomplish and become engaged in the learning process. They begin dialoguing with their fellow students about the experiment and the chemical concepts involved. Students should initiate the formation of teams and make decisions about what variables to investigate, what amounts to use, and how their team can contribute. They can encourage their classmates in recording data on the chalkboard, and help them with difficulties they encounter. Preferably, students should lead and run the discussion at the end of class by reviewing the experiment and the concepts that were the focus of the laboratory.
Student response to the SWH approach can differ from the ideal classroom profile. Often, students will “jump through all the hoops” that the teacher has placed in front of them, but that is the extent of their ambition. Their main objective is to finish following the directions in the lab as quickly as possible and leave the classroom as soon as it is allowed by the teacher. They will form teams, run an experiment, and record their data on the chalkboard as required by the teacher, but intellectual involvement will not take place. They can be unwilling to discuss chemical concepts with their peers and refuse to participate in the end of class discussion. Even with effective teacher implementation of the SWH, the students’ response to the SWH approach will determine the extent of its success, and the students’ success.

The classroom dynamic is not the only aspect of the SWH. Writing is another key component of learning (Kovac & Sherwood, 1999). Instead of a more traditional laboratory report where the students fill in what the teacher tells them to complete (title, purpose, procedure, etc.), the SWH asks the students to respond to questions that resemble scientific research. After reading the assigned laboratory experiment, the students are to develop and write down a beginning question. What questions still remain about the experiment? What experiment do they want to carry out? Are there any chemical concepts they want to investigate to understand them better? One example would be: How does the mass of magnesium sulfate affect the change in temperature of the solution? Beginning questions encourage students to think about the laboratory experiments before they ever enter the classroom. Students then need to answer the question of how they will stay safe in the classroom. This way, safety issues must be written in their own words instead of “in one ear and out the other” as the teacher explains safety concerns prior to the experiment. They need
to answer the question of designing an experiment in order to proceed. Beginning questions, safety, and procedure sections of a laboratory report should be completed prior to class.

During the class, students answer the questions of “What did I see?” and “What did I do?” They need to make observations as any scientist who is investigating a research question would do. They need to write clearly what they have observed and what data they have collected. Then, the students need to make a claim. “What can I claim?” To answer this question they need to review what happened during the laboratory, and summarize it into a one or two sentence statement, a claim. An example of a claim is: As the mass of magnesium sulfate dissolved in solution increases, the change in temperature of the solution also increases. They need to answer, “What is my evidence?” The students need to review and organize their data into an argument that defends the claim that they constructed. Last of all, the students need to complete their report by answering questions in the reading and reflection component of their report. This has been a difficult part of the SWH for students. They can discuss how their ideas have changed from their beginning questions, they can ask new questions, or link the concepts from the laboratory to the lecture portion of the course.

Throughout the report, an emphasis is placed on the student’s writing skills (Carlisle & Kinsinger, 1977).

It is not an easy task to help students learn. Yet, I believe that as a teacher I can have an impact on student learning. The SWH is an effective tool for teaching students chemistry concepts in a laboratory setting. It promotes critical thinking, communication, teamwork, and writing skills, as well as generating interest, motivation, and enthusiasm (Poock, Burke, Cantonwine, Greenbowe, & Hand, 2003; Poock, Greenbowe, Burke, & Hand, 2004; Rudd, Greenbowe, & Hand, 2001; Rudd, Greenbowe, Hand, & Legg, 2001).
Research Incentive

Previous SWH research (Rudd, Greenbowe, & Hand, 2001; Rudd, Greenbowe, Hand, & Legg, 2001) has shown that students using the SWH in the laboratory are more mentally engaged, have a better attitude towards chemistry, and leave with a deeper understanding of the chemical content explored in the laboratory experiments. The success of these studies was the motivation for continued research utilizing the SWH. Various questions provided direction for the research. How does the level of teacher implementation have an impact on student learning when using the SWH? What is the effect of student response to the implementation of the SWH? Is there a connection between teacher implementation and student response? Are there effects due to gender or student ability? Does teacher training influence the effectiveness of the SWH? What are the results when the SWH is implemented for an entire year? These questions were the focus of the research that was conducted in this study and is presented in this dissertation.

Organization of the Dissertation

This dissertation presents a series of related manuscripts that have been submitted for publication. Each is related in some way to the process of implementation of the science writing heuristic. Chapter 1 is an introduction and reviews the key components of the SWH in general terms. A comprehensive review of the literature, including writing to learn, the science writing heuristic, inquiry, collaborative group work, and gender is presented as a part of Chapter 3. Chapter 2 is a manuscript that has been accepted by the Journal of College Science Teaching and discusses the impact and role of teaching assistants in effectively implementing the SWH. Chapter 3 is a manuscript to be submitted to the Journal of Research in Science Teaching. It discusses the results of implementing the SWH into the
entire freshman chemistry course for science and engineering majors. A review of the literature and statistical data are presented in this paper. Chapter 4 is a manuscript submitted to the *Journal of Chemical Education*. It discusses the results of implementing the SWH into the entire freshman chemistry course for science and engineering majors over a two semester sequence. Chapter 5 presents general conclusions.

References


CHAPTER 2. TRAINING CHEMISTRY TEACHING ASSISTANTS TO USE THE SCIENCE WRITING HEURISTIC

A paper accepted for publication in the Journal of College Science Teaching

K.A. Burke, Brian Hand, Jason Poock, Thomas Greenbowe

General Introduction. The Science Writing Heuristic (SWH) approach successfully incorporates guided inquiry methods with writing to learn strategies (Hand and Keys, 1999; Keys, Hand, Prain, and Collins, 1999; Rudd, Greenbowe, and Hand, 2001; Rudd, Greenbowe, Hand, and Legg, 2001; Hand and Prain, 2002). Interactive guided inquiry laboratory activities are coupled with student-centered classroom practices that include intra- and inter-group discussions. Learners negotiate meaning from experimental data and observations. Students construct concepts/ideas by making claims (drawing inferences) and supporting them with evidence from their experimental work. Focused reflection scaffolds on prior knowledge to integrate new ideas.

The method has been effectively incorporated into science curricula (including, biology, chemistry, general science, geology, physical science, and physics) from middle school through post-secondary levels (two- and four-year institutions). Currently (Fall 2004), learners from pre-kindergarten through elementary school are engaging in age-appropriate SWH hands-on activities and writing strategies. Results of this most recent study are eagerly anticipated.

Students whose instructors have productively integrated SWH activities and methods into their curriculum will demonstrate a deeper understanding of the science they have learned. The more effective the instructor is and the more receptive the learner is, the more
impact the SWH has had on learning gains (please see Appendix 2). Sufficiently instructor preparation to integrate the SWH approach is critical and is the focus of this manuscript.

**Background.** Graduate teaching assistants are hired to assume some of the teaching duties in large general chemistry programs. They serve as liaison between students enrolled in the course and the professor in charge.

Being assigned to teach immediately upon arrival at graduate school may be overwhelming to novice graduate students. When sending them into the classroom, we assume that they know what a TA is and how to teach, understand how the class is structured, are comfortable being placed in a position of authority, completely understand the chemistry level they are to teach, and convey enthusiasm for their material and for their task (Stacy, 2000). However, most graduate students do not plan to teach once they have completed their degree program (Jones and Makinen, 1991; Cooper, Pienta, and Greenbowe, 2004). For many, the first-year teaching assignment is a requirement for graduation.

Virtually no TAs and few novice or veteran professors have had any formal (or informal) background in teacher training (learning theory, pedagogy, or methodology). Those who have, basically received their training during their TA experience. The model for most is a teacher-centered, lecture-oriented, knowledge transmission paradigm (Tien, Roth, and Kumpmier, 2002; Luft, Krudziel, and Turner, 2003). Thus, teacher as information source is familiar to novice TAs, and what they believe they should emulate.

Trainees of TAs need to counter the paradigm of teacher as knowledge provider by implementing training programs that effectively model active learning strategies. The program must engage novice TAs in learning experiences that will allow them to encounter some of the same challenges/frustrations and excitement that their students will (National
Science Education Standards, 1996; McNeal, 1998; Crowther, 1999; Luft, Krudziel, and Turner, 2003; Poock, Burke, Greenbowe, and Hand, 2004b). The more thoroughly TAs are exposed to strategies, the more readily they are likely to "buy into" the approach. Thus, time is needed for practicing these strategies.

Because TA training sessions may in part compensate for lack of prior training in educational methods/concepts, aspects of the following should be provided (Brown and Campione, 1994; Ronkowski, 1998; Poock, Burke, Greenbowe, and Hand, 2004b):

a. Academic content knowledge and problem-solving skills;

b. Pedagogical content knowledge, methods, and skills;

c. Learning theory;

d. Modeling student-centered active learning strategies.

Ronkowski (1998) recommends experienced graduate students provide input, as well as participate in training novice TAs.

Although TAs value the opportunity to receive some kind of training, one short "TA boot camp" cannot prepare novices for all they will encounter, especially for the variety of courses they might be assigned. An on-going series of shorter training exercises during the semester is likely to serve the novices better than one overwhelming introductory session (Nurrenbern, Mickiewicz, and Francisco, 1999; Stacy, 2000; and Luft, Krudziei, and Turner, 2003).

Since a majority of the TAs are novices and many of the students are first-semester freshmen, all parties assume the SWH approach is just a part of the introductory chemistry program and pragmatically assimilate its use. Teaching assistants are made aware that it generally requires about three weeks of experience for an instructor (novice or experienced)
to achieve a comfort level with mentoring students in the use of the SWH. The learning curve for students varies, but the early adaptors may produce good work in three to four weeks. The TAs are aware that their efforts to understand the benefits of SWH strategies parallels their students’ struggles to conduct fruitful discussions and to prepare acceptable laboratory reports. Usually both TAs and students are competent and confident users of the SWH by midterm.

**Training TAs to facilitate the SWH approach.** To assist the novice TAs to conduct their SWH-oriented laboratory teaching roles, they are provided several days of targeted classroom and laboratory training. This training has two purposes (McNeal, 1998; Crowther, 1999; Luft, Krudziel, and Turner, 2003; Poock, Burke, Greenbowe, and Hand, 2004b): to put the TAs in the role of student (to specifically to learn about using the SWH) and to model for them their role as TA.

The TA preparation is a process, a series of mutually supportive steps consisting of:

- Learning about principles of the SWH in conjunction with guided inquiry/active learning.

- Going to the laboratory to experience the process.

- Completing two laboratory experiments facilitated by experienced TA mentors to provide adequate exposure to student-centered laboratory practices.

- Discussing the differences observed between traditional and student-centered classrooms.

During "SWH training", TAs experienced in the SWH method model and mentor the process for novice TAs during a series of sessions.

1. **The SWH is explained.** TAs are provided an overview explanation of the SWH by an experienced TA. Each component of an SWH laboratory report is compared and
contrasted with a traditional laboratory report and the roles that good TAs will adopt. Table 1 compares the features of the SWH student report to a traditional verification format.

Table 1. Comparing Student Report Formats for the Science Writing Heuristic and Traditional Laboratory.

<table>
<thead>
<tr>
<th>Standard Report Format</th>
<th>Science Writing Heuristic Student Template</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Title, purpose.</td>
<td>1. Beginning Questions—What are my questions?</td>
</tr>
<tr>
<td>2. Outline of procedure.</td>
<td>2. Tests—What do I do?</td>
</tr>
<tr>
<td>3. Data and observations.</td>
<td>3. Observations—What can I see?</td>
</tr>
<tr>
<td>4. Discussion.</td>
<td>4. Claims—What can I claim?</td>
</tr>
<tr>
<td>5. Balanced equations, calculations, graphs.</td>
<td>5. Evidence—How do I know? Why am I making these claims?</td>
</tr>
<tr>
<td></td>
<td>6. How do my ideas compare with other ideas?</td>
</tr>
<tr>
<td></td>
<td>7. How have my ideas changed?</td>
</tr>
</tbody>
</table>

a. **Beginning questions** should be those answered by having to carry out the experiment. Emphasis is placed on moving away from yes/no or a "how much of" types of question to "How does one measurable/observable quantity depend on another measurable/observable quantity?" For example, how does reaction time depend on temperature of the reactant system?

b. **Tests and observations** are made during the laboratory activity. The tests students perform may be vaguely outlined for them or may be something they design completely themselves. The more students have opportunity to provide input on procedures they use, the more ownership they feel.

c. Based on their experimental observations and data, what **claim(s)** can they make and what **evidence** (data/calculations) have they collected to support their claim(s)? The process of making and supporting one or more claims helps students work together to

   i) Negotiate meaning from what they have done and

   ii) Formulate/construct chemistry concepts.
This is an area where students have difficulty. TA guidance is useful.

d. **Reflection.** Using their results, how do their claims compare to colleagues' claims or how do they compare to what they have learned in class? How have their ideas been affected or changed by their lab work?

2. **Mystery activity.** In order to help them distinguish between claims and evidence, TAs take part in a non-chemistry based mystery activity.

   a. Divided into groups of three or four, they are asked to read a short story outlining the scenario of a death (see Appendix I, Part 1).

   b. In their groups, they are asked to suggest beginning questions and discuss them.

   c. Each group writes a claim about the scenario on the chalkboard, along with supporting evidence.

   d. Each group reads their claim aloud and provides arguments to support their evidence. Other class members are encouraged to ask clarifying questions.

   e. After each group has had a turn, the experienced TA facilitator talks with them. They may continue the activity with Appendix I, Part 2 and further dialog. Or, the moderator may proceed directly to the culminating discussion: "You have taken a position and defended it. We have talked together as a class. If you now had the opportunity, what questions would you ask the investigating detective team?" This results in a flurry of inquiries to clarify bits of provided evidence.

   f. Finally, novice TAs are asked to summarize why they think they did the activity, including what they thought they learned about beginning questions, claims, evidence, and reading/reflections. This experience has successfully provided TAs with a concrete example to understand the SWH, especially differentiating claims and evidence.
3. **Student-centered learning atmosphere.** Novice TAs must not only understand structural features of the SWH, but also how to support a student-centered learning environment. They must create an ambiance where students accept group work as beneficial to learning, and feel comfortable discussing ideas with peers. Because many novice TAs have not had exposure to group work or student-centered learning environments, their training is accomplished via modeling by TAs experienced with both the SWH paradigm and student-centered classroom strategies. During two separate laboratory experiments, experienced TAs model setting the stage for students' active learning, encouraging group work, and moderating group data generation/collection/discussion.

Each laboratory exercise is chosen to illustrate different approaches novices could use for student active learning strategies. One of the two experiments is discussed here in detail. It is an experiment students are assigned to learn about integrating the SWH approach.

**Salt water experiment.** TAs are provided a short descriptive paragraph and asked to determine how density of a salt-water solution is related to variables that can be experimentally manipulated. They are issued an equipment drawer, bottles of solid sodium chloride, and advised to propose one or more beginning questions. Experienced TAs model the TA role/student-centered laboratory by encouraging novices to talk with one another in pairs or groups to review what is meant by density. After they have recalled that density measures mass per unit volume, they are asked to devise an experimental strategy relating density to two experimental variables. They are invited to go to the chalkboard to outline experiments that could be undertaken. This forces novice TAs (as students) to talk with one another about what variables they could manipulate to study the density of salt water.
Novice TAs are quickly able to draft a strategy for their work. At the same time, they are able to recognize the ways in which the experienced TAs guided them to generate their own strategy and pursuant procedure(s) rather than telling them how.

TA teams generate and enter data into tables they have created on the chalkboard. Experienced TAs model how to encourage students to discuss their findings, including trends, anomalies in trends, missing data, etc. Novice TAs are asked how they could answer their beginning questions by making claims from collected data, and what part of that data constituted their evidence. They are asked what further questions they might have and what further reading they might do to support any part of what they thought they had learned. Finally, they are encouraged to consider how their thinking has changed as a result of the process.

Novice TAs are able to understand the value of talking with one another about what they have learned rather than being told by someone else. They realize how much more of a meaningful learning opportunity it has been for them to experience the entire process rather than to have someone else simply tell them what to do, how to do it, or what they learned. Because they devised an experimental procedure to answer their own beginning questions, they were more motivated to find an answer. They realize they had had to assume primary responsibility for their own learning. The process was something they had to do themselves, not something that could be done for them.

**Longitudinal mentoring.** Clearly, a two-day "how-to" session about SWH training for TAs cannot begin to anticipate all questions/issues/situations that could arise during a semester. Because members of the TA team have a variety of backgrounds, course demands, and research obligations, each approaches the teaching assignment differently and has
individual needs for mentoring. In order to facilitate the TA teaching experience, weekly staff meetings include a discussion of the upcoming experiment. An experienced mentor provides both oral and written suggestions for active engagement of students, hints about possible student difficulties or errors, and tips for grading reports. An experienced SWH TA mentor is present in the laboratory room during at least the beginning portion of each scheduled period. In this way, any uncertainties, awkwardness, or trepidation can be remediated. TAs who have laboratory sessions later in the week are encouraged to attend and observe sessions earlier in the week (as their schedule permits), as well as talk with colleagues who have already "run" the lab. In this way, there is a process of continuous support among the graduate student team.

Feedback has been overwhelmingly positive. TAs have realized the care taken to facilitate their first semester teaching experience. Because the SWH format is new to them, TAs find the mentoring process invaluable to understanding how to promote student-centered learning environments/experiences as well as how to evaluate students' first attempts at compiling laboratory reports using the SWH format.

**TA first session with students.** The first session the TA has with students tends to parallel TA training exercises.

1. *The TA explains the SWH template to students.* The TA reviews the SWH student template. Each aspect of the SWH is discussed along with the number of points that will be assigned to each part of a correctly completed laboratory report. From this explanation, students must be able to draft a lab report following the SWH format. A written copy of the SWH protocol is also provided.
2. *TA facilitates the mystery activity.* The mystery activity is a good icebreaker for students at their first laboratory meeting. The activity is non-threatening and does not depend on prior chemistry knowledge. The TA leads students through the activity from the point of view of the different parts of the SWH, from beginning questions to reading/reflections, helping them to make the connection for themselves of how it all fits together. At this time, students can ask questions to help them to clarify any misunderstandings they might have.

3. *The TA sets up student-centered active learning.* Although laboratory experimental procedures/analyses will differ from week to week, basic student-centered strategies will not. Table 2 compares a student-centered to a more traditional laboratory environment.

   a. Students are grouped in pairs (three at the most if there is an odd number). Each person should have a task on which the success of all other group members depends.

   b. Students have been given the outline of a procedure and discuss it among themselves in their group to decide what beginning question(s) they have.

   c. The TA encourages class members to write one or more beginning questions on the chalkboard. Students should evaluate beginning questions (combining similar ideas and rewording when appropriate). They should discuss which one or ones they want to investigate. Their experimental work should revolve around this/these beginning question(s).

   d. The TA encourages students to devise data tables that will collect the pertinent information. The data tables should clearly identify what variables are being studied as well as which groups are working on each part. One section of the data table should include necessary calculations.
e. The TA tells students to enter data in the table as soon as they have collected it. Only when all (or most) of the data has been entered can the class identify anomalies or outlying data points and begin to make meaning from information collected.

f. The TA circulates through the classroom, engaging students by asking probing questions to determine how well they are understanding what they are doing, and what the exercise is meant to help them to discover. If asked a question, the TA tries to return the question to the group to help the students to learn that they have peers who are frequently able to answer their questions.

g. After all data has been collected, students are encouraged to determine what trend(s) can be observed.

h. Students are encouraged to make a claim and support it with evidence. The claim may or may not answer a beginning question. Through the course of the laboratory period, students' beginning questions may change. Posing claims and supporting evidence should help them to make meaning from experimental results.

i. Students are then asked what other question(s) they might have for one another or the TA after completing discussion. They should also be asked what information they could read in their text.

4. First student laboratory activity. Students are distributed a one-page handout to complete during the laboratory session. They are asked to investigate how density of a salt-water solution can be related to two separate experimental variables that they must determine themselves. They are provided this goal, but no overt procedure for how to accomplish it. They must work together to generate it.
Table 2. Comparing a traditional laboratory session to a student-centered laboratory session.

<table>
<thead>
<tr>
<th></th>
<th>Traditional lab</th>
<th>Student-centered lab</th>
</tr>
</thead>
</table>
| **Pre-lab**          | TA gives step-by-step directions, asks for questions related to "cookbook" procedure. | a. Students write beginning questions (BQs) on chalkboard.  
b. Together the class discusses which BQs to investigate.  
c. Students talk about how to divide the tasks among groups, and what data needs to be collected.  
d. Students prepare class data table on the chalkboard. |
| **Students perform experimental work** | Students follow procedure outlined in lab manual or outlined by TA. Students stay at their own experimental workstation and talk mainly with their partner (unless they ask the TA a question). | a. Students perform lab work necessary to answer their own questions.  
b. Students talk with other group members and other lab groups about what they are finding. |
| **Data collection**  | Lab partners check with one another to be certain that both have all data, then leave. | a. Each group enters data in class data table on the chalkboard.  
b. Groups who have finished "their" part walk around the classroom to check with other groups to determine whether any other group needs help in completing their task(s) or calculations. |
| **Discussion**       | Student may ask a question of partner and/or TA, then leaves the classroom.     | a. As soon as more than half of the data has been entered in the table, students begin to look for trends to answer their BQs. If data does not agree with an apparent trend, they may repeat their work.  
b. When all data is on the board, students critically evaluate the information.  
c. Students work together to negotiate meaning, construct a concept, and answer BQs.  
d. Students write and discuss an appropriate claim and provide supporting evidence. |
The density of saltwater solutions exercise is a good lead-in to student-centered learning and the SWH. The concept of density is not overwhelmingly challenging. Several students in each group will recall the density relationship between mass and volume. Usual measurement units are grams (mass) and milliliters/cubic centimeters (volume). Most students are familiar with these units. The experiment utilizes group work, designing data tables on the chalkboard, entering data in the tables, and generating discussions among students. Students become familiar with balances and their mass tolerances, volumetric equipment, and its ability to provide them with useful information. Students must work together to generate a plan of what they want to study, but the task is not overwhelmingly challenging. With peer guidance, even those whose laboratory skills are minimal can be successful.

Success. Given the difficulties in the willingness and abilities of the large number of TAs required for our freshman chemistry laboratory course, we are pleased with the impact of the SWH approach. Our data (Poock, Burke, Cantonwine, Greenbowe, and Hand, 2003; Poock, Burke, Greenbowe, and Hand, 2004a; Poock, Burke, Greenbowe, and Hand, 2004b) shows that when both TA and students actively use the SWH approach, there are significant gains made on the ACS First Semester standard examination compared to students who have experienced poor or no implementation of the method. (A brief description of the studies is provided in Appendix II.) In addition, student composite scores in the lecture portion of the course are statistically significantly higher for those who have experienced a high level of implementation of the SWH approach in the laboratory. Such success encourages us to continue refining and improving strategies to help TAs play a meaningful role in helping chemistry students succeed.
References


Appendix I
Solving a Mystery—Part 1: Observations, Claims, and Evidence

You and your partner are private detectives who have been hired to investigate the death of the wealthy but eccentric Mr. Xavier, a man who was well known for his riches and for his reclusive nature. He avoided being around others because he was always filled with anxiety and startled easily. He also suffered from paranoia, and he would fire servants that he had employed for a long time because he feared they were secretly plotting against him. He would also eat the same meal for dinner every night, two steaks cooked rare and two baked potatoes with sour cream.

Upon arriving at the tragic scene, you are told that Mr. Xavier was found dead in his home early this morning by the servants. The previous evening after the chef had prepared the usual dinner for Mr. Xavier, the servants had been dismissed early in order to avoid returning home during last night’s terrible storm. When they returned in the morning, Mr. Xavier’s body was found face down in the dining room.

Looking into the room, you start your investigation. The large window in the dining room has been shattered and appears to have been smashed open from the outside. The body exhibits laceration wounds and lies face down by the table, and there is a large red stain on the carpet that emanates from under the body. An open bottle of red wine and a partially eaten steak still remain on the table. A chair that has been tipped over is next to the body, and under the table is a knife with blood on it.

With this information, come up with a single claim and supporting evidence that explains how Mr. Xavier died.
Appendix I
Solving a Mystery—Part 2: More Observations, Claims, and Evidence

Let's continue the story...

Due to his paranoid nature, Mr. Xavier always had Kurt Wagner, the butler, lock all doors to the mansion at night. However, detectives found that the back door had in fact been left open. Detectives found that the chef, Robert Drake, had been the last employee to leave that night. When questioned, Mr. Drake stated that the doors are supposed to lock behind him when he leaves. In addition, a bottle of medication for high cholesterol was discovered in the medicine cabinet. Also, the carpet in the dining room was wet.

With this additional information, come up with a single claim and supporting evidence that explains how Mr. Xavier died.
Appendix II—Some Results of SWH Studies

In a longitudinal study over three semesters, TAs and their students were observed for more than 700 hours by two independent researchers (inter-rater reliability of over 0.95). Using a qualitative rubric, the TAs were ranked as being high (H) medium (M), or low (L) implementers of the SWH. Students were ranked as being H, M, or L in their acceptance of the SWH approach.

At the outset of the semester (prior to instruction/laboratory exercises), all students were administered the ACS California Diagnostic Examination followed by the ACS First Semester Examination at the conclusion of the term. Their improvement scores (IS) were monitored.

\[
IS = \frac{\text{labo} \text{ratory section's gain score}}{\text{lab} \text{oratory section's potential gain score}}
\]

\[
IS = \frac{\text{ACS First Sem. Exam} - \text{ACS Cal. Diag. Exam}}{100 - \text{ACS Cal. Diag. Exam}}
\]

The more highly both the TA and the student group were ranked, the more apparent the learning gains were (based on improvement score). The average improvement score for a high classroom dynamic (interaction between the TA and students) was 0.32, while the average improvement score for a low classroom dynamic was 0.11. The difference between the high and low classroom dynamic was 0.21. This represents a variation of one whole grade level on the students' cumulative semester results. This score was regardless of student ability level (e.g., students in the top half of the class vs. the bottom half of the class).
CHAPTER 3. THE EFFECT OF USING THE SCIENCE WRITING HEURISTIC ON STUDENT PERFORMANCE IN GENERAL CHEMISTRY

A paper to be submitted to the Journal of Research in Science Teaching

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Abstract

The Science Writing Heuristic (SWH) was implemented in an introductory chemistry laboratory course at a large university in the Midwest of the USA to determine whether the implementation of the SWH by teaching assistants and quality interaction among the student participants had an impact upon student performance on chemistry examinations. Implementing the SWH approach necessitates student-centered work as well as incorporating a writing structure for laboratory reports that scaffolds students' critical thinking. The interaction between the teaching assistant and the students creates a classroom dynamic that has the potential to impact student learning. This research was based on a quasi-experimental mixed-method design. The qualitative measures involved observations of teaching assistants and students in the laboratory. Two independent observers ranked the ability of the teaching assistants and students to effectively implement the SWH on a scale of High, Medium, and Low implementation. The quantitative data gathered included results from the American Chemical Society's California Chemistry Diagnostic Test and the General Chemistry First Semester Examination. The results of the study indicate that the interaction between instruction and student dialogical engagement was critical for creating a classroom dynamic that impacted significantly on student performance and understanding. Importantly, the implementation of the SWH enabled the difference in the achievement gap between males and females to be closed.
Introduction

There are differing views of the value of the laboratory component in science classes. A traditional or verification style laboratory environment does not promote conceptual understanding (Gunstone & Champagne, 1990) nor does it demonstrate the scientific process (Lloyd & Spencer, 1994; Spencer, 1994). Traditional laboratories leave students unable to solve transfer problems (Rudd, Greenbowe, & Hand, 2001), relate their laboratory experience to scientific concepts (Lazarowitz & Tamir, 1994), and do not encourage inquiry, as promulgated by the National Science Education Standards (National Science Education Standards, 1996). In a traditional laboratory, students write their laboratory report in the format assigned (typically title, purpose, procedure, data and observations, chemical equations, and discussion). If an instructor makes no attempt to intervene, students will follow a cookbook recipe, complete the work, and leave the laboratory as quickly as possible (Rudd, Greenbowe, & Hand, 2001). The traditional laboratory report is designed to communicate in a compressed format the essential components of the experiment to another scientist. However, formal scientific laboratory reports and publications tend to indicate that the author understood the experiment the first time he or she performed it. In fact, knowledge generation from an experiment is negotiated and discussed in informal settings with co-researchers, with the lead scientist, in research group meetings, in initial drafts of the report, with peer reviewers, and in seminars all before the final report is submitted for publication. Although it is important that science and engineering majors learn how to write formal science laboratory reports, the traditional laboratory report format may not be the tool to use if the goal is to help students understand science concepts and principles (Wallace & Hand, 2004).
Hawkes (2004) has argued that the science laboratory component of a college level course does not help students understand chemical principles and may not even be needed. Importantly, research has shown that traditional laboratory work in science classes produces no significant difference in tests regarding information, application, or laboratory performance and does not influence students’ scores in the laboratory or lecture portion of the course (McKeachie, 1978; Gibbs & McKeachie, 1999; Shibley & Zimmaro, 2002).

However, a number of studies have demonstrated that laboratory experiences can impact student performance in the course when inquiry is appropriately implemented (Lunsford, 2004; Rudd, Greenbowe, Hand, & Legg, 2001; Gabel, 1989; Tien, Rickey, & Stacy, 1999). Mason (2004, p. 1241) believes that “direct laboratory experience is one of the best ways to bring home lessons and have meaningful learning experiences”. Other studies have shown that the laboratory can be helpful in improving student attitudes towards science and specifically chemistry (Bowen, 2000; Shibley & Zimmaro, 2002; Lunsford, 2004). McKeachie makes the point that “the effectiveness of the laboratory depends on the manner in which the work is taught” (McKeachie, 1978, p. 85; Gibbs & McKeachie, 1999).

Although weaknesses of verification laboratories and the strength of inquiry activities have been reported (Domin, 1999; Hilosky, Sutman, & Schmuckler, 1998; Gallet, 1998; Abraham et. al., 1997; Nakhleh, 1994; Lloyd & Spencer, 1994; Lloyd, 1992; Stensvold & Wilson, 1992; Lazarowitz & Tamir, 1994; Hofstein & Lunetta 1982), there is little research to date that has explored the kind of teaching and learning occurring in the laboratory. Student interaction and engagement, as well as instructor engagement may be the two most important factors in determining whether or not participation in the laboratory activities at the university level has an influence on student learning.
This study explores the question of whether effective teaching by a laboratory instructor combined with active involvement and an appropriate response to that instruction by students enrolled in a college chemistry laboratory course can facilitate students' understanding of chemistry. We examined the impact that implementing the Science Writing Heuristic, which includes collaborative learning and uses a different format for the laboratory report, in a college chemistry laboratory course would have on the lecture component of the course. We also examined the impact of both gender and ability.

Review of the Literature

The Science Writing Heuristic (SWH) utilizes the power of both writing to learn and inquiry strategies to foster students' critical thinking about scientific concepts. The theoretical framework is grounded in a constructivist view of learning. While various forms of constructivism have been employed by science educators (Bodner, 1986; Phillips, 1995; Shiland, 1999) there is general agreement that students need to construct scientific concepts themselves and within a social setting. Such construction processes require that students have to negotiate meaning across a range of different social settings and writing forms. Research on semiotic approaches to understanding the use of language reveals that language is a critical component used in the process of establishing the meaning of an event (Berkenkotter & Huchin, 1993; Halliday & Martin, 1993).

Bereiter and Scardamalia (1987) have attributed the discovery of insight while writing to active problem solving. They argue that when an individual composes an original written passage, he or she actively deals with conceptual understanding by linking new knowledge to existing concepts. This results in the transformation of old knowledge to new knowledge. In particular, Elbow (1973) had argued that the discovery of ideas, insights, or
“this doesn’t make sense” occurs when students are encouraged to write a first draft without worrying about grammar, organization, or correctness of the content knowledge. Understanding occurs when an individual uses problem-solving skills, rhetorical skills, and content knowledge to rewrite and refine his or her written work.

Writing to Learn

The ability to clearly and effectively communicate in science is critical (Carlisle & Kinsinger, 1977). There is a need to place importance on writing in the chemistry curriculum because as Rosenthal (1987, p. 996) suggests, there “is no question that students majoring in chemistry, and perhaps other sciences as well, graduate with underdeveloped writing skills”. Paulson (2001, p. 1049) further adds that “the most often-mentioned weakness of students is their writing skills”. In terms of freshman chemistry, Tilstra (2001) has suggested that it should not be assumed that students entering the course have the necessary writing skills to produce a formal report. However, research studies have shown that students who write regularly are better prepared and equipped for future writing tasks (Kovac & Sherwood, 1999). Writing practice helps students to become better writers, it is a powerful learning tool, and an essential professional skill (Kovac & Sherwood, 1999; Rossi, 1997; Bizzell & Herzberg, 1986). Kovac and Sherwood (1999) stated it well when they said, “If chemistry faculty use writing assignments to promote independent learning, they will also address students’ future professional needs” (p. 1399).

Writing in chemistry can accomplish more than one goal. While teaching students to write effectively as will be needed in their profession, the writing process itself is a means for the students to learn and understand chemical concepts. Keys (1999) described how writing in scientific genres can generate new knowledge in that “the requirements for logical
presentation, linear organization, explicitness in connections between concepts, and coherence in conventional scientific genres can foster deep thinking about science” (p. 122).

A number of articles have been published that describe the various ways writing has been incorporated into the chemistry classroom (Shires, 1991; Gordon, Newton, Rhodes, Ricci, Stebbins, & Tracy, 2001; Tilstra, 2001; Paulson, 2001). Kovac and Sherwood (2001) even developed a handbook for teachers to promote writing in the chemistry curriculum.

*The Science Writing Heuristic (SWH)*

Hand and Wallace (formerly Keys) (1999) introduced the SWH as a bridge between informal expressive writing designed to construct scientific understanding and formal writing designed to succinctly communicate the results of an experiment. Similar to Gowin’s Vee Heuristic (Novak & Gowin, 1984), the SWH provides students a template to construct laboratory reports. This laboratory report format consists of a series of questions designed to help students deal with framing a research question, designing an experiment to answer the question, understanding experimental data, and the science concepts associated with the experiment. The SWH template prompts students to write beginning questions, claims (responses to the beginning questions), and evidence for claims. Next, students compare their laboratory findings with others, including peers and information in textbooks. Finally, the template asks students to write how their own ideas have formed, changed or been strengthened as a result of doing the experiment and writing the report.

The teacher template includes eight possible activities associated with the laboratory experiment: (a) exploring pre-instructional ideas, (b) engaging in pre-laboratory writing activities, (c) doing the laboratory activity, (d) writing personal meanings for the laboratory data, (e) sharing personal interpretations of the data with peers in small groups, (f)
comparing laboratory data with relevant ideas and or known values in printed sources, (g) writing about how ideas have changed and writing a product for public viewing, and (h) doing post laboratory instruction that focuses on trends in the class data and the associated concepts.

The results of previous SWH studies indicate that writing to learn in science activities can develop students’ conceptual understanding and logical reasoning (Keys, Hand, Prain, & Collins, 1999; Hand & Keys, 1999; Hand & Prain, 2002). In part, having students write passages, using the SWH, helps transform science content and science terminology under investigation in a science laboratory to something meaningful students can understand and remember. Negotiating meaning from social interaction is clarified in the SWH teacher template and through conducting the laboratory session in a guided – inquiry, student – centered manner. Keys et al. (1999, p. 1066) have emphasized that “these processes of negotiating meaning are essential to allow students to construct, refine, alter, and reconstruct their science conceptions”. Greenbowe and Hand (2005) reported that students, who effectively implement the SWH along with an instructor who effectively integrates collaborative learning and the SWH in the laboratory, perform better on chemistry examinations compared to students who have traditional laboratory instructors and who do not use an SWH laboratory report format.

**Inquiry**

Inquiry is a broad term that can take on a variety of meanings depending upon the situation. In the widest sense of the term, it is a learning strategy that covers all aspects of the course. Most commonly it is referring to teaching in the laboratory, using hands-on experiments and activities to engage students to become active in the learning process
Inquiry involves using the laboratory to introduce concepts instead of verifying them. Laboratory activities are inductive (DeBoer, 1991), have an undetermined outcome, and require students to develop the experimental procedure (Domin, 1999). The teacher's role is that of guide or facilitator and not solely as a source of information to help students complete the laboratory experiment and get the "right" answer. Instead, the students take ownership of the laboratory (Roth & Bowen, 1994; Roth, 1995) and produce the data necessary to complete the experiment. Problem-solving activities and focusing on the process of science, in addition to concepts, are goals of inquiry (Abraham, 2005). Research has shown that inquiry is an effective teaching strategy with respect to attitudes, motivation, concept learning, and process learning (Lawson, Abraham, & Renner, 1989; Lawson, 1995; Abraham, 1998; Rudd, Greenbowe, Hand, & Legg, 2001; Merrit, Schneider, & Darlington, 1993; Kern & Carpenter, 1984).

An inquiry laboratory should have the possibility of more than one right answer (Hand & Keys, 1999). Pickering (1987) reports that using a flexible format for writing reports for an investigative activity helps with students understanding related scientific concepts. The MORE thinking frame (Tien, Rickey, & Stacy, 1999) makes use of a modified guided inquiry format with both written and oral reports. The MORE approach was used in a study by Tien (1998) that provided evidence that students in an inquiry laboratory, emphasizing authentic inquiry designed to promote metacognition, have fewer misconceptions and better critical-thinking skills than students in a traditional laboratory setting. Students using the MORE approach outperformed students using a standard approach on fundamental chemistry algorithmic problems and on fundamental conceptual
problems, however both groups of students had similar low scores on problems requiring a transfer of information and concepts to new settings (Rickey, 1999).

**Collaborative Group Work**

Collaborative inquiry is a fundamental component of creating a student-centered classroom environment (Smith, Hinckley, & Volk, 1991; Nurrenbern & Robinson, 1997). Collaborative work can be seen as a less structured type of cooperative group work (Springer, St anne, & Donovan, 1999; Snodgrass & Bevevino, 2000; Shibley & Zimmaro, 2002; Cooper, 2005). Collaborative learning assumes that students participating in activities are competent in the social skills required to work in peer groups and implies that they have a cooperative-type learning background (Snodgrass & Bevevino, 2000; Selco & Roberts, 2003). Collaborative learning is a more independent, less structured process where participants negotiate their goals, define their problems, develop their procedures, and construct their knowledge in small groups. In collaborative groups, evaluation is often individually based, even though it requires more involvement from all members than in cooperative learning. Lloyd and Beard (1995) and Lunsford (1991) suggested that collaborative learning strategies have the following characteristics:

- Promote problem finding as well as problem solving;
- Aid students in learning abstractions;
- Facilitate knowledge transfer and assimilation;
- Foster interdisciplinary thinking;
- Lead to sharper critical thinking.

Collaborative learning strategies benefit students in a variety of ways (Deckert, Nestori, & DiLullo, 1998; Bowen, 2000; Hass, 2000; Shibley & Zimmaro, 2002; Williamson & Rowe, 2002; Duprey, Sell, & Lowe, 2003). These strategies strengthen students' interpersonal communication skills and self-assurance. Students develop the skills necessary to
collaborate effectively, which is as important as high-quality data and good conceptual understanding as they are more open to interaction with one another than those in more traditional environments. They perceive that they learn more collaboratively than they would alone, and learn to rely on one another, thereby do not ask as many questions of the instructor. There is a feeling of camaraderie along with communal support as students struggle together to accomplish their joint goal(s). Snodgrass and Bevevino (2000) observe that: “Through the personalization and contextualizing of activities, students link[ed] their previous knowledge and experiences to the new learning so that information [was] not learned in an isolated manner” (p. 40). This encourages slower students and promotes positive interdependence, which in turn leads to students who are more motivated, creative, have an improved work ethic, have better attitudes towards science (Bowen, 2000 and Duprey, Sell, & Love, 2003), and have higher achievement overall (Lunsford, 1991 and Hass, 2000).

**Gender**

Research has shown that achievement scores in physics and chemistry vary with regard to gender (Becker, 1989), with females generally not performing as well as males (Matyas, 1985; Kahle, 1990a; Kahle, 1990b; Baker & Scantelbury, 1995). In seeking to understand these results, it is not unreasonable to question what factors with regard to gender are responsible for these differences. Studies have noted that females enter college with fewer science experiences, less confidence to do science, more anxiety about science, fewer mathematical skills, and a lower ability to generate simple visual aids (Kahle, 1985; Kahle & Lakes, 1983; Sjoberg, 1986; Sells, 1973; Wong, 1988). Females who are taught how to represent problems, score as well as males on particulate nature of matter diagram
problems in chemistry, whereas those who were not taught how to represent problems scored significantly lower than males (Bunce & Gabel, 2002). In a study about how spatial ability impacts achievement, Halpern (1992) suggests that males and females learn differently due to their different spatial abilities. This idea is challenged by Goldstein, Haldane, & Mitchell (1990) who argue the difference is due to the testing situation. Kahle (2004) makes an interesting point with regard to achievement based on gender differences. Instead of “placing the blame” on the females due to their gender, the differences in achievement can be viewed as a response to the teaching environment. The SWH is a tool that can be utilized to change the teaching environment and affect the achievement gap between males and females.

Methods

Research Questions

We believe that in order for students to learn science content they need to be able to think logically, develop organizational skills (Lazarowitz & Tamir, 1994), identify and resolve scientifically unacceptable concepts that they hold, and express their understanding of science by writing (Keys, Hand, Prain, & Collins, 1999). A critical component of these processes is the opportunity for learning science as an “inquiry-based process” (National Science Education Standards, 1996).

The results from our previous small scale studies on using the SWH (Rudd, Greenbowe, Hand & Legg, 2001) encouraged us to conduct a full-scale study for an entire class of chemistry students. In particular, given the theoretical framework described above, the following research questions guided us:
1. Does the level of teacher implementation of the SWH (High, Medium, or Low) have an impact on student scores?

2. Does the level of student response to the implementation of the SWH (High, Medium, or Low) have an impact on student scores?

3. Is there an interaction between teacher implementation and student response of the SWH that has an impact on student scores?

4. Does the implementation of the SWH have an impact of student scores according to gender?

5. Does the implementation of the SWH have an impact on student scores according to students’ ability level?

Context

This study was conducted in a large Midwestern university in the United States in a freshman chemistry laboratory course for science and engineering majors to determine whether effective teaching assistants and quality interaction among the student participants had an impact upon student performance on chemistry examinations. This research was based on a quasi-experimental mixed-method design. Although students selected which laboratory section to attend based on their schedule, the laboratory sections observed by the first two authors (research observers) were randomly selected from among those that were available.

Sample

Students. Subjects in this study were enrolled in a first semester college general chemistry class for science and engineering majors. High school chemistry and algebra were two pre-requisites for this course. A total of 661 students were enrolled in the laboratory
portion of the course, 686 students were in the lecture portion of the course, and 631 students took both the laboratory and the lecture. Of the 661 students in the laboratory, 313 students were observed in their laboratory sections by the research observers. Out of the 313 students observed in the laboratory, 309 were also in the lecture portion of the course. Students observed in this research study were enrolled in laboratory sections chosen at random to the extent possible. Students were instructed on how to do inquiry, collaborative group work and how to hand-write their reports, using the SWH format, in a laboratory notebook consisting of alternating white and yellow pages, a carbon-copy notebook. Each report was graded by the teaching assistant in charge of the laboratory section and returned to the students the following week.

Instructors and Teaching Assistants. In this study, 20 teaching assistants taught 37 laboratory sections using the SWH approach. Out of this sample, 14 teaching assistants involved with 18 laboratory sections during the semester, were observed by two trained observers and rated on their effectiveness in implementing the SWH approach. Of the 14 observed TAs, four taught two laboratory sections each. The teaching assistants were graduate students enrolled in masters or doctoral degree programs in chemistry.

To effectively implement the SWH, the teacher must frame the laboratory session correctly in order to create an environment that promotes discussion among the students. Collaborative learning is used in order to assist the students negotiate meaning through that social interaction. This interactive classroom environment sets the stage for how the resulting laboratory session develops. In this study, many of the teachers conducting the laboratory sessions were first-year teaching assistants without prior teaching experience. This was a concern because "the pedagogical content knowledge of beginning teachers is
undeveloped, as it requires the integration of the supporting knowledge domains of subject matter, pedagogy and context” (Roehrig & Luft, 2004, p. 5; Grossman 1990). In addition, as instructional decisions are linked to teacher beliefs (Richardson, 1996) and with the number of teaching assistants involved in the course, a wide range of teacher beliefs were present. Research has also shown that while many beginning teachers hold to student-centered beliefs, they conduct their classroom in a teacher-centered manner (Salish I Research Project, 1997). Since teacher beliefs impact teacher practice (Roehrig & Luft, 2004), proper training to support the teaching assistants to conduct the laboratory in an inquiry fashion became essential (Burke, et al., in press).

*Teaching Assistant Preparation.* All teaching assistants received instruction about the SWH prior to the start of classes. This included a five day pre-semester TA training program, presentations about the SWH, examples of how to grade SWH laboratory reports written by the students, suggestions for how to conduct a SWH guided-inquiry laboratory, and discussion of various teaching strategies on how to promote active student learning in a laboratory setting. All received handouts about the SWH. Additional instruction was provided at weekly staff meetings throughout the semester with respect to further implementation, teaching strategies, and techniques for engaging the students in the laboratory. The research observers provided comments, encouragement, and suggestions on implementation during weeks 1, 2, and 3 when they were present in the laboratory classroom to facilitate the implementation of the SWH. Also, when requested by the teaching assistant in charge of that laboratory, one researcher modeled correct implementation of the SWH by conducting the beginning of the laboratory session. Weeks 8 and 11 were devoted to this modeling of the SWH in a completely open inquiry format.
The schedule of which laboratory sections received modeling of the SWH can be seen in Table 1.

(Table 1 about here)

Qualitative Component

The qualitative measures involved observations of teaching assistants and students in the laboratory. The first two authors ranked the ability of the teaching assistants to effectively implement the SWH on a scale of High, Medium, and Low implementation. The same two observers ranked the interactions between students in the class. These ratings were also based on a scale of High, Medium, and Low as a measure of student response to the SWH. A quantitative component of the study addressed student performance on two standardized American Chemical Society examinations (American Chemical Society California Diagnostic Test, ACS Examinations Institute, 1993; American Chemical Society First Semester Examination, ACS Examinations Institute, 1997) and total points earned from the lecture portion of the course.

There were seven non-consecutive weeks (weeks 4, 5, 6, 9, 10, 12, and 13) when research observers made teacher and student observations. These observations were made during weeks when there was no formal modeling of the SWH provided. They also made observations during the practical examinations (weeks 7 and 15) to maintain a consistent presence in the laboratory and thus not be viewed by the students as intrusive or disruptive during any other observation segment. At the end of the semester, the two trained research observers independently ranked the ability of the teaching assistants to implement the SWH on a scale of High, Medium, and Low. The inter-rater reliability between the observers was above ninety-five percent.
Throughout the course of the semester, students wrote 11 laboratory reports in the SWH format. All laboratory sessions were conducted following a student-centered guided-inquiry model as much as was allowed by the laboratory experiment and direction of the teaching assistant. These inquiry activities were based on constructivist learning theories (Herron, 1975; Bodner, 1986; Shiland, 1999). Two laboratory exercises were fully open-inquiry, a thermodynamics laboratory in week 9 and a kinetics laboratory in week 12. Students also completed two laboratory practical examinations during the semester.

Data Collection

There were three laboratory sections meeting at any given time. Laboratories lasted two hours and fifty minutes and on occasion ran late. The research observers would begin making observations in a randomly selected laboratory classroom. Observations were recorded at the end of a fifteen minute interval and then the observer rotated to the next laboratory classroom. In any laboratory period, a maximum of 12 observations could be made. Since these 12 observations covered all three laboratory meeting periods, four observations of each teaching assistant and section of students could be made if the experiment lasted the entire 170-minute session. Each week observations were made involving 18 laboratory sections with approximately twenty students enrolled in each section. Even when the research observers were not making observations, they maintained their presence in the laboratory to be a consistent influence and so as to not be a disruption when actually making observations.

The research observers made observations with regards to the classroom environment. This consisted of the degree of implementation of the SWH by the teaching assistant and the quality and quantity of dialogue between students in the classroom.
Successful implementation of the SWH by the teaching assistants included opportunities to discuss beginning questions, creating a laboratory environment to support student-centered work, allowing students to assign groups, tasks, and devise data collection tables, having the class data presented on the chalkboard, analyzing the class data, and guiding a class discussion over the concepts covered in laboratory. The observations of student interactions were rated based upon student group size, type of interaction, and percentage of students engaged at that level. A discussion group with 1, 2 or 3 students involved was a small group, while a group of 4 or more students was rated as a large group. A one-way interaction was one student sharing information with another student or students. A two-way interaction was a sustained dialogue between the students involved in the discussion (three or more interchanges). These two factors, group size and type of interaction, result in four different categories. These categories are: large groups involved in two-way interactions, large groups involved in one-way interactions, small groups involved in two-way interactions, and small groups involved in one-way interactions. Once the category was determined, the level of student participation was established. There were three levels of participation. These levels were the same regardless of the group. The levels were determined by the percentage of students participating: up to 25%, up to 50%, and over 50% of the students participating. A diagram of the different categories and levels of participation is presented in Table 2.

(Table 2 about here)

Quantitative Component

Standardized examinations from the American Chemical Society were used as a dependent measure of student performance along with the student composite score from the lecture component of the course. The American Chemical Society California Diagnostic
Test (ACS Examinations Institute, 1993) was given during week one of the laboratory course. The American Chemical Society First Semester Examination (ACS Examinations Institute, 1997) was administered at the end of the semester as an optional test and was taken by the 96% of the students. In order to make comparisons between these exams, scores were normalized to a 100-point scale. A composite score (total points) in lecture was also used for the assessment of student performance. This consisted of 15 homework assignments, 10 quizzes, 4 one-hour exams (35-40% multiple choice or short answer [no partial credit possible] and 60-65% problem solving [partial credit possible]), and the instructor-written, predominately multiple choice comprehensive final exam. There were 700 points total for the course. Each student’s total points earned in the course were converted to a percentage.

As with most large lecture classes in a university setting, it is not possible to have all students complete all the exams at all times. Table 3 shows the numbers of students of the total 313 who had been observed who completed the listed measures.

(Table 3 about here)

An advantage of using the lecture composite score was that the grading of the quizzes, tests, etc. was independent of the implementation of the SWH in the laboratory. The same teaching assistants who taught the laboratory sections also graded the laboratory reports. While instruction, guidance, and practice in grading laboratory reports was provided to the teaching assistants, some of the teaching assistants consistently graded laboratory reports more leniently or more harshly than other teaching assistants. This potential bias was eliminated by using scores from examinations administered in the lecture portion of the course. There was no relationship between a student’s laboratory section and which lecture section she or he attended. Grading was more clearly defined through the use of grading
schemes for all homework assignments, quizzes, and examinations. Thus, the grading in the lecture portion of the course is independent of implementation of the SWH by the teaching assistants in the laboratory as well as the level of student interaction in the laboratory.

A limitation of this study is that standardized American Chemical Society examinations use a multiple-choice format for all questions and numerical problems. These examinations assess chemistry content knowledge, conceptual understanding, and problem-solving skills, but these examinations do not assess student understanding or explanations through written explanation.

Data Analysis

Statistical comparisons were made using the Tukey-Kramer HSD (honestly significant difference) test (Tukey, 1953; Kramer, 1956). This test protects the significance of all combinations of pairs and the LSD (least significant difference) intervals become much greater than the student’s $t$ pairwise LSDs and thus is a more conservative test. In addition, improvement scores (IS) have been used as a means of comparison. An improvement score is a laboratory section’s gain score divided by their potential gain (Sheskin, 2000). All measures of assessment in this study were normalized to a 100-point scale. The laboratory section’s gain score was equal to their average score on the American Chemical Society First Semester Exam (ACS Examinations Institute, 1997) minus their average on the American Chemical Society California Diagnostic Test (ACS Examinations Institute, 1993). Their potential gain score was the possibility of achieving an average score of 100 minus their average score on the American Chemical Society California Diagnostic Exam. The equation for calculating an improvement score is shown in Equation 1.

(Equation 1 about here)
Results

*Comparison of the subjects observed versus students not observed*

The students observed in this study were not statistically different from the rest of the class at the beginning of the study, with respect to the three measures used in assessing students as shown in Table 4, and therefore can be assumed to serve as a representative sample of the total population.

The lecture composite score (total points in the course) includes students who passed both the laboratory and the lecture components of the course.

(Table 4 about here)

With respect to the American Chemical Society California Diagnostic Test (ACS Cal. Diag.): There was no significant difference between the observed students and the students who were not observed.

For the American Chemical Society End of the First Semester Exam (ACS End of Sem.): There was no significant difference between the observed students and the students who were not observed.

For the Lecture Composite (Lecture Comp.): There was no significant difference between the observed students and the students that were not observed.

*Effect of Teaching Assistants on Student Performance*

In order to investigate Research Question #1: “Does the level of teacher implementation of the SWH (either High, Medium, or Low) have an impact on student scores?”, each instructor’s effectiveness in implementing the SWH was classified as High, Medium, or Low based on their total scores received from the two independent observers evaluating numerous laboratory sessions. Figure 1 lists the types of instructor activities that
were classified as ineffective (Low) and effective (High). A classification of medium was
given to instructors who were not high implementers of SWH, but who were doing better
than instructors who carried out a more traditional approach.

(Figure 1 about here)

There were three teaching assistants who were ranked High, seven who ranked
Medium, and four who ranked Low with respect to implementing the Science Writing
Heuristic. The two observers agree on the ranks for all the TAs except for two, Hillary and
Mike. This is due to the fact that because of schedule conflicts, one observer made fewer
observations of both Hillary and Mike. Thus the final ranking was based upon the observer
who had attended more sessions for those teaching assistants. The two research observers
are in agreement that the implementation of the SWH between the TAs ranked at the various
levels was noticeably different. Teaching assistants ranked High were much different from
those ranked Medium and teaching assistants ranked Medium were different from those
ranked Low with respect to implementing the SWH.

The statistical differences between student scores can be analyzed according to
teaching assistant rank determined by the research observers as shown in Table 5. Using the
results of the ACS California Diagnostic Test (Form 1993), there were no statistically
significant differences between the groups at the start of the semester (effect size = 0.07
(High vs. Low).

However, by the time students took the ACS End of First Semester Exam, the group
with a High TA scored significantly better than the group with a Medium TA and the group
with a Low TA (F (2,235) = 4.9765, p = 0.0076, effect size = 0.52 (high vs. low), MSE =
271.18).
A parallel difference also shows up in the lecture composite score, with the High group again statistically different from the Medium and Low groups (F (2,287) = 10.4334, p < 0.0001, effect size = 0.54 (High vs. Low), MSE = 92.441).

(Table 5 about here)

**Effect of Student Interaction Using the SWH on Student Performance**

Research Question #2: Does the level of student response to the implementation of the SWH (High, Medium, or Low) have an impact on student scores? With respect to student interaction at the end of the semester, all of the ratings for the different laboratories were tabulated and each section was assigned a rank of High, Medium, or Low. In order to establish a ranking system, a hierarchy of student–student interaction had to be ascertained. All interactions involving a large group (N ≥ 4) of students out-ranked small group (N < 4) interactions because traditionally students struggle to interact with more than just their laboratory partner. A two-way interaction was considered a sustained dialogue between the students involved, while a one-way interaction was considered to be either asking or answering simple questions between the students involved. Within group size, two-way interactions out-ranked one-way interactions. After that, the ranking increased with the level of student participation. In all, 401 observations were recorded with each observation period being 15 minutes. There were four sections that were ranked High, nine sections that were ranked Medium, and five sections that were ranked Low with regards to student interaction when the SWH was implemented in the laboratory. There were significant differences between the various levels. The two observers had an inter-rater reliability of over 0.95.

Statistically significant differences were found between student rankings as shown in Table 6.
Using the means of the results from the ACS California Diagnostic Test, there were no differences between the groups at the beginning (F (2,284) = 1.9485, p = 0.1444, effect size = 0.24 (High vs. Low), MSE = 200.570).

However, when the students took the ACS End of Semester Exam, the groups with the “High” students scored significantly better than the group with “Medium” students and the group with “Low” students (F (2,235) = 6.2396, p = 0.0023, effect size = 0.59 (High vs. Low), MSE = 268.41). There was no significant difference between the “Medium” and “Low” groups.

This difference also shows up in the lecture composite score, with the High group again statistically significantly different from the Medium and Low groups (F (2,287) = 9.5581, p <0.0001, effect size = 0.65 (High vs. Low), MSE = 92.970). There was no significant difference between the “Medium” and “Low” groups.

Interactions between teaching assistant and students

Research Question #3: Is there an interaction between teacher implementation and student response of the SWH that has an impact on student scores? Given the nature of the teaching required when implementing the SWH, there is an emphasis on interaction between the implementation of the SWH by the teaching assistants and the dialogue among the students. The teaching assistants were ranked High, Medium and Low with regards to implementation and the students were ranked High, Medium, and Low with regards to a dialogical interaction. This results in the three by three grid shown in Table 7.
An interesting observation is that if the TA was effectively implementing the SWH the students would respond in a positive manner. Out of the five sections that had a teaching assistant ranked High, four of those sections also had the student interactions ranked as High. Statistical differences between the various groups are shown in Table 8.

(Table 8 about here)

Using the ACS California Diagnostic Test, there were no statistically significant differences between the groups at the outset (F (5,281) = 1.1818, p = 0.3182, MSE = 201.261).

However, by the time students took the ACS End of Semester Test, group A (high TA implementation, high student response) scored significantly better than groups D (medium TA implementation, low student response) and E (low TA implementation, medium student response) (F (5,232) = 3.1322, p = 0.0093, MSE = 268.211).

This difference was also observed in the recitation composite score, with group A (high TA implementation, high student response) again statistically significantly different from groups C (medium TA implementation, medium student response), D (medium TA implementation, low student response), and E (low TA implementation, medium student response) (F (5,284) = 5.4055, p <0.0001, MSE = 91.502).

Using the improvement score provides some additional insight. Considering the top three sections vs. the bottom three sections, a Low student ranking can be remediated by a High TA. However while the L, L group does not look different statistically from any other group, the difference shows up in the improvement score.
Gender

In order to answer Research Question #4: “Does the implementation of the SWH have an impact on student scores according to gender?”, students were classified by gender and scores on the assessment measures were compared between males and females.

Using the ACS California Diagnostic Test, there was a statistically significant difference between the groups at the outset (F (1,285) = 14.5298, p = 0.0002, effect size = 0.45, MSE = 192.78). Men scored higher than women on the initial diagnostic exam.

However, by the time students took the ACS Special Exam, First Semester General Chemistry, the difference between genders had disappeared (F (1,236) = 0.0822, p = 0.7746, effect size = 0.04, MSE = 281.365).

This disappearance is also evident in the recitation composite score (F (1,288) = 2.3062, p <0.1300, effect size = 0.18, MSE = 98.033).

Pre-existing chemistry knowledge

In order to answer Research Question #5: “Does the implementation of the SWH have an impact on student scores according to students’ ability level?”, differences in pre-existing chemistry knowledge were compared based on the American Chemical Society California Diagnostic Test. The top half of the students had scores ranging from 42 to 27. The bottom half of the students had scores ranging from 26 to 11. There were 110 students that scored in the top half and 177 students that scored in the bottom half of the group.

Using the ACS California Diagnostic Exam, there was a statistically significant difference between the groups at the beginning (F (1,285) = 506.4587, p < 0.0001, effect size = 2.70, MSE = 73.0).
By the time students took the ACS End of Semester Test, the difference between ability remained, but had greatly decreased (F (1,217) = 27.0445, p < 0.0001, effect size = 0.74, MSE = 243.97). This decrease is also evident in the recitation composite score (F (1,268) = 39.7876, p < 0.0001, effect size = 0.80, MSE = 87.27).

The improvement score (IS) is noteworthy. Students in the top half only had an improvement score of 0.08 while the students in the bottom half had an improvement score of 0.28. Even though the groups remain statistically different throughout the course, the difference between the groups is evident in the improvement score (see Table 9).

(Table 9 about here)

With regard to the males, using the ACS California Diagnostic Exam, there were no differences between the groups at the outset (F (5,147) = 0.7714, p = 0.5718, MSE = 235.038).

When the male students took the ACS end of semester test there were still no significant differences (F (5,114) = 1.4481, p = 0.2125, MSE = 317.026).

There was also no significant difference in the recitation composite score (F (5,148) = 1.6462, p <0.1513, MSE = 90.033).

Regarding the females, using the ACS California Diagnostic Exam, there were no differences between the groups at the outset (F (5,128) = 1.5160, p = 0.1893, MSE = 143.719).

However, by the time the female students took the ACS end of semester test, group A (high TA implementation, high student response) scored significantly better than group C (medium TA implementation, medium student response) (F (5,112) = 3.2469, p = 0.0089, MSE = 218.083).
This difference also shows up in the recitation composite score. With group A (high TA implementation, high student response) again statistically significant from groups C (medium TA implementation, medium student response), and D (medium TA implementation, low student response) \((F(5,130) = 6.3477, \ p < 0.0001, \ MSE = 87.959)\) (see Table 10).

(Table 10 about here)

In analyzing the top half, using the ACS California Diagnostic Exam, there were no differences between the groups at the outset \((F(5,104) = 1.7578, \ p = 0.1281, \ MSE = 79.164)\).

When the students in the top half took the ACS end of semester test there were still no significant differences \((F(5,67) = 1.8620, \ p = 0.1128, \ MSE = 265.460)\).

However there is a significant difference in the recitation composite score. Group A (high TA implementation, high student response) is statistically different from group D (medium TA implementation, low student response) \((F(5,100) = 3.4386, \ p < 0.0066, \ MSE = 68.717)\).

With regard to the bottom half, using the ACS California Diagnostic Exam, there were no differences between the groups at the outset \((F(5,171) = 1.4490, \ p = 0.2092, \ MSE = 66.5617)\).

When the students in the bottom half took the ACS end of semester test there were still no significant differences \((F(5,140) = 1.5920, \ p = 0.1662, \ MSE = 220.905)\).

However in there is a significant difference in the recitation composite score. Group A (high TA implementation, high student response) is statistically different from group C.
(medium TA implementation, medium student response) \( (F(5, 158) = 2.5188, p = 0.0318, \) MSE = 89.888).

**Discussion**

The results of this study indicate that implementing the Science Writing Heuristic (SWH) had an impact on student performance through the classroom dynamic that was developed. The level of the classroom dynamic appeared to impact the quality of the negotiation of scientific dialogue between students and the students' performance on test measures. Importantly, the level of implementation of the SWH approach had varied impact across gender and student ability, with females and low ability students showing the greatest improvement on standardized exam scores. The results would indicate two critical and interconnected components of this classroom dynamic. The first is the importance of the teaching assistant, and the second is the involvement of the students.

The role of the teaching assistant was critical in structuring the laboratory session effectively for the SWH. Teaching assistants who implemented the SWH at a High level had students who performed statistically better than students who had a teaching assistant who implemented the SWH at either a Medium or Low level. Even though all the teaching assistants involved in the study started each laboratory session with pre-laboratory instructions on issues of safety and appropriate techniques, there was a variation in the establishment of a framework in which the students conducted the laboratory experiment and the requirements for the laboratory report. Importantly the framework established by each individual teaching assistant impacted the level of negotiation that occurred in the laboratory among the students and the effort put forth by students in their writing.
The other crucial component of the classroom dynamic is the students’ response to the SWH through their level of engagement in scientific dialogue with their peers and the quality of the writing of their laboratory reports using the SWH format. Student groups who became engaged in a High level of scientific dialogue with their peers scored significantly better statistically on the standardized American Chemical Society First Semester Examination than students who only became engaged in scientific dialogue at a Medium or Low level. High level student engagement was noted by the responses to the framework presented by the teaching assistant through the collaborative work they engaged in when assigning tasks and forming sub-groups to complete the laboratory experiment. Presenting class data on the chalkboard, determining patterns or trends, noting anomalies, and becoming engaged in discussion with one another were strong indications of high level responses to the SWH. While all students were required to write their laboratory reports in the SWH format, the quality of the writing of the reports was determined by the level of student effort. The response of the students to the SWH did impact their performance and thus is viewed as a critical component of the resulting classroom dynamic.

These two parts of the classroom dynamic are not independent of each other. As the teaching assistant provides the framework for the laboratory and puts the implementation of the SWH in motion, the students are then under those constraints in the laboratory and are thus affected by how the teaching assistant structures the laboratory. Across the large number of observations conducted in this study, the research observers noted that for the majority of laboratory sections, students followed the guidance of the teaching assistant and responded in a positive manner to implementation of the SWH. That is, if there was a high implementation level by the teaching assistant, then the student level was also high. Given
that there were three levels of implementation of the SWH by the teaching assistants and three categories of scientific dialogue among the students, there were nine possible student-to-teaching-assistant classroom-dynamic scenarios. Only six of those possibilities occurred. Focusing on the level of implementation by the teaching assistant, there were five sections where the teaching assistants were ranked at the High level. Out of those five sections, four of them also had laboratory sections where the students were ranked at the High level of student interaction. When the teaching assistant was ranked at Medium or Low level of implementation for the SWH, the level of student interaction only reached Medium or Low. These results would indicate that if the SWH in not properly implemented, students may lack opportunities to maximize the effectiveness of the approach because the laboratory is not structured appropriately. The results would indicate that implementation of inquiry using the SWH is not simply the teacher giving instructions or the students pursuing the inquiry on their own. That is, there is a need for a dynamic interaction between both teacher and students, that is, there is a critical connection between the teaching assistant and the students needed for success.

The strength of this classroom dynamic is noted through the improvement score statistic. Given that there were six possible combinations of teaching assistant/student engagement, the research observers would point out that there were two distinct groupings when improvement scores were considered. The first grouping consisted of high teaching assistant/high student engagement (0.32), high teaching assistant/low student engagement (0.20) and medium teaching assistant/medium student engagement (0.22). The second grouping consisted of medium teaching assistant/low student engagement (0.11), low teaching assistant/medium student engagement (0.07) and low teaching assistant/low student
engagement (0.13). The difference between these two groups is critical in that it indicates that success in undertaking inquiry-based laboratory activities using the SWH requires either high or medium levels of commitment from both the teaching assistants and the students. Low student engagement in the dialogical interactions required by the SWH approach can be overcome if there is a strong commitment by the teaching assistant to the claims and evidence structure of the SWH when students complete the write up. A medium or low level of commitment by the teaching assistants resulted in much lower improvement scores for the same low level of student dialogical interaction, that is, poor teaching does not overcome poor student engagement. This dynamic between teaching assistants and student engagement needs to be viewed as critical in helping freshman university general chemistry students gain success in building understanding of key concepts of chemistry through their laboratory activities.

Further evidence of this critical classroom dynamic is noted by the impact of the SWH approach on gender. At the beginning of the semester there was a statistically significant difference between males and females in favor of males on the ACS California Diagnostic Exam. By the end of the semester there was no longer a statistically significant difference based on gender with respect to student scores on either the ACS End of Semester Exam or in the final composite score (including exams, quizzes, and homework problems) in the lecture component of the course. Critically, for the males, if the level of implementation of the SWH by the teaching assistant or the level of student dialogue in the laboratory section was ranked as Low, the improvement scores were negligible (0.02, 0.04, and 0.00 for groups D, E, and F respectively). The males only benefited when the classroom dynamic was at higher levels, that is, medium or high implementation. This trend was not duplicated
for the females. Although the different groups did vary in their improvement score, as a whole, the females benefited from the SWH regardless of the specifics of the classroom dynamic that was present in the laboratory. Given that low implementation meant that there was poor dialogue being generated, the researchers would suggest that the scaffolded writing experience impacted on the learning of the females more than the males. That is, even though in situations where there was low teaching assistance or low student engagement, the writing required by the SWH process favorably assisted the females. In this study, the implementation of the SWH changed the teaching environment and the difference in the achievement gap between males and females was closed.

Further evidence of the impact of the SWH was noted by the closing of the gap between high and low ability students. The students in the bottom half of the course with respect to their scores on the American Chemical Society California Diagnostic Exam started off statistically different from students in the top half of the course. This statistical difference remained even at the end of the semester. However, the gap between the two groups changed significantly. Students in the top half of the course had an improvement score of 0.08 while students in the bottom half had an improvement score of 0.28. At the beginning of the course, the groups differed by 23.3 percentage points. At the end of the semester, they differed by 11.7 percentage points on the ACS End of First Semester Exam, and by only 7.4 percentage points when comparing their average composite scores in the lecture portion of the course.

Differences in responses to the SWH based on ability are shown in more detail when looking at the classroom dynamic separated by ability. Students in the top half of the course have good improvement scores only if they are in groups where they engage in at least
medium levels of student dialogue. The only exception is where there is high teaching assistant implementation with low student engagement. In the two groups in which there was low-level student engagement, the improvement score was negative, that is, for the high ability students who did not engage in dialogue, their chemistry scores across the semester actually decreased. The same trend did not hold true for students in the bottom half of the course. Even though the improvement scores vary for the different groups, all of the groups had good improvement scores. Students in the bottom half of the course with regard to ability appeared to have benefited from the SWH regardless of the classroom dynamic that was created in the laboratory. One explanation is that where there is low student dialogical interaction, the scaffolded nature of the writing where students are required to make claims and evidence appears to assist student understanding.

Conclusion

The results of this study suggest that the benefits from the SWH on student performance are derived from both the classroom dynamic that is created in the laboratory that affects the level of negotiation among the students and the thoroughness of the requirements that are placed on writing a complete laboratory report following SWH guidelines. Both the teaching assistants and the students in the laboratory section are responsible for the classroom dynamic that develops. Females and students in the bottom half of the course benefit from the SWH, not only from the level of the classroom dynamic, but also from the structured writing experience, while males and students in the top half of the course appear to only benefit from the SWH at higher levels of the classroom dynamic.
References


American Chemical Society, DivCHED Examinations Institute. California Chemistry Diagnostic Test, Form 1993. University of Wisconsin-Milwaukee, Milwaukee, WI.

American Chemical Society, DivCHED Examinations Institute. Special Chemistry Exam, First-Term General Chemistry, Form 1997. University of Wisconsin-Milwaukee, Milwaukee, WI.


Table 1. Modeling of the Science Writing Heuristic.

<table>
<thead>
<tr>
<th>TA*</th>
<th>Sections*</th>
<th>SWH modeled week 8</th>
<th>SWH modeled week 11</th>
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<tr>
<td>Bill</td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cindy</td>
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<td>yes, both sections B and N</td>
</tr>
<tr>
<td>Alice</td>
<td>C,D</td>
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<td></td>
</tr>
<tr>
<td>Justin</td>
<td>E</td>
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<td></td>
</tr>
<tr>
<td>Doug</td>
<td>F, G</td>
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<td></td>
</tr>
<tr>
<td>Kristen</td>
<td>H</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Larry</td>
<td>I</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Isabelle</td>
<td>J</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elli</td>
<td>K</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>Greg</td>
<td>L</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>Fran</td>
<td>M, R</td>
<td>yes, only section M</td>
<td></td>
</tr>
<tr>
<td>Nancy</td>
<td>O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mike</td>
<td>P</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hillary</td>
<td>Q</td>
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* Names of the teaching assistants and section numbers have been changed to maintain privacy
Table 2. Rating of student interaction.

<table>
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<th>Group Size</th>
<th>Interaction Type</th>
<th>Level of Interaction</th>
<th>Rating</th>
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<tbody>
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<td>Large</td>
<td>Two-Way</td>
<td>Over 50%</td>
<td>Highest</td>
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<td>Up to 50%</td>
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<tr>
<td></td>
<td></td>
<td>Up to 25%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>One-Way</td>
<td>Over 50%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Up to 50%</td>
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<td></td>
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<td>Up to 25%</td>
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<tr>
<td>Small</td>
<td>Two-Way</td>
<td>Over 50%</td>
<td>Lowest</td>
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<td>Up to 50%</td>
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<tr>
<td></td>
<td></td>
<td>Up to 25%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>One-Way</td>
<td>Over 50%</td>
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<tr>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Up to 25%</td>
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</tbody>
</table>
Table 3. Measures completed by observed students.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Number of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACS Cal Diag</td>
<td>287</td>
</tr>
<tr>
<td>ACS End of Sem Exam</td>
<td>238</td>
</tr>
<tr>
<td>Recitation Composite</td>
<td>290</td>
</tr>
<tr>
<td>ACS Cal Diag and ACS End of Sem Exam</td>
<td>219</td>
</tr>
<tr>
<td>ACS Cal Diag and Recitation Composite</td>
<td>270</td>
</tr>
<tr>
<td>ACS End of Sem Exam and Recitation Composite</td>
<td>231</td>
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<tr>
<td>All Three</td>
<td>214</td>
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</table>
Table 4. Mean scores of observed students and students not observed.

<table>
<thead>
<tr>
<th>Student group</th>
<th>ACS Cal. Diag.</th>
<th>ACS End of Sem.</th>
<th>Lecture Composite</th>
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</thead>
<tbody>
<tr>
<td>observed</td>
<td>59.8</td>
<td>68.2</td>
<td>74.9</td>
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<tr>
<td>not observed</td>
<td>61.4</td>
<td>68.5</td>
<td>73.9</td>
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</table>
Table 5. Statistical differences between student scores categorized by teaching assistant rank.

<table>
<thead>
<tr>
<th></th>
<th>ACS Cal Diag Mean</th>
<th>Tukey HSD*</th>
<th>ACS End of Sem Mean</th>
<th>Tukey HSD*</th>
<th>Rec. Comp Mean</th>
<th>Tukey HSD*</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>61.6</td>
<td>A</td>
<td>73.5</td>
<td>A</td>
<td>81.7</td>
<td>A</td>
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<td>Medium</td>
<td>58.5</td>
<td>A</td>
<td>66.8</td>
<td>B</td>
<td>75.6</td>
<td>B</td>
</tr>
<tr>
<td>Low</td>
<td>60.6</td>
<td>A</td>
<td>64.8</td>
<td>B</td>
<td>76.6</td>
<td>B</td>
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<tr>
<td>d</td>
<td>*0.07</td>
<td>*0.52</td>
<td></td>
<td>*0.54</td>
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<tr>
<td>p-value</td>
<td>0.2635</td>
<td>0.0076</td>
<td></td>
<td></td>
<td>&lt; 0.0001</td>
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</tr>
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</table>

Tukey HSD: Groups with different letters are statistically different.

ACS Cal Diag Mean: Mean score on the American Chemical Society California Diagnostic Exam

ACS End of Sem Mean: Mean score on the American Chemical Society End of the First Semester Exam

Rec. Comp Mean: Mean Composite score for the lecture portion of the course including homework, quizzes, hour exams, and the final exam
Table 6. Statistical differences between student scores categorized by student rank.

<table>
<thead>
<tr>
<th></th>
<th>ACS Cal Diag</th>
<th>Tukey HSD*</th>
<th>ACS End of Sem</th>
<th>Tukey HSD*</th>
<th>Rec. Comp</th>
<th>Tukey HSD*</th>
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<tbody>
<tr>
<td>High</td>
<td>62.8</td>
<td>A</td>
<td>74.8</td>
<td>A</td>
<td>82.0</td>
<td>A</td>
</tr>
<tr>
<td>Medium</td>
<td>58.7</td>
<td>A</td>
<td>66.6</td>
<td>B</td>
<td>76.2</td>
<td>B</td>
</tr>
<tr>
<td>Low</td>
<td>59.4</td>
<td>A</td>
<td>65.3</td>
<td>B</td>
<td>75.8</td>
<td>B</td>
</tr>
<tr>
<td>d</td>
<td>*0.24</td>
<td>*0.59</td>
<td>*0.65</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>0.1444</td>
<td>0.0023</td>
<td>&lt; 0.0001</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Tukey HSD: Groups with different letters are statistically different
Table 7. Interaction between teaching assistants and students by laboratory section.

<table>
<thead>
<tr>
<th>TA Rank</th>
<th>Student Rank</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>A,B,C,D</td>
<td></td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Medium</td>
<td>E,F,G,J,K,L,M</td>
<td></td>
<td></td>
<td>Q,R</td>
</tr>
<tr>
<td>Low</td>
<td>H,I</td>
<td></td>
<td></td>
<td>O,P</td>
</tr>
</tbody>
</table>

Note: Laboratory sections have been changed to letters to maintain privacy.
Table 8. Statistical differences between student scores categorized by classroom dynamic groups.

<table>
<thead>
<tr>
<th>Group Label</th>
<th>TA, Std</th>
<th>ACS Cal Diag</th>
<th>Tukey HSD*</th>
<th>ACS End of Sem</th>
<th>Tukey HSD*</th>
<th>Rec Comp</th>
<th>Tukey HSD*</th>
<th>IS means</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>H,H</td>
<td>62.8</td>
<td>A</td>
<td>74.8</td>
<td>A</td>
<td>82.0</td>
<td>A</td>
<td>0.32</td>
</tr>
<tr>
<td>B</td>
<td>H,L</td>
<td>56.2</td>
<td>A</td>
<td>65.0</td>
<td>AB</td>
<td>79.9</td>
<td>AB</td>
<td>0.20</td>
</tr>
<tr>
<td>C</td>
<td>M,M</td>
<td>58.5</td>
<td>A</td>
<td>67.8</td>
<td>AB</td>
<td>76.5</td>
<td>B</td>
<td>0.22</td>
</tr>
<tr>
<td>D</td>
<td>M,L</td>
<td>58.5</td>
<td>A</td>
<td>63.2</td>
<td>B</td>
<td>72.5</td>
<td>B</td>
<td>0.11</td>
</tr>
<tr>
<td>E</td>
<td>L,M</td>
<td>59.4</td>
<td>A</td>
<td>62.3</td>
<td>B</td>
<td>75.4</td>
<td>B</td>
<td>0.07</td>
</tr>
<tr>
<td>F</td>
<td>L,L</td>
<td>62.1</td>
<td>A</td>
<td>67.2</td>
<td>AB</td>
<td>78.0</td>
<td>AB</td>
<td>0.13</td>
</tr>
<tr>
<td>p-value</td>
<td>0.3182</td>
<td>0.0093</td>
<td>(A vs. D,E)(&lt;0.0001)</td>
<td>(A vs. C,D,E)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Tukey HSD: Groups with different letters are statistically different
Table 9. Statistical differences between student scores categorized by classroom dynamic groups and divided by gender.

<table>
<thead>
<tr>
<th>Group Label</th>
<th>TA, ACS Std</th>
<th>ACS End of HSD*</th>
<th>Tukey HSD*</th>
<th>Rec Comp</th>
<th>Tukey IS Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>H,H</td>
<td>67.5 A</td>
<td>74.0 A</td>
<td>80.7 A</td>
<td>0.20</td>
</tr>
<tr>
<td>B</td>
<td>H,L</td>
<td>59.0 A</td>
<td>68.7 A</td>
<td>82.8 A</td>
<td>0.24</td>
</tr>
<tr>
<td>C</td>
<td>M,M</td>
<td>61.7 A</td>
<td>71.1 A</td>
<td>78.8 A</td>
<td>0.25</td>
</tr>
<tr>
<td>D</td>
<td>M,L</td>
<td>62.5 A</td>
<td>63.4 A</td>
<td>74.7 A</td>
<td>0.02</td>
</tr>
<tr>
<td>E</td>
<td>L,M</td>
<td>60.5 A</td>
<td>62.2 A</td>
<td>75.3 A</td>
<td>0.04</td>
</tr>
<tr>
<td>F</td>
<td>L,L</td>
<td>63.7 A</td>
<td>63.7 A</td>
<td>77.8 A</td>
<td>0.00</td>
</tr>
<tr>
<td>p-value</td>
<td>0.5718</td>
<td>0.2125</td>
<td>0.1513</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>H,H</td>
<td>59.5 A</td>
<td>75.4 A</td>
<td>82.9 A</td>
<td>0.39</td>
</tr>
<tr>
<td>B</td>
<td>H,L</td>
<td>50.5 A</td>
<td>57.6 AB</td>
<td>73.0 AB</td>
<td>0.14</td>
</tr>
<tr>
<td>C</td>
<td>M,M</td>
<td>54.5 A</td>
<td>64.5 B</td>
<td>73.5 B</td>
<td>0.22</td>
</tr>
<tr>
<td>D</td>
<td>M,L</td>
<td>52.9 A</td>
<td>62.8 AB</td>
<td>69.6 B</td>
<td>0.21</td>
</tr>
<tr>
<td>E</td>
<td>L,M</td>
<td>57.9 A</td>
<td>62.4 AB</td>
<td>75.6 AB</td>
<td>0.11</td>
</tr>
<tr>
<td>F</td>
<td>L,L</td>
<td>60.1 A</td>
<td>71.0 AB</td>
<td>78.3 AB</td>
<td>0.27</td>
</tr>
</tbody>
</table>

p-value: 0.1893 0.0089

*(A vs < (A vs C,D) C,D)

Tukey HSD: Groups with different letters are statistically different.
Table 10. Statistical differences between student scores categorized by classroom dynamic groups and divided by ability.

<table>
<thead>
<tr>
<th>Group Label</th>
<th>TA, ACS</th>
<th>ACs Cal HSD*</th>
<th>Tukey ACs End of Sem HSD*</th>
<th>Rec Comp</th>
<th>Tukey IS HSD*</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top ½</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>H,H</td>
<td>77.7</td>
<td>A</td>
<td>82.0</td>
<td>A</td>
<td>86.4</td>
</tr>
<tr>
<td>B</td>
<td>H,L</td>
<td>76.8</td>
<td>A</td>
<td>80.3</td>
<td>A</td>
<td>88.5</td>
</tr>
<tr>
<td>C</td>
<td>M,M</td>
<td>74.3</td>
<td>A</td>
<td>78.0</td>
<td>A</td>
<td>80.8</td>
</tr>
<tr>
<td>D</td>
<td>M,L</td>
<td>72.2</td>
<td>A</td>
<td>67.0</td>
<td>A</td>
<td>76.6</td>
</tr>
<tr>
<td>E</td>
<td>L,M</td>
<td>71.6</td>
<td>A</td>
<td>77.9</td>
<td>A</td>
<td>81.2</td>
</tr>
<tr>
<td>F</td>
<td>L,L</td>
<td>70.6</td>
<td>A</td>
<td>67.8</td>
<td>A</td>
<td>81.0</td>
</tr>
<tr>
<td>p-value</td>
<td>0.1281</td>
<td>0.1128</td>
<td>0.0066</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom ½</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>H,H</td>
<td>51.3</td>
<td>A</td>
<td>70.0</td>
<td>A</td>
<td>78.3</td>
</tr>
<tr>
<td>B</td>
<td>H,L</td>
<td>48.7</td>
<td>A</td>
<td>60.4</td>
<td>A</td>
<td>77.2</td>
</tr>
<tr>
<td>C</td>
<td>M,M</td>
<td>50.6</td>
<td>A</td>
<td>63.4</td>
<td>A</td>
<td>74.2</td>
</tr>
<tr>
<td>D</td>
<td>M,L</td>
<td>47.7</td>
<td>A</td>
<td>60.7</td>
<td>A</td>
<td>68.9</td>
</tr>
<tr>
<td>E</td>
<td>L,M</td>
<td>52.7</td>
<td>A</td>
<td>60.8</td>
<td>A</td>
<td>73.2</td>
</tr>
<tr>
<td>F</td>
<td>L,L</td>
<td>54.1</td>
<td>A</td>
<td>67.8</td>
<td>A</td>
<td>75.5</td>
</tr>
<tr>
<td>p-value</td>
<td>0.2092</td>
<td>0.1662</td>
<td>0.0318</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Tukey HSD: Groups with different letters are statistically different
Figure 1. A comparison of characteristic of ineffective instructors to effective instructors.

<table>
<thead>
<tr>
<th>Ineffective Instructor</th>
<th>Effective Instructor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning questions not discussed.</td>
<td>Opportunities to discuss beginning questions.</td>
</tr>
<tr>
<td>TA tells students exactly what needs to be done.</td>
<td>Setting up the lab for student-centered work.</td>
</tr>
<tr>
<td>Individual work or pairs work separately from the class.</td>
<td></td>
</tr>
<tr>
<td>Instructor assigns tasks.</td>
<td>Allowing students to assign groups and tasks.</td>
</tr>
<tr>
<td>No sharing or analysis of class data.</td>
<td>Class data are presented on the chalkboard.</td>
</tr>
<tr>
<td>Students immediately leave when finished with their work.</td>
<td>Class data are analyzed as a group.</td>
</tr>
<tr>
<td></td>
<td>Instructor guides a class discussion of concepts covered in the laboratory.</td>
</tr>
</tbody>
</table>
Equation 1. Calculation of an improvement score

\[ IS = \frac{\text{group's gain score}}{\text{group's potential gain score}} \]

\[ IS = \frac{\text{ACS First Sem. Exam} - \text{ACS Cal. Diag. Exam}}{100 - \text{ACS Cal. Diag. Exam}} \]
CHAPTER 4. USING THE SCIENCE WRITING HEURISTIC IN THE GENERAL CHEMISTRY LABORATORY TO IMPROVE STUDENTS' ACADEMIC PERFORMANCE

A paper submitted to the *Journal of Chemical Education*

Jason Poock, K. A. Burke, Thomas Greenbowe, Brian Hand

Abstract

A two-semester longitudinal study investigated the role a laboratory instructional strategy, the Science Writing Heuristic (SWH), had on improving student academic performance in the lecture portion of the course. The SWH helps students do inquiry science laboratory work by structuring the laboratory notebook in a format that guides students to answer directed questions instead of using a traditional laboratory report. In this approach, students must make a claim (inference) about what was learned through the laboratory experiment and provide evidence to support that claim. Then, through reflection, students continue to negotiate meaning from the experiment(s) they conducted. The structure of a successful implementation of the SWH requires a student-centered learning environment. In this study, both students and instructors were rated on how well they implemented the SWH and inquiry. The more proficiently an instructor engages students to do inquiry and use the SWH, the more effectively students respond to learning. This approach helps women close the gender gap that exists at the beginning of the course and it helps students who enter the course with less chemistry knowledge than their peers learn chemistry during the second semester of the course when more difficult topics are studied.

Keywords: Chemical Education Research, General Chemistry, Inquiry, Collaborative Learning, Laboratory Instruction, TA Training, Teaching/Practice
Introduction

The worth and validity of college general chemistry laboratories were recently called into question (1,2) because of a seeming lack of evidence of that laboratories contribute to students' overall understanding of science (1,3). Hawkes' (1) main point is "it has not been shown that such understanding is improved by laboratory work, and judging from McKeachie's (3) review, it is not." Others (2, 4, 5) had already identified the issue of lack of research evidence connecting laboratory experience with improving students' understanding of science. Recently, there have been several research studies that provide evidence that guided-inquiry activities, collaborative learning, and a framework for promoting thinking and active-learning, can help students learn and retain science concepts and principles (6-8).

There are four factors that can influence the effectiveness of a laboratory experience:

- the instructor;
- the students;
- the type of learning activities;
- the quality and type of laboratory notebook written by the student.

Effective laboratory instructors (9-11)

- facilitate inquiry activities;
- know how students learn;
- promote students asking questions;
- are able to help students understand the activity;
- explain and demonstrate laboratory techniques;
- motivate students to do their best.

Writing (12-14) and the use of guided-inquiry and the learning cycle (15,16) are effective active learning techniques that help students learn chemistry.

Using an explicit approach, such as the MORE Framework (7), helps students work through chemistry inquiry laboratory activities and provides a structure for writing the
laboratory notebook. The laboratory manual can be written in an inquiry manner, but if the instructor does not teach in an inquiry manner and students do not engage in doing inquiry, then the laboratory experience will not result in an improvement of student understanding.

Gender is a fifth factor that has been shown to have an impact on students’ achievement in physics and chemistry (17). Research on science achievement and gender has shown that, in general, females do not achieve as well in science classes as males (18-21). In general, females enter college with

- fewer science experiences;
- less confidence to do science;
- more anxiety about science;
- fewer mathematics skills;
- less ability to generate simple visual aids (22-26).

Females who are taught how to represent problems, score as well as males on particulate nature of matter diagram problems in chemistry, whereas those who were not taught how to represent problems scored significantly lower than males (27). Interventions that explicitly teach females skills on how to improve their learning of a subject matter are beneficial.

An approach incorporating some of the factors described above is the Science Writing Heuristic (SWH). The SWH helps students do inquiry science laboratory work by structuring the laboratory notebook in a format that guides students to answer directed questions instead of using a traditional laboratory report (Title, Purpose, Procedure, Data, Results, Conclusion) format (28-33). Several research studies have shown that the SWH promotes an increase in students’ understanding of science (34, 35).

In the SWH approach, students must make a claim (inference) about what was learned through the laboratory experiment and provide evidence to support that claim. Then, through reflection, students continue to negotiate meaning from the experiment(s) they
conducted. The structure of successfully implementing the SWH also requires a student-centered learning environment. Students need to take ownership of the laboratory experiment. They do this by discussing their beginning questions, forming groups, assigning specific tasks in order to design and perform laboratory experiments, and by analyzing and discussing resulting data as an entire class. In order to reap the benefits of the SWH, it is critical that proper implementation of the SWH by the instructor or teaching assistant is followed in kind by a willing response by the students.

This study is a two-semester longitudinal investigation of the role a laboratory instructional strategy, the Science Writing Heuristic, and its effect on student performance on chemistry lecture examinations. The study addressed the main issue of whether or not a college level general chemistry laboratory experience can be “effective” in helping students improve their understanding of chemistry. In this study, both students and instructors were rated as to the degree they successfully implemented the SWH and inquiry while doing their chemistry laboratory work.

Methods

The Science Writing Heuristic (SWH) was implemented at Iowa State University in the laboratory component of a general chemistry course for science and engineering majors for the duration of an entire academic year (a two-semester sequence). During the first semester of the course (Chemistry 177), a total of 661 students were enrolled in the laboratory portion of the course and 631 students were enrolled in both the laboratory and the lecture. A total of 313 students were observed by two researchers in randomly selected laboratory sections. During the second semester course (Chemistry 178), a total of 342 students were enrolled in the laboratory and 330 students were enrolled in both the
laboratory and lecture. Second semester, 164 students in randomly selected laboratory
sections were observed by the same two researchers. Professor A taught the first semester
of the course and Professor B taught the second semester of the course. Eighty students who
were observed during the first semester of the course were also observed during the second
semester of the course. These eighty students are the focus of this research.

The main research question was: Does the quality of implementation of guided-
quiry and the Science Writing Heuristic in the laboratory have an impact on student
performance on total points earned in the lecture course and does it depend upon gender and
pre-existing chemistry knowledge?

Two experienced observers rated the degree of implementation of the SWH by the
teaching assistants who were assigned to teach the various laboratory sections. Factors that
the observers looked for with respect to successful implementation included:

- opportunities for students to discuss beginning questions;
- encouraging the students to self-assign groups and tasks needed to complete
  the laboratory experiment;
- having students record data on the chalkboard as part of a class data set;
- having the teaching assistant guide but not direct a class discussion at the end
  of the laboratory over the relevant concepts covered.

Teaching assistants were rated at the end of each course as either “High” or “Low” in
their ability to successfully implement the SWH. Thus, over two semesters, students ended
up in one of four categories. They could have had a “High” teaching assistant for both
courses, a “High” teaching assistant for the first course and a “Low” teaching assistant for
the second course, a “Low” teaching assistant for the first course and a “High” teaching
assistant for the second course, or students may have encountered a “Low” teaching
assistant for both courses. These combinations will be revered to as H, H; H, L; L, H; and L, L respectively.

The observers appraised the amount of scientific dialogue exchanged among students and between student(s) and instructor. A discussion of scientific and chemical principles involved in the laboratory was classified as a deeper engagement compared to students simply exchanging factual or procedural information with one another. Scientific dialogue that involved a greater number of students (four or more students) was thought to be a greater acceptance of the SWH approach on the students' part compared to a discussion between a smaller number of students (three or fewer). This was considered appropriate because the scientific process involves discussion, argumentation, and communication among peers (36). As the number of discussions increased between students and the number of students involved in those discussions increased, the response to the SWH by students was considered to be more successful and was then ranked higher than instances where there was a lack of student involvement in scientific dialogue. An average inter-rater reliability coefficient for all of the categories was 0.97 which is considered high (37, 38).

During the first week of class in the first semester, the American Chemical Society California Diagnostic Examination, Form 1993 (CALD) (39) was administered to all students enrolled in the laboratory portion of the course. This instrument was used to determine whether there were any differences among groups at the outset of this research. Raw scores were converted to a percentile for comparative statistical purposes. To determine the effect of the SWH on student performance, total points earned in the lecture (composite score) were used (177 Comp. and 178 Comp. for first and second semester courses respectively). Composite scores included homework and lecture assignments, quizzes, four
hour exams, and the instructor-written comprehensive final examination. Since implementation of the SWH takes place in laboratory, using lecture composite scores reduces possible instructor bias in grading. In the lecture course, there is no connection between student enrollment in a given laboratory section and the lecture section in which the student is enrolled. Thus, all grading in the lecture portion of the course is done independently of the laboratory section in which the SWH was implemented.

Results

Figure 1 and Table 1 show the scores from subgroups on the CALD at the start of the semester and scores from subsequent lecture examinations.

At the start of the semester, based on the results of the ACS California Chemistry Diagnostic Examination, there are no statistically significant differences among the four teacher groups, $F(3, 75) = 1.6367, p = 0.1880, MSE = 222.473$. By the end of the first course, statistically significant differences had developed. The H, H group scored statistically better than either the L, H group, or the L, L group, but did not score statistically differently from the H, L group, $F(3, 76) = 4.2988, p = 0.0074, MSE = 86.885$. It needs to be kept in mind that at this time, students had either been with a “High” teaching assistant or a “Low” teaching assistant for one semester. The average scores in Table 1 show a clear difference in performance of students having a “High” teaching assistant and a “Low” teaching assistant for the first semester. By the end of the second course, the distribution among the four teacher groups is striking. The H, H group scored statistically differently
from the L, L group with the H, L group and the L, H group in the middle. F (3, 74) = 5.1379, p = 0.0028, MSE = 219.13. The IS2 (second improvement score) show a split between "High" and "Low" teaching assistants for the second course. Students having a "High" teaching assistant for the second semester had improvement scores of 0.04 and 0.02, while students having a "Low" teaching assistant for the second course have improvement scores of -0.22 and -0.38. The average composites scores at the end of the second semester (178 Comp.) parallel the level of SWH implementation by teaching assistants that students received. The H, H group scored highest (83.7), then the H, L group (77.5), then the L, H group (75.1), and the L, L scored lowest (65.3).

Pre-existing chemistry knowledge. Figure 2 and Table 2 shows the effect of the SWH on students' scores when taking pre-existing chemistry knowledge into account. The results of the CALD show statistically significant differences among the groups with regard to ability at the start of the semester, F (1, 78) = 148.5398, p < 0.0001, MSE = 78.8. At the end of the first semester, the statistical differences remained, but the bottom half had greatly closed the gap, F (1, 78) = 17.0297, p < 0.0001, MSE = 82.01. In this case, it is useful to look at improvement scores (Equation 1).
Equation 1. Calculation of an improvement score

\[ IS = \frac{\text{group's gain score}}{\text{group's potential gain score}} \]

\[ IS_1 = \frac{177 \text{ Comp.} - \text{ACS Cal. Diag. Exam}}{100 - \text{ACS Cal. Diag. Exam}} \]  
(improvement score after the first semester)

\[ IS_2 = \frac{178 \text{ Comp.} - 177 \text{ Comp.}}{100 - 177 \text{ Comp.}} \]  
(improvement score after the second semester)

The top half had an improvement score of 0.35 while the bottom half had an improvement score of 0.50. This same effect can be seen second semester, \( F(1, 73) = 4.5078, p = 0.0372, \text{MSE} = 245.92 \). The top half had an improvement score of -0.23 while the bottom half had an improvement score of -0.12. The negative value for the improvement score indicates that the second semester course resulted in lower student scores in comparison to the first semester course.

Figure 2 and Table 2 about here

Gender. The effect of the SWH on student scores with respect to gender is seen in Figure 3 and Table 3. The results of the CALD show no statistically significant differences between the groups (females and males) at the start of the semester, \( F(1, 78) = 3.2625, p = 0.0748, \text{MSE} = 221.495 \). Although not statistically significant, there is a gap between the males and females, with the males scoring higher (64.3\% for males versus 58.1\% for females). By the end of the first semester, the difference in the average composite score
between males and females had practically disappeared. The females had nearly an identical average score compared to the males. F (1, 78) = 0.2891, p = 0.5923, MSE = 98.6570. At the end of the second course, the females had similar averages scores compared to the males. F (1, 74) = 0.4174, p = 0.5203, MSE = 257.916. By the end of the first semester, females had an average composite score of 78.8% compared to 80.0% for males. At the end of the second semester the females had a higher average composite score (77.8%) compared to males (75.3).

Discussion

The results from comparing the effectiveness of the teaching assistants’ successful implementation of the SWH impacting student performance, are striking. The four teacher groups start the academic year with statistically equivalent beginning knowledge of chemistry. At the end of the first semester, the difference in the students’ composite score between groups that had a teaching assistant rated “High” with respect to the degree of implementation of the SWH compared to the groups who had a teaching assistant rated “Low”, are statistically significant. It should be kept in mind that at the end of the first semester, both H, H and H, L groups had just completed a semester of instruction with a “High” ranked teaching assistant while both L, H and L, L groups had a semester with a “Low” ranked teaching assistant. The difference clearly indicates that having a “High” ranked teaching assistant for implementing the SWH is superior to having a “Low” ranked teaching assistant. The groups clearly split between those with a “High” teaching assistant and a “Low” teaching assistant. The results of the analysis of data from the second semester reveal this same split. The H, H group’s average score for second semester was best of all.
four teacher groups. Students benefit from having an effective teaching assistant implementing the SWH. The H, L group’s composite score was lower when compared to the H, H group. We attribute this outcome to students having a teaching assistant who failed to effectively implement the SWH the second semester. The L, H group benefited from having an effective teaching assistant for the second semester course. The group had an improvement score similar to the H, H group. The L, L group continued to perform poorly and ended the second semester course with the lowest score of the four teacher groups.

During both semesters, student performance differs between groups who had a “High” ranked teaching assistant and those with a “Low” ranked teaching assistant, with “High” always outperforming “Low”. It is noteworthy that the SWH has an impact over both semesters. In addition, the SWH can be implemented effectively and impact student scores even after a semester with an ineffective teaching assistant for students.

With regard to pre-existing chemistry knowledge, the effect of the SWH is again striking. Scores on the CALD were used to classify the students into the top half and bottom half of their class. The difference in their average scores is 24.6%; i.e., as expected the students in the top half of the course start the course with more knowledge and skills compared to the students in the bottom half of the course. By the end of the first semester, while a statistical difference remained, the difference in the average composite scores had been reduced to 8.5%. Improvement scores demonstrate the same trend with scores of 0.35 and 0.50 for the top half students and bottom half students respectively. By the end of second semester, the difference in the overall composite scores of the two ability groups had been reduced to 7.9%. Improvement scores of -0.23 for the top half and -0.12 for the bottom half show that when the topics became more difficult, the bottom half of the students were
able to grasp the material as well as the top half of the students. The lower ability students did not experience as great a decrease in their composite scores. This shows that the SWH has a positive impact on student performance over an entire academic year, though it currently appears that the greater gain may be accomplished in the first semester.

With respect to gender, female subjects in this study entered the course with a slightly lower level of chemistry knowledge compared to the males. At the end of the first semester, the women who had an effective laboratory instructor earned as many points in the course as their male counterparts. At the end of the second semester, women who had an effective laboratory instructor earned more points than the men. This is consistent with results from previous gender studies that conclude that females can succeed in science as well as males, if instruction on how to use skills to learn the course material are provided (21, 40)

**Conclusions**

The results of this experiment provide evidence that appropriate chemistry laboratory experiences can contribute to students' overall learning of chemistry. In order for the laboratory experience to be effective, three conditions must exist. First, laboratory activities should be inquiry-based. Second, the instructor should be a facilitator and use inquiry and the SWH as a framework to help students learn chemistry. Third, students should use the SWH to guide their discussions, to structure their laboratory notebooks, and to facilitate their learning of chemistry. A key feature of this approach is the guidance provided by the instructor to the students to engage in meaningful discussions and to write clear passages in their student laboratory notebooks. These conditions are consistent with the statement by William Leonard (41) that,
"Maximum benefit can be derived from laboratory and field experiences by having students work in groups and share their ideas, perceptions, and conceptions. Group design and interpretation of laboratory work are also effective strategies for exposing the changing misconceptions. In addition, students should prepare written reports describing the rationale for the experimental design, the data, and their interpretations", p 166.

When instructors or teaching assistants effectively implement inquiry and the SWH process and teach this process to their students, learners benefit. Students who willingly embrace this approach to doing science laboratory activities exhibit better academic success in the lecture portion of the course. In this experiment, the SWH was shown to benefit students over a typical two-semester general chemistry course. The more proficiently an instructor engages students, the more effectively students respond to learning. Even if students did not have an effective laboratory instructor the first semester, they still can benefit by having an effective laboratory instructor during the second semester of the course. This approach helps women close the gender gap that exists at the beginning of the course. Implementation of the SWH and guided inquiry in the chemistry laboratory provides evidence that “that the effectiveness of the laboratory depends on the manner in which the work is taught” (42, p 168).

References

Figure 1. TA implementation of the SWH.
Figure 2. The effect of the SWH on ability.
Figure 3. The effect of the SWH on gender.
Table 1. Effect on student scores from TA implementation of the SWH

<table>
<thead>
<tr>
<th>TA ranks</th>
<th>ACS Cal. Diag.</th>
<th>177 Comp.</th>
<th>IS₁</th>
<th>178 Comp.</th>
<th>IS₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>H then H</td>
<td>63.0</td>
<td>83.1</td>
<td>0.54</td>
<td>83.7</td>
<td>0.04</td>
</tr>
<tr>
<td>H then L</td>
<td>66.2</td>
<td>81.6</td>
<td>0.46</td>
<td>77.5</td>
<td>-0.22</td>
</tr>
<tr>
<td>L then H</td>
<td>56.0</td>
<td>74.7</td>
<td>0.43</td>
<td>75.1</td>
<td>0.02</td>
</tr>
<tr>
<td>L then L</td>
<td>58.7</td>
<td>74.8</td>
<td>0.39</td>
<td>65.3</td>
<td>-0.38</td>
</tr>
<tr>
<td>p-value</td>
<td>0.1880</td>
<td>0.0074</td>
<td>0.0028</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Table 2. Effect of the SWH on student scores in regard to ability

<table>
<thead>
<tr>
<th>Ability</th>
<th>ACS Cal. Diag.</th>
<th>177 Comp.</th>
<th>IS₁</th>
<th>178 Comp.</th>
<th>IS₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top 1/2</td>
<td>75.9</td>
<td>84.3</td>
<td>0.35</td>
<td>80.7</td>
<td>-0.23</td>
</tr>
<tr>
<td>Bottom 1/2</td>
<td>51.3</td>
<td>75.8</td>
<td>0.50</td>
<td>72.8</td>
<td>-0.12</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
<td></td>
<td>0.0372</td>
<td></td>
</tr>
</tbody>
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Table 3. Effect of the SWH on student scores in regard to gender

<table>
<thead>
<tr>
<th>Gender</th>
<th>ACS Cal. Diag.</th>
<th>177 Comp.</th>
<th>IS₁</th>
<th>178 Comp.</th>
<th>IS₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>64.3</td>
<td>80.0</td>
<td>0.44</td>
<td>75.3</td>
<td>-0.24</td>
</tr>
<tr>
<td>Females</td>
<td>58.1</td>
<td>78.8</td>
<td>0.49</td>
<td>77.8</td>
<td>-0.05</td>
</tr>
<tr>
<td>p-value</td>
<td>0.0748</td>
<td>0.5923</td>
<td></td>
<td>0.5203</td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER 5. CONCLUSIONS

General Conclusions

Our research has shown that when the SWH is properly implemented, student performance on examinations improves and is better than if a traditional approach to the laboratory had been utilized. The students score better. But there is more than just that factor to consider. The SWH laboratory classroom is a complete contrast to the laboratories where there is a silence hanging over the room and the students complete their required instructions in order to escape the clutches of the chemistry laboratory. The students, and the teaching assistants, have a more positive experience with science and learning chemistry when the SWH is effectively implemented. The laboratory classroom is “alive” with investigations, experimentation, and discussion.

Success of the Science Writing Heuristic

There are a number of ways to look at the success of the SWH. One is through the analysis of student scores on standardized exams and through course grades. When the classroom dynamic that is created when the SWH is ranked high with respect to both teacher implementation and the student response, student scores are higher than when the classroom dynamic is not ranked high in both aspects. Students with a teacher who effectively implements the SWH and who responded to that implementation in a positive manner, outperformed students in other classes on almost every single measure that was investigated. Students scored better in laboratory and in the lecture portion of the course. This includes all aspects of the course; homework, quizzes, exams, standardized exams, and in-class assignments. The difference in their overall course grade could change a student’s grade
from a C to a B-. That is almost an entire letter grade. That alone is convincing enough to adopt the SWH into the laboratory component of a course.

In addition to the improvement in student scores, the SWH shows a connection between the teacher and the students. The SWH was most successful when properly implemented by the teacher and responded to enthusiastically by the students. It shows that for ultimate success it takes the cooperation of both teachers and students. The teacher alone can not cause the students to learn. The students will flounder without the guidance, insistence, and the framework provided by the teacher. It’s encouraging to have been involved in research that shows that teachers can have an impact on student learning. But this doesn’t negate the students’ responsibility. Students are the learners and it is necessary for them to become actively engaged and take responsibility for their own learning.

Another exciting result of this research has been the link between the laboratory setting and the lecture portion of the course. The SWH was implemented in the laboratory portion, but the examinations upon which the data analysis was built were taken from the lecture portion of the course. This shows that the learning that was taking place in the laboratory carried over and was demonstrated in the lecture portion of the course. This research shows that the concepts being taught in the laboratory were learned by the students. SWH students performed better on their examinations and coursework compared to students in sections where the SWH had not been properly implemented.

There are additional benefits to the SWH that are harder to quantify. One additional benefit is attitude. The attitude of the teachers towards teaching and the attitude of the students towards learning improved. The teachers involved in the study enjoyed teaching laboratory to a greater extent than when using a more traditional approach. They could tell
that the science writing heuristic was influencing their students' learning. There was a
positive interaction that developed in the laboratory classroom and the teachers felt that they
had more impact on student learning. The students' became more engaged in the laboratory.
The SWH gave students ownership and interest in the experiments that they were
conducting. Students commented that their laboratory experience was much more positive.

**Robustness of the SWH**

What is meant when it is said that the SWH is robust? It can handle a wide variety of
conditions. It can handle different experiments, different students, different conditions and it
can handle problems. Experiments can be modified, at times, with little or no effort to the
experimental set up.

An example would be the coffee – cup calorimeter experiments used when studying
thermodynamics. Typically all the students do the same not very exciting experiment. When
implementing the SWH approach, all that is necessary is to vary the amount of water in the
coffee – cup and ask what the effect is when changing that variable. Or we could change the
amount of substance dissolved in the coffee – cup, what would happen then? Could we do
both? Absolutely! With a little forethought on the part of the teacher and some organization
prior to the experiment by the students, a number of variables can be investigated
simultaneously. A more lively and though provoking laboratory experiment results.

The SWH can even handle problems. Here is another example from the laboratory.
Students were working on a kinetics experiment and getting vastly different results when
repeating the experimental work. The experiments were being duplicated to verify the
results. However, students didn’t get the expected results. In a typical laboratory setting the
experiment might have been a failure. Results couldn’t be duplicated. Since we were using
the SWH, (I think it was a preliminary study) we just changed our question. Why can’t we duplicate this experiment? The students reorganized to study this new question. New variables had to be controlled for and others needed to be investigated. The results: students discovered that one bottle of a reagent had the wrong concentration. Another result: students discovered the rate of stirring the solution with a magnetic stir bar had an effect on the rate of the reaction. It was exciting to see students take control of the laboratory experiment and investigate what was going on. The experiment went from a failure, if doing a traditional laboratory experiment, to a unique investigation when implementing the SWH.

**Future investigations**

There is an intangible quality to effectively implementing the SWH. Every instructor is different and will implement the SWH in her or his own unique way according to her or his personality. Implementation of the SWH does not follow a “cookbook” recipe. There are strategies and a teacher template, but the classroom dynamic that is created in the laboratory is specific for the teacher and the group of students involved. It is a difficult factor to define and measure. Yet, when the SWH is implemented properly and the group of students becomes engaged, it is obvious to anyone who walks into the laboratory room that the students are occupied in investigation, experimentation, and dialogue. The laboratory classroom becomes “alive” and is very active. The difference between an active and engaged SWH laboratory and a traditional laboratory is striking. Yet, there is a difficulty in defining and quantifying that difference.

A starting place for focusing on the development of the classroom dynamic might be the attitude of the teacher. These studies encountered the spectrum of attitudes, from teachers who only seemed to implement the SWH when observers were present in the
laboratory, those that gave a token effort, those that tried but didn’t really buy into the process, to those that worked and were successful in their classroom teaching. What seemed to make the biggest difference was the inherent attitude and teaching philosophy of the teacher. They either thought that the SWH was just another aspect of being a teacher or they thought that the SWH made sense and was worth implementing. Information from a focus group interview, which was not incorporated into this research, revealed that one teacher had to teach another laboratory course without the SWH before understanding its impact. How do you show the impact of the SWH without experiencing a SWH laboratory? This also reinforces the importance of training the teachers and provides a direction for future research.

Research needs to be conducted in implementing the SWH in the organic chemistry laboratory. Are the outcomes the same? It would also be an exciting research project to conducted a longitudinal study following students through and entire year of general chemistry and then to track those same students as they more into the organic chemistry course. What happens to knowledge retention in that scenario as compared to students not utilizing the SWH over that period of time. Continued improvement of teacher training incorporating the use of multimedia and “just in time learning” is yet another avenue for future research.
APPENDIX: GRAPHICAL REPRESENTATION OF DATA PRESENTED IN CHAPTER 3

TA effect High, Med, Low

Percentile

ACS Cal Diag ACS End of Sem Rec Comp

Exam

- High TA
- Med TA
- Low TA
Student effect High, Med, Low

- High Students
- Medium Students
- Low Students

Percentile

ACS Cal Diag
ACS End of Sem
Rec Comp

Exam
The graph illustrates the relationship between different interactions (H,H, H,L, M,M, M,L, L,M, L,L) and student performance across various exams: ACS Cal Diag, ACS End of Sem, and Rec Comp. The vertical axis represents the percentile, while the horizontal axis indicates the different exams. The data shows how different levels of interaction correlate with student performance across these exams.