# Excerpts from

# The Process of Using Inquiry and the

# Science Writing Heuristic

**Prepared for the Middle Atlantic Discovery Chemistry Program**
**Moravian College**
**Bethlehem, PA**
**June 5 and 6, 2005**



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## Introduction to the Manual: The Process of the Science Writing Heuristic

This manual is meant to provide an overview about implementation of the process of the Science Writing Heuristic. We attempt to summarize what as been learned, but cannot begin to share all of our experiences in a static document. The process is constantly evolving for even those instructors who are experienced implementers of the SWH process. We hope that you will find the ideas presented here useful and invite your comments or suggestions for improvement.

A more dynamic overview of the process of the SWH can be found at our web site, http://avogadro.chem.iastate.edu/SWH/homepage.htm. This site is under development, therefore is also constantly evolving.

This handout is an abbreviated version of materials posted on our web site.

## Instructor's Introduction to the Science Writing Heuristic, SWH

Constructing science knowledge is not a casual but a purposeful activity based upon posing questions, determining claims, and providing evidence. The Science Writing Heuristic, SWH, is a process that has been devised to encourage students to use hands-on guided inquiry laboratory activities and collaborative group work to actively negotiate meaning and construct conceptual knowledge.

The method has been effectively incorporated into science curricula (including biology, chemistry, general science, geology, physical science, and physics) from pre-kindergarten/elementary through post-secondary levels (at two- and four-year institutions). It has also been successfully incorporated into pre-service teacher training courses.

The Science Writing Heuristic (SWH) approach integrates guided inquiry processes and interactive group work 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; Hohenshell, 2004; Omar, 2004; Poock, 2005; Burke, Hand, Poock, and Greenbowe, 2005; Burke, Greenbowe, and Hand, 2005: Poock, Burke, Greenbowe, and Hand, 2005a, b). Students are engaged in collaborative, guided inquiry laboratory investigations. Instructors encourage students to use interactive constructivist techniques (where meaning is socially constructed as well as personally constructed) (Bodner, 1986; Phillips, 1995; Henriques, 1997; Shiland, 1999) to frame their questions, hypotheses, and experimental designs.

The SWH provides an alternate format for students to guide their peer discussions and their thinking and writing about how hands-on guided inquiry activities relate to their own prior knowledge via beginning questions, claims and evidence, and final reflections (Table 1). Although making observations in the SWH format may be similar to traditional verification work, the process of making claims (drawing inferences) and supporting them with evidence from their experimental work helps the student to interactively construct a deeper understanding of the concept(s) being explored by the laboratory exercise. In traditional laboratory format, procedures are uniform for each student, data are similar, and claims match expected outcomes; results and conclusions often lack opportunities for more extensive student learning about the topic or for developing scientific reasoning skills. The SWH is designed to help students think about the relationships among questions, evidence, and claims. The SWH promotes students' participation in laboratory work by requiring them to frame questions, propose methods to address these questions, and carry out appropriate investigations.

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

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

Data collected via experimentation may be interpreted in more than one way. Students collaborate within and between groups to construct possible explanations for what has been observed. Learners negotiate meaning from experimental data and observations. Reflection scaffolds on prior knowledge to integrate new ideas. Learners focus on how their knowledge has changed, which helps them to confront possible misconceptions and construct a deeper, more appropriate understanding.

A student's learning environment is important (Domin, 1999). A change in the external influences impacting the student may affect the outcome of the learning experience. The Science Writing Heuristic requires an effective student-centered learning environment. Instructors serve to guide or coach, not lead. Students are the focus of interest and activity in inquiry learning. The more students are able to make decisions, the more ownership, responsibility, and accountability they feel towards the laboratory exercise. They become more engaged—they exert more effort, are more interested in the outcome, and learn more as a result (Poock, Burke, Hand, Greenbowe, 2004a,b). Activities that engage people establish motivation (Hand, 2004).

The instructor role is more than that of a coach. The instructor taps the reservoir of all of the skills formerly used to design teacher-centered experiences, and puts them into practice in a student-centered environment by interacting *with* students, not simple talking *at* them. The experienced instructor anticipates how and where students will struggle with certain concepts and designs activities to confront potential misconceptions. The instructor orchestrates student-student interactions in such a way that the students more effectively analyze the concept(s) under investigation.

The study of the Science Writing Heuristic, SWH, in post-secondary laboratory programs is an evolving process (Rudd, Greenbowe, and Hand, 2001; Rudd, Greenbowe, Hand, and Legg, 2001: Poock, Burke, Hand, and Greenbowe, 2003; Greenbowe and Hand, 2005; Poock, 2005; Burke, Hand, Poock, and Greenbowe, 2005; Burke, Poock, Hand, and Greenbowe, 2005;). Instructors are confident the method is powerful. In the past, there was no real set of guidelines or strategies that had been devised for implementing the SWH in the post-secondary classroom. Pilot studies were small enough that only one or two instructors were involved. Thus, teaching methods could be modified and all participants informed with relatively little effort. Moving to a larger scale implementation involved a team of mentors. Coordinating the efforts of a larger teacher pool was key to success of integrating guided inquiry, cooperative group work, and the SWH (Burke, Hand, Poock, and Greenbowe, 2005).

Learners negotiate meaning from experimental data and observations. Collaborative intra- and inter-group discussions provide ample opportunity for socially constructing 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. Although the Science Writing Heuristic might be classified as a writing-to-learn technique, the scope is much more inclusive. The SWH strategy mirrors the processes of dialogue and argumentation that scientists use to construct a theory or concept. Using the SWH is part of an instructional sequence. The format requires:

- guided inquiry activities;
- interactive group work;
- meaning making via a collective negotiated exchange of ideas and argumentation;
- reflective writing.

## SWH Format—Detailed Explanation

**Beginning Questions.** What will I do? A pre-laboratory discussion helps to define beginning questions to investigate experimentally. After reading the laboratory material, write a question or two that can be answered *by doing the experiment*. Often the questions are in the form of a quantitative relationship. Sometimes the questions are qualitative in nature. Acceptable examples are: How does the length of the non-polar region of a molecule relate to the equilibrium constant? How does the reaction demonstrate equilibrium? How does the amount of compound dissolved in water affect $\Delta H_{rxn}$? Unacceptable examples are: What is the limiting reagent? What color is my product? "Why" questions cannot be answered by doing the lab experiment and are considered nonproductive. For example: Why are there buffers? Why do we use a burette? Questions regarding procedure are not useful. (An example would be: How do I set up a vacuum filtration apparatus?) Most of the time, students will need to share data in order to answer a question that has a relationship. For example: How does the amount of the limiting reagent affect the percent yield? Even though a question may seem obvious, it is important to ask that question, make a claim about it, and then back up the claim with evidence.

**Safety.** How will I stay safe? After reading the laboratory, list the major safety concerns for the experiment you are about to do. This is separate from the web-based safety assignments. Additions can be made to your safety section during the pre-lab lecture. For example, some safety considerations include: using gloves when appropriate, using the fume hood when producing a toxic gas, and appropriate disposal of waste products.

**Tests/ Procedure.** What tests will I conduct or what procedure will I follow? After reading the lab, list the steps that you will take to perform the laboratory experiment. Remember, the entire class will work on this project. How will you divide the labor?

You may have multiple sections. You may reference the lab manual, but keep in mind that a list of the major procedural steps may be useful on the lab practical, the laboratory "exam" that you will take in this course. What would you want to include if someone were going to use *only* your procedure to do the lab?

**Data/Observations, Graphs, Balanced Equations, and Calculations.** What information will I gather? During the lab, list all data, complete observations, notes, calculations, equations, chemical information etc. in your lab notebook. Do not use another notebook or scratch sheets of paper. You can use your laboratory notebook during the lab practical exams.

**Claims.** What can I claim? This is to be a one- or two-sentence statement about the results of your laboratory work. For example: If the concentration of reagent A doubles, so does the rate of the reaction. An inappropriate claim would be: My product weighed 2.3 grams.

**Evidence.** How do I know? Why am I making these claims? This is a written explanation that supports your claims. How do you know that the rate of the reaction increases as the concentration increases? Include time vs. concentration data. Explain the meaning behind the data and calculations. Graphs, balanced equations, and calculations need to be interpreted and explained in order to count as evidence. Simply referring to them is not enough. Appropriate balanced chemical equations and necessary mathematical calculations can be used to support your claims, but the emphasis is on the interpretation and explanation of these results.

**Reading/Reflection.** How have my ideas changed? Discuss your initial question. Have your ideas changed? Do you have a new question? How do your results compare to other groups or the textbook or literature value? What connections did you make between the lab and lecture?

## Asking Guiding Questions

### Guiding Content Questions

Teacher response to a student question can either encourage the student to continue to think or deter a student from thinking about an issue any further. To avoid discouraging further thought, Kovacs-Boerger (1994) recommends reiterating and or paraphrasing a student's response in reply. The contention is that when a student hears the idea again, she or he can revisit what was said while being encouraged to think again about the question and think further than what has already been said. This encourages students to operate more independently, participate more readily. The quality of their critical thinking improves and they are more readily able to transfer that knowledge to novel situations.

Students ask a number of questions for which they may already know the answer or can be channeled in that direction by an instructor who guides them there. Instructors must remember that the key to the process is to paraphrase a statement or redirect a question rather than answering it in order to promote continued thought.

For example, in a chemical combination/oxidation reaction process, students are collecting information to determine the empirical formula of a starting material. The starting material reacts with oxygen in the air to form the product, but they do not know this. A typical dialogue includes the following:

S: How do I know when it's done?
    I: How do you know that a reaction occurred? What have you observed?
S: I saw the starting material turn a different color and it gave off a vapor.
    I: So, how would you know the reaction is complete?
S: I don't know.
    I: How did you know it was reacting?
S: The smoke and the color change.
    I: The smoke and the color change. How will you know it is finished reacting?
S: I guess when there is no more smoke and the color stays all the same changed color?
    I: Have you compared your observations with your classmates?

S: Will they be the same?

I: Why don't you ask them what they have observed.

The conversation continued:

S: I think I did mine wrong. It gained mass.

I: Why do you think that is wrong?

S: Last week, the substance lost mass.

I: True, last week the reactant lost mass. What was the reactant last week?

S: It was that compound with water.

I: A compound with water. What kind of compound was it?

S: Hydrate.

I: What does hydrate mean?

S: Waters in the formula that burned off when you heated it and lost mass.

I: Is your substance this week a hydrate?

S: How can you tell?

I: How did you know last week?

S: The formula had a "$\cdot X\ H_2O$" in it.

I: Was that in the formula this week?

S: No, not that I remember. I wasn't given a formula this week. It's what I'm supposed to find. So why would I gain mass?

I: Did you compare your results with any of your classmates?

S: Not yet.

I: Why don't you talk with a few people who have gotten as far as you have gotten in your work and ask them what they found and why they think that is what they found.

The conversation continued. The student's partner joined the discussion.

S1: For everyone I talked to, the reactant in their experiment gained mass. What could it gain? Water? From where?

I: What information do you know about either the reactants or the products?

S2: The reactant red powder is either pure copper powder or an oxide of copper.

I: Do you have any other information?

S2: No, not that I remember. Do I?

I: Do you know anything about the product?

S1: Not yet. Oh, they tell you in the book that it's copper (II) oxide, so I guess I know a formula. Let's see, copper with a charge of two plus and oxygen with a charge of two minus give a formula of one to one, CuO? Oh, I guess we did that already. Yes, CuO.

I: If the red powder was pure copper metal, and the product is CuO, then…

S2: Oh, then the powder had to react with oxygen, because it's the only other thing in the formula. Where did the oxygen come from?

S1: From the air. There's oxygen in the air.

In a calorimetry experiment, students are working to determine the $\Delta H_{neutralization}$. A sample student-instructor dialogue might include the following questions about the system:

I: What is gaining heat?
S: The water.
I: The water is gaining heat. From what or where is the water gaining heat? What is losing heat?
S: The chemical reaction.
I: The chemical reaction is losing heat. How does the chemical reaction generate heat?
S: Bonds are broken and bonds are formed.

In each of these conversations, the instructor guides the student(s) to answer the questions by posing questions to focus the student's attention on what she or he already knows.

## The SWH Process

The Science Writing Heuristic (SWH) can be understood as both an alternative format students use for their laboratory reports, and a teaching technique used by the instructor to help guide the flow of activities associated with an experiment (Poock, Burke, Greenbowe, and Hand, 2003; Burke, Poock, Greenbowe, and Hand, 2004). There is a synergistic effect between the creation of a classroom dynamic (instructors framing a student-centered learning environment using collaborative inquiry and students embracing the opportunity to devise their own experiments and explore and debate their results) along with thoughtful reflection about the conceptual understanding that emerges from these activities.

There are dramatic differences between traditional and SWH laboratory activities. Collaborative inquiry is the main approach used in SWH laboratory activities. Students need to understand all the safety requirements and any laboratory techniques where required; therefore, safety instructions and laboratory techniques are explicitly taught. However, specific detailed instructions for doing an experiment are not provided to students. Instructors may help to facilitate the design of an experiment intended to answer the student's beginning questions. Using the SWH along with inquiry experiments requires that teachers actively guide students to help them to understand what they are doing, why they are doing it, and to develop conceptual understanding. The intent of the SWH is to engage students in a process where they are have input and a sense of control over their activities. The instructor does not simply let the students do what they want – but rather, promotes student discussion (small and entire class groups), to determine how to achieve the outcomes required. There often will be more than one way to accomplish this. This is where students assume more accountability for their own learning.

As a whole, using both a guided-inquiry format for the experiments and the Science Writing Heuristic format for the laboratory report, provides students with opportunities to be involved in authentic science laboratory activities rather than doing traditional "cookbook" activities to reconfirm the same literature value or similar task.

Using inquiry, collaborative group work, and the SWH template, students are encouraged to talk about, deliberate, and negotiate their understandings of the chemistry concepts they are investigating. The template for doing a SWH laboratory report (Figure 1) encourages learners to outline beginning questions, claims, and evidence for claims. It also prompts them to share and compare their laboratory findings with others (including their peers), and with information in the textbook, on the Internet, or other sources.

## SWH Laboratory—What Does It Look Like? Beginning

*Pre-laboratory discussion.* At the outset, a pre-laboratory discussion among students and instructor will alert everyone in the classroom about any special safety or procedural concerns. During this time, students will:

- discuss beginning questions
- assign their own work groups;
- decide what data to gather;
- prepare a classroom data grid to be completed by the different collaborating groups;
- frame that data grid on the chalkboard so that all students can add to it through the course of the laboratory period;
- determine among themselves which group(s) would be responsible for individual tasks.

If students do not move in the direction the instructor thinks will be most effective for them, the students may be provided with some initial guidance.

*Beginning Questions.* At the beginning of the term, students experience whole group training exercises that help them learn to write Beginning Questions (Burke, Hand, Poock, and Greenbowe, 2005). These questions must be able to be answered by doing an experiment, i.e., are researchable questions. Table 2 provides examples of productive and non-productive beginning questions.

Table 2. Comparing Non-Productive and Productive Beginning Questions.

| Non-productive Beginning Questions | Productive Beginning Questions |
|---|---|
| 1. Why is the experiment performed in an evaporating dish, not a crucible?<br>2. Why is the reactant powder red and the product powder black?<br>3. Is the red powder actually the opposite of the black? | 1. Is there a relationship between the initial mass of reactant and the final formula of the product?<br>2. Does the mass of oxygen reacting depend on the original mass of reactant?<br>3. Does the empirical formula of the reactant depend on the mass of reactant? |

Prior to arrival at the laboratory, students draft one or more Beginning Questions that will frame their investigation. In the laboratory, they write their questions on the chalkboard. The entire class discusses which one(s) should become the class project. This freedom of choice will promote greater student engagement and motivation (Hand and Greenbowe, 2005; Burke, Greenbowe, Poock, and Hand, 2005). Once they have decided on a strategy, students divide themselves into work groups to study aspects of the problem.

By having the students write their individual Beginning Questions, and then having them design an experimental procedure to answer their own question(s), they are more likely to be able to explain aloud to the instructor or to write about what they are doing and why they are doing it.

## SWH Laboratory—What Does It Look Like? Middle

*Experimental work.* Student groups organize themselves and work together to draft appropriate data compilation tables on the chalkboard, then begin collecting experimental information. The instructor moves among student groups, keeping learners on task, asking guiding questions, or redirecting student inquiries to classmates. As each group generates data, the information is recorded in a class data table, both on the chalkboard and in an Excel database. This is important because each group will likely not be reproducing exactly the same procedure as others. Groups can decide to divide up the tasks, vary the ratio/quantities of materials used, or replicate experimental work for comparison purposes. Making meaning requires that students examine patterns or trends arising from the experiment. Frequently, they will make a graph to see whether there is a relationship between variables and whether there appear to be any anomalies.

Students study the results, ready to repeat experiments to replace inconsistent numbers. If any group finds it difficult to complete their assigned task(s), other groups step in to help until all students are prepared to analyze and discuss their findings.

At the conclusion of a collaborative laboratory activity, students are required to have class-wide discussion about what the outcome of the experiment is. The SWH is designed to promote classroom discussion during which individual student explanations and observations are compared and confirmed or contested against the insights and assistive support of the entire group. This is accomplished by constructing their ideas via peer discussion, argumentation, and negotiation. The instructor facilitates the discussion, but does not tell students what they should have learned from the experiment.

**SWH Laboratory—What Does It Look Like? End**

*Claims and evidence.* Learners are encouraged to make explicit associations among questions, observations, data, claims, and evidence as well as to be able to defend their position. When students make a claim for an investigation, they are expected to note a pattern, demonstrate a generalization, articulate a relationship, or provide an explanation that they have uncovered by their work. Such activities encourage a greater sense of ownership among the students–they are not merely following the step-by-step model to complete their weekly cookbook procedure and follow-up report to "earn" the grade they want or need. They have designed an experiment and they are making meaning of their results.

Students will not develop understanding by consulting the textbook or the instructor and copying answers they were expected to find for the laboratory activity. Rather, they should actively discuss their research, struggle with the analysis process, and be able to state a claim from what they have investigated. By being able to state a claim and provide rational evidence for their claim, learners display scientific argumentation and reasoning skills. The knowledge being discussed is their knowledge – they are required to test their knowledge and understanding against what the expectations of the activity are.

For students using the SWH, the biggest change from their past traditional laboratory experiences is in writing the laboratory notebook. Instead of responding to the five traditional sections (purpose, methods or procedure, observations, results and conclusions), students are expected to respond to prompts eliciting their questions related to the activity, knowledge claims, evidence, description of data and observations, methods, and to reflect on changes in their own thinking. Little debate or negotiation occurs within a traditional laboratory setting or even in a traditional write up. Guided inquiry, collaborative group work, and SWH activities require that students negotiate scientific argument by having to agree with their peers about what beginning questions are worth answering in the laboratory, what is the optimum experimental design to answer the questions, who will undertake which tasks and what strategies they will use, and what evidence supports the claims made on the basis of the data collected. This process is part of every SWH laboratory activity.

*Reflections*. The "Reflections" section in the SWH format suggests that students look back on the experience of the laboratory activity to think about how their own ideas have changed. This approach has been shown to be superior to students completing a "discussion" section in their laboratory report. When students can explain what they think they know and justify their understandings, it becomes obvious that they have learned something and are not providing a rote reply.

The more reflective reasoning learners do, the more scaffolding is accomplished. Students make connections between prior or existing knowledge (from past coursework or in the text or their class notes) and new concepts. By examining how their ideas have changed through the experimentation and writing processes, students confirm their conceptual understanding.

Using guided-inquiry, collaborative group work, and the Science Writing Heuristic as the basis of the laboratory activity and writing the laboratory report, students do better on lecture examinations and laboratory practical tasks. Females benefit by having an effective SWH instructor—their examination scores improve more than those of their male counterparts. Other research studies (Keys, Hand, Prain, Collins,1999; Hand, Hohenshell, Prain, 2004) provide evidence that the SWH format for structuring laboratory activities and notebook helps students understand science concepts better than students using traditional laboratory notebook format. The SWH is an important component of doing inquiry in the chemistry laboratory and promotes purposeful student thinking about chemistry. While there is a period of adjustment for both students and instructors to implement inquiry and the SWH (approximately three weeks), the learning curve is not steep and the benefits to be gained are invaluable.

## SWH Instructor Role—Detailed

**What is the instructor role?** Ideally, the instructor facilitates the laboratory session from the side. The instructor must be able to relinquish control of the class to the students. Instead of providing information, the instructor asks guiding questions and redirects students to interact with one another (rather than attempting to determine an answer by directly asking the instructor). Initially, students are disequilibrated when the instructor does not answer their question(s). They soon learn that there are members of their own group who actually *can* answer them. They also discover, to their surprise, that they themselves know the answer if they invest the time and effort needed to think through the problem. The key is ongoing communication among the students with prompts from the instructor.

A Science Writing Heuristic classroom is consistent with any other classroom employing an active learning strategy that promotes collaboration. The noise level is perceptibly higher as groups interact with one another. Students are animated and on-task. They are responsible to one another to complete all necessary tasks, record their data and observations appropriately on the chalkboard for all to share, and attempt to formulate claims based on the evidence collected. The ensuing discussions help students to connect their experimental work with related chemistry, constructing their own understanding of the concept(s) under consideration.

**What does it mean to be a good instructor for inquiry?** What strategies need to be used and when? At the outset, the tone must be set for active student learning with a student-centered pre-laboratory discussion. The instructor needs to know how to frame a guided learning experience to engage the students. The instructor must facilitate setting up the lab at the beginning to encourage the students to generate the data, observations, and results that should be discussed at the end. Whenever possible, the responsibility for carrying out laboratory work needs to put in the hands of the students.

Students should

- assign their own groups;
- decide what data to gather;
- prepare the classroom data grid to be completed by the different collaborating groups;
- determine among themselves which group(s) would be responsible for individual tasks.

If they are not moving in the direction the instructor wishes, they can be guided there.

It is important to have the instructor constantly circulating around the room from group to group (Kyle, Penick, and Shymansky, 1979; Shymansky, Penick, Kyle, 1979; Herrington and Nakhleh, 2003; Roehrig, Luft, and Kurdziel, 2004) asking probing questions of students to determine what they are discovering and what they are learning. The instructor is there as a presence, willing to guide them into answers to their questions. The more the instructor can try to redirect students' questions back to them to answer, the more the students are encouraged to think about and process what they are learning. By not circulating among them and talking with them, the instructor is judged to be indifferent. Students who receive overt answers from instructors usually do not interact as much nor are they as motivated as students who talk with one another. By having the instructor answer their questions directly, the students will become too dependent on that avenue for answers and not dependent on one another, which means they lapse into complacency and not do think for themselves.

Focus is on student-centered techniques and peers talking with one another (student to student) rather than with the instructor. Instructors who foster this environment can clearly observe the great potential students have for interacting with one another. One instructor observed, "I have not seen students so interactive as those using the SWH strategies."

**Table 3. Comparing a traditional laboratory session to a student-centered laboratory session.**

| | **Traditional lab** | **Student-centered lab** |
|---|---|---|
| **Pre-lab** | Instructor gives step-by-step directions, asks for questions related to "cookbook" procedure. | a. Students write beginning questions (BQs) on chalkboard.<br>b. Together the class discusses which BQs to investigate.<br>c. Students talk about how to divide the tasks among groups, and what data needs to be collected.<br>d. Students prepare class data table on chalkboard. |
| **Students perform experimental work** | Students follow procedure outlined in lab manual or outlined by instructor. Students stay at their own experimental work station and talk mainly with their partner (unless they ask the instructor a question). | a. Students perform lab work necessary to answer their own questions.<br>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.<br>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 instructor, 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.<br>b. When all data is on the board, students critically evaluate the information.<br>c. Students work together to negotiate meaning, construct a concept, answer BQs.<br>d. Students write and discuss an appropriate claim and provide supporting evidence. |

**Abbreviated Suggestions for SWH Instructors**

Allow the students opportunities to discuss their beginning questions. Have them work in pairs or in groups of four and then write their beginning questions on the board.

Set up the lab for student-centered work. Do not tell the students the answer to the lab! This is their opportunity to learn. Ask questions of the students to lead them towards the answers. If someone asks you a question, do not answer directly. First, see whether you can get someone else in their group to answer. If they cannot answer, ask probing questions to help them to arrive at the answer themselves. Be patient with yourself and with your students—this may take time and practice!

Allow (encourage) the students to form their own groups and decide themselves which task(s) they will perform and how they will divide their work. Do not assign groups! Do not assign a group to a task! You can require that students work with a new partner, but minimal intervention is recommended.

Have the students organize some kind of data table on the chalkboard and enter their results. Do not write it down for them! For example, you can remind students they are responsible to study a range of masses of a particular compound between 1.0000 g and 2.0000 g. You can ask them how many pairs of students are in the room and how they think they should divide the mass range in order to replicate values. They will have little difficulty suggesting dividing the range into tenths of grams (e.g., 1.0000 g, 1.1000g, etc.), and replicating each tenth.

At the end of lab, have the students work in groups to come up with two or three claims and write them up on the chalkboard. Ask the group to explain their claim to the class using experimental evidence to support their claim.

Guide a class discussion of the concepts covered in the laboratory and bring up any points they missed by asking probing questions of the group.

Where should they go for their reading and reflection? Some instructors require at least three sources (the text, other student(s), class notes, the instructor, etc. Figure 1 summarizes ineffective versus effective instructor techniques.

| **Ineffective Instructor** | **Effective Instructor** |
|---|---|
| Tells students what to do and what will happen; beginning questions not discussed. | Provides opportunities for students to discuss beginning questions. |
| Individual work or pairs work separately from the class. | Sets up the lab for student-centered work. |
| Assigns tasks. | Allows students to assign their own groups and tasks. |
| Does not promote sharing or analysis of class data. Shows students how to do calculations and tells students what their results mean. | Class data are presented on the chalkboard. Class data are analyzed and discussed as a group. |
| Students immediately leave when finished with their work. | Instructor guides a class discussion of concepts covered in the laboratory. |

Figure 1. A comparison of characteristics of ineffective instructors to effective instructors.

**SWH Grading—Rubric and Rubric Grid**

Student reports are graded using a ten-category, 40-point grading rubric. This could be modified to meet the needs of any grading scheme. Students are provided a thorough verbal and written explanation of how the points are awarded so that they are well-informed about how detailed their reports should be. An abbreviated version of the rubric and a grading grid follow this section.

1. Can the beginning questions be potentially answered by the results of the laboratory experiment?
   - 0- Questions cannot be answered by doing experimental work or the questions are not related to the lab
   - 1- One or two inappropriate, trivial, or factoid questions (ex. Why questions: why are there buffers?; What questions: what color is my product?)
   - 2- One directed question that can be answer by doing experimental work
   - 3- More than one or two questions that demonstrate understanding of what the lab could result in.
   - 4- One or two questions that demonstrate understanding of independent and dependent variables, a generalization, or an appropriate application of what the lab could result in. Or, the student improves his or her questions (makes a significant change) as the purpose of the lab becomes clearer or the class agrees to take the experiment in a different direction.
2. What is the quality of the data and observations?
   - 0- Does not display any understanding or shows no data.
   - 1- Only limited portions of data are recorded.
   - 2- Listed all data.
   - 3- Lists all data, observations and appropriate calculations. Good organization of the data and observation. Correct use of significant figures and units.
   - 4- Lists all data, observations and appropriate calculations and notes additional chemical information such as potential tends, likely reactions, balanced equations, etc. Good organization of the data and observation. Showed all appropriate steps in the calculation. Correct use of significant figures and units. Displays an understanding of how and why the data was collected.
3. Are the claims a direct result of the data and observations?
   - 0- No, missed the point or showed a misunderstanding of the lab or a lack of understanding of the lab.
   - 1- Has claims for only a portion or sections of the data.
   - 2- Has claims for all data but only has numeric answers and doesn’t grasp bigger picture (ex. trends)
   - 3- Has claims for all data- numeric and concepts. Writes using proper English.
   - 4- Several claims for all data, numeric and concepts.

4. How well are your data and observations used in the evidence statements?
   0- Not used in evidence statements.
   1- Referred to some of the data.
   2- Restates data or observation, which would support the claim.
   3- Interprets graphs, calculations, and balanced equations. Correct use of significant figures and units,
   4- Interprets graphs, calculations, and balanced equations and explains how the interpretations relate to claims. Correct use of significant figures and units. Writes a paragraph using proper English with clear logical statements.

5. Are the claims backed up in the evidence?
   0- Evidence does not support claims made.
   1- Claims and procedures are simply restated, but not explained.
   2- Refers to chemical equations, calculations, and graphs.
   3- Explains the chemical equations, calculations, and graphs. Correct use of significant figures and units. Writes using proper English.
   4- Explains and interprets chemical equations, calculations, and graphs. Restates claims and clearly defends them. Mathematic calculations, all steps, are clearly written and explained. Correct use of significant figures and units. Writes a paragraph using proper English with clear logical statements. Inferences drawn.

6. How well does the student answer all of the questions that were asked in the laboratory write-up for this particular experiment?
   0- No questions were answered or the questions were answered but 80% were incorrect.
   1- Some questions answered, but the majority were not answered or answered incorrectly.
   2- 50% of the questions were answered correctly.
   3- 80% of the questions were answered correctly
   4- All questions answered correctly.

7. How well does the student analyze the data and observations to make the experimental measurements or observations meaningful?
   0- No or very little attempt at doing everything necessary for the analysis
   1- Did less than 50% of the analysis
   2- Did 60% of the analysis
   3- Did 80% of the analysis
   4- Everything necessary for the analysis was done and done well.

8. Do the results of the experiment come close to the accepted values, or identify an unknown compound correctly, or show an accepted comparison, trend, etc.?
   0- Results are so far off as to be meaningless.
   1- The results are within the ballpark, but not on the playing field.
   2- Within 40% of the accepted value.
   3- Within 60% of the accepted value.
   4- Within 80% of the accepted value.

9. In the reflection and readings how many sources are used and how are they connected?

0- No sources
1- One source but linked poorly to experiment.
2- One source and linked well.
3- More than one source and linked well to evidence, very helpful to explain data.
4- More than one source, and refers to place of found knowledge (ex. Graphs, comparisons, a reference to a textbook or handbook with the "literature value"). Linked directly to claims and evidence. Defines meaning behind graph slopes, pH levels, and other explainable elements. Relates all of science content back to the experiments results and or discusses the results in terms of commercial, medical, household, etc. applications.

10. Does your readings and reflection discuss your initial questions? Does your reading and reflections aid your claims and evidence?

0- No, not related
1- Only discusses some of your questions (maybe indirectly). does explain and define parts of your evidence.
2- Yes, the questions are answered based on the results of your experiment. explains and defines all or most of your evidence.
3- Yes, the questions are answered based on the results of your experiment and have stated new questions or have discussed how ideas/concepts have changed or how ideas/concepts are now better understood. explains and defines all or most of your evidence, plus discusses initial questions and changing ideas, new questions and one outside source.
4- Initial questions are answered by an analysis of the results, new questions and changed ideas/concepts (or better understood ideas/concepts) have been stated, and results have been compared to other groups, teachers, textbooks, and other sources. Writes a paragraph using proper English with clear logical statements, explains and defines all or most of your evidence, including terminology that would aid the readers understanding plus discusses initial questions and changing ideas. Refers to place of found knowledge (e.g., graph). Also includes the use of several outside sources including textbooks (page numbers), other groups' results, literature (e.g., handbook values), class lecture notes (date), teacher, etc.

**SWH Grading Grid for Instructor—40 points total for each lab**

| Rubric categories | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 1. Can the beginning questions be potentially answered by the results of the lab? | | | | | |
| | | | | | |
| 2. What is the quality of the data and observations? | | | | | |
| | | | | | |
| 3. Are the claims a direct result of the data and observations? | | | | | |
| | | | | | |
| 4. How well are your data and observations used in your evidence? | | | | | |
| | | | | | |
| 5. Are the claims backed up in the evidence? | | | | | |
| | | | | | |
| 6. How well does the student answer all of the questions that were asked in the laboratory write-up for this particular experiment? | | | | | |
| | | | | | |
| 7. How well does the student analyze the data and observations to make the experimental measurements or observations meaningful? | | | | | |
| | | | | | |
| 8. Do the results of the experiment come close to the accepted values, or identify an unknown compound correctly, or show an accepted comparison, trend, etc.? | | | | | |
| | | | | | |
| 9. In the reflection and readings how many sources are used and how are they connected? | | | | | |
| | | | | | |
| 10. Does your reading and reflection discuss your initial questions? Does your reading and reflections aid your claims and evidence? | | | | | |

## To the Student

You are now beginning one of the first chemistry courses you will take in college. One of the richest learning experiences you can have will be your work in the chemistry laboratory. Because in the real world teams of individuals accomplish much of the work, you will work on a team during your laboratory session. Sometimes you will work alone but consult directly with a partner; sometimes you will need to have a partner to complete the tasks that you will design.

You and your classmates will design the experiments that you will conduct in the laboratory. The best way for you to learn is to take charge of how you do it. Your focus will be on student-centered techniques and talking with your peers (student to student) rather than with your instructor. You will find this process to be more interesting as well as more instructive to you. By designing your own experiments, you will learn and remember more about what you have done. Your instructor will provide you with plenty of guidance. Instructors who foster this environment can clearly observe the great potential students have for interacting with one another and understanding what they are doing.

Ideally, your instructor guides or coaches the laboratory session. Instead of directly providing you with information when you ask a question, your instructor will ask guiding questions and will redirect you to interact with your group mates. Initially, you may find it frustrating when your instructor does not directly answer your question(s). But, you will soon learn that there are members of your own group who actually *can* answer these questions. You may also discover that you yourself know the answer if you invest the time and effort needed to think through the problem. Your instructor will provide you with support to answer your questions—you will not be abandoned. You will realize that you are relying more on yourself and your peers and less on your instructor.

An SWH classroom is a classroom employing active learning strategies to promote collaboration. You are responsible to one another to complete all necessary tasks, record your data and observations appropriately on the chalkboard for all to share, and attempt to formulate claims based on the evidence collected. The ensuing discussions help you and your classmates to connect your experimental work with related chemistry, constructing your own understanding of the concept(s) under consideration.

What strategies need to be used and when? At the outset, a pre-laboratory discussion among you, your classmates, and your instructor will alert you and your classmates of any special safety or procedural concerns. You and your classmates will

- Assign your own groups;
- Decide what data to gather;
- Prepare the classroom data grid to be completed by the different collaborating groups;
- Determine among yourselves which group(s) would be responsible for individual tasks.

If you are not moving in the direction your instructor thinks will be most effective for you, you will be guided there.

Your instructor will be constantly circulating around the room from group to group asking you questions to determine what you are discovering and learning. The more your questions are redirected back to you to answer, the more you will be encouraged to think about and process what you are learning. Students who receive overt answers from their instructors usually do not interact as much with one another nor are they as motivated as students who talk with one another. By having your instructor answer your questions directly, you will become too dependent on that avenue for answers which means you will think less for yourselves.

**Comparing a traditional laboratory session to a student-centered laboratory session.**

| | **Traditional lab** | **Student-centered lab** |
|---|---|---|
| **Pre-lab** | The instructor gives step-by-step directions, asks for questions related to "cookbook" procedure. | a. Students write beginning questions (BQs) on chalkboard.<br>b. Together the class discusses which BQs to investigate.<br>c. Students talk about how to divide the tasks among groups, and what data needs to be collected.<br>d. Students prepare class data table on chalkboard. |
| **Students perform experimental work** | Students follow procedure outlined in lab manual or outlined by instructor. Students stay at their own experimental workstations and talk mainly with their partner (unless they ask the instructor a question). | a. Students perform lab work necessary to answer their own questions.<br>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.<br>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 instructor, 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.<br>b. When all data is on the board, students critically evaluate the information.<br>c. Students work together to negotiate meaning, construct a concept, answer BQs.<br>d. Students write and discuss an appropriate claim and provide supporting evidence. |

## SWH Format—Detailed Explanation for the Student

**Beginning Questions.** A pre-laboratory discussion helps to define beginning questions to investigate experimentally. After reading the laboratory material, write a question or two that can be answered *by doing the experiment*. What will you investigate? Often the questions are in the form of a quantitative relationship. Sometimes the questions are qualitative in nature. Acceptable examples are: How does the length of the non-polar region relate to the equilibrium constant? How does the reaction demonstrate equilibrium? How does the amount of compound dissolved in water affect $\Delta H_{rxn}$? Unacceptable examples are: What is the limiting reagent? What color is my product? "Why" questions cannot be answered by doing the lab experiment and are considered nonproductive. For example: Why are there buffers? Why do we use a burette? Questions regarding procedure are not useful. (An example would be: How do I set up a vacuum filtration apparatus?) Most of the time, students will need to share data in order to answer a question that has a relationship. For example: How does the amount of the limiting reagent affect the percent yield? Even though a question may seem obvious, it is important to ask that question, make a claim about it, and then back up the claim with evidence in order to construct a concept.

**Safety.** How will you stay safe? After reading the laboratory, you should list the major safety concerns for the experiment you are about to do. This is separate from the web-based safety assignments. Additions can be made to your safety section during the pre-lab lecture. For example, some safety considerations include: use gloves when appropriate, use the fume hood when producing a toxic gas, and dispose of your waste products appropriately.

**Tests/ Procedure.** What will you do? After reading the lab, list the steps that you will take to perform the laboratory experiment. If you are required to propose your own procedures, what strategy will you take to explore your beginning question(s)? Remember, the entire class will work on this project. How will you divide the labor?

You may have multiple sections. You may reference the lab manual, but keep in mind that a list of the major procedural steps may be useful on the lab practical, the laboratory "exam" that you will take in this course. What would you want to include if someone were going to use *only* your procedure to do the lab?

**Data/Observations, Graphs, Balanced Equations, and Calculations.** What will you see? During the lab, list all data, complete observations, notes, calculations, equations, chemical information etc. in your lab notebook. Do not use another notebook or scratch sheets of paper. You can use your laboratory notebook during the lab practical exams.

**Claims.** What can you claim? This is to be a one- or two-sentence statement about the results of your laboratory work. It should answer your beginning question(s). For example: If the concentration of reagent A doubles, so does the rate of the reaction. An inappropriate claim would be: My product weighed 2.3 grams.

**Evidence.** How do you know you can make your claim? Why are you making your claim? This is a written explanation that supports your claims. How do you know that the rate of the reaction increases as the concentration increases? Include time vs. concentration data. Explain the meaning behind the data and calculations. Graphs, balanced equations, and calculations need to be interpreted and explained in order to count as evidence. Simply referring to them is not enough. Appropriate balanced chemical equations and necessary mathematical calculations can be used to support your claims, but the emphasis is on the interpretation and explanation of these results.

**Reading/Reflection.** How do your ideas compare with others' ideas? Discuss your initial question. Looking back before and during the experiment, have your ideas changed and if so, how? Do you have a new question? How do your results compare to other groups or the textbook or literature value? What connections did you make between the lab and lecture?

**Student Guidelines for the Science Writing Heuristic and Inquiry Laboratories**

Because inquiry-based laboratories are student-centered, you will be responsible for how you design your experiments and how you collect and analyze your data. Your instructor will serve as a guide or coach to help you to be successful. We have provided a suggested outline of what your responsibilities are during the process of the SWH.

1. Prior to arrival in lab
    a. Prepare beginning question(s), BQs;
    b. Outline procedural strategy;
    c. List safety concerns.
2. Upon arrival in lab
    a. Write BQs on chalkboard while students are storing coats, book bags, etc.;
    b. Discuss BQs with partner or group mates;
    c. Discuss BQs with class to decide which one(s) to study as a group.
3. After deciding on BQ(s), discuss what strategies would be appropriate to answer the BQs,
    a. Divide class into groups (usually four people who can than subdivide into teams of two) to experimentally study all aspects of BQ(s). All team members are expected to be working on some kind of laboratory procedure. No one should just watch!

       Each team member will need to understand how to conduct all parts of the laboratory. Eventually, when working the same kind of experimental procedures for the laboratory practical examination, each team member will be responsible to know what to do for each experiment.

b. Be certain to provide for appropriate replication of procedures to create a large pool of "good" data.

c. On the chalkboard, draft appropriate data collection tables, including dependent and independent variables to be investigated.

d. Identify by initials which student groups or pairs are responsible for different runs. In this way, anyone can talk with the persons who collected any piece(s) of data.

4. After data has been collected, analyze it to try to interpret it.
   a. Look for trends, patterns, and anomalies.
   b. If there are anomalies, decide who will repeat the experiment to replace that data. How do you decide which part(s) too repeat?
   c. It is often useful to graph results and interpret your graph.
5. Enter your data in the class database that can be found on the laboratory computer. This will contribute to the overall course-wide data pool.
6. While waiting for all students to complete work and enter data, propose your claim(s), and cite supporting evidence.
7. Discuss results as class to create an understanding of the concept(s) for the lab. Your instructor will help to guide your discussion.
8. After lab,
   a. Consult the course-wide database that you can find on WebCT to determine whether the data collected by you and your classmates agrees with the data collected by classmates in other laboratory sections.

b. Consult at least three appropriate resources to explain, confirm, or dispute what you have learned in the laboratory. This could be your text, another reference text, the Internet, your instructor, your class notes, etc.

c. Answer any "Post laboratory discussion questions" that have been posed by your instructor or proposed in your laboratory manual.

# Appendices

# Appendix A

## Mystery Activity Exercises

## Mystery Activity 1

The mystery activity is a good ice-breaker for students at their first laboratory meeting. The activity is non-threatening and does not depend on prior chemistry knowledge. The instructor 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. It is especially useful to help them distinguish between claims and evidence.

a. Divided into groups of three or four, they are asked to read a short story outlining the scenario of a death.

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

c. Each group writes a claim about the death 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 a turn, the instructor talks with them: "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 questions asked to clarify bits of provided evidence.

You as instructor may wish to continue the activity at this point by providing your students with Part 2 of the Mystery Activity.

# Solving a Mystery: Observations, Claims, Evidence and Conclusions

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 early this morning the servants found Mr. Xavier dead in his home. 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 B

## Example of
## Inquiry Laboratory Activity

### Determining the Identity of a Chemical Reactant

Experiment 4

# 4

# Determining the Identity of a Chemical Reactant

**Overview**

A bottle containing a red powder is labeled "Oxide of Copper." Heating measured portions of the red oxide of copper in open air results in a chemical reaction. Is the original red powder pure powdered copper metal that has been mislabeled, or some other compound?

**Procedure**

To do this analysis, you and your classmates should divide into groups to design experiments, to run several experiments, and to collect data. Some of you will decide to perform specific experimental runs using different masses of the red powder, others will choose to replicate data. Each person should conduct the experiment at least once. As a group, you should decide what information to tabulate on the chalkboard.

Suggestions for running the experiment:

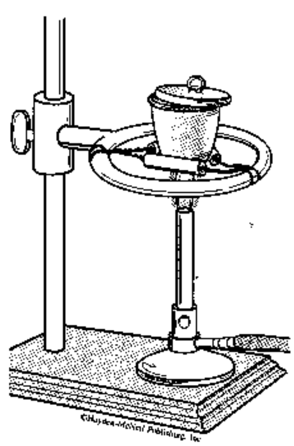

*Figure 4-1. A chemical compound is heated in a crucible with the crucible lid slightly ajar over a flame from a Bunsen burner. A clay triangle is used to support the crucible.*

- Place your ring stand under the hood so that fumes will be drawn away from your experiment.

- Attach an iron ring to your ring stand to support your crucible in a clay triangle.

- Weigh a clean, dry crucible and its lid (washed, rinsed with distilled water).

- Set your Bunsen burner on the base of the ring stand and adjust the height of the iron ring so that the bottom of the crucible rests at the top of the inner blue flame.

  With the crucible lid on top of the crucible, but slightly ajar, heat the crucible with nothing in it and lid for two minutes. Allow the crucible and lid to cool to room temperature. Use crucible tongs to monitor the progress of your heating and cooling. Obtain the exact mass of the crucible with the lid. Re-heat and repeat this procedure. This technique is called heating to constant mass.

- Now place the red powder in your crucible and obtain the exact mass of this red powder. Record the mass of the crucible, lid, and red powder. Determine the mass of the chemical. With the crucible lid slightly ajar, heat the crucible and heat the red powder so that it completely reacts. Use crucible tongs to monitor the progress of your reaction. What color does the product have? Record this observation in your notebook.

- When you have heated your sample enough to convert it, turn off the burner and allow your crucible and its contents to cool to room temperature. Use crucible tongs to handle the crucible and its lid. Determine the mass of the product *after* the crucible has cooled to room temperature (about five minutes).

- Repeat the heating and cooling until the mass of your product is within 1% of the mass found after the first (or second) heating. Record the exact mass of your product in your laboratory notebook.

- Dispose of the product in the labeled jar in the laboratory.

**Analysis**

How can you determine the composition and chemical name of the red powder, the reactant.

Evaluate your tabulated results with your classmates. You may find it useful to consider the following questions as you conduct your class discussion.

1. What can we learn from the percent by mass composition of the product, copper(II) oxide?
   a. For example, how much copper is in the product and from where did it come?
   b. How do we know this and why is it important?
   c. What other element is present in the product? From where did it come?
   d. How is the Law of Conservation of Mass involved?

2. How do your results compare with those of your classmates?

3. What claim can you make about the red powder you used as a reactant—was it a pure copper metal powder, was it just copper ions, or was it another form of copper

oxide? What claim can you make about the composition of the red powder? How does your evidence support your claim?

4. Working with your classmates, write a balanced chemical equation that represents what happens when the red powder is heated to produce copper (II) oxide. Is this a chemical reaction or a physical process? If it is a chemical reaction, classify the type of reaction.

## Instructor Suggestions for Determining the Identity of a Chemical Reactant

While you are opening their drawers and collecting last week's lab, have them find a partner and choose at least one beginning question (BQ) from those they have written prior to class. They should write the question on the board.

When all of the questions are on the board, see how many are identical. Have them decide which one or two questions they would like to investigate as a class.

Possible BQs:
Is the original compound pure copper or an oxide of copper?
If it is an oxide, how does the empirical formula depend on the amount of compound used in the experiment?
Should each student get the same empirical formula even if they start with a different amount of reactant?

a. Prelab guided questions:

1. What is an empirical formula? (simplest whole number ratio of moles of elements)
2. What from where do we get that information? (from the subscripts in the formula)
3. What do we know about the product in this experiment? (it is CuO) Is this true for everyone? (yes)
4. What are the reactants in this experiment? (the powder and oxygen from the air)
5. What is the formula for the powder? (Cu or $Cu_xO_y$)
6. What is the equation for the reaction?

   $Cu_xO_y + O_2 \longrightarrow CuO$

7. Looking only at the product CuO, what elements are present? (Cu and O)
8. From what reactant(s) on the left does each element come? (Cu from $Cu_xO_y$ and O from both $Cu_xO_y$ and $O_2$)
9. If we are to believe the law of conservation of matter, what is true about the mass in grams of each of the elements in the product? (the number of grams of Cu in the product CuO will be the same as the number of grams of Cu in $Cu_xO_y$ ;
   the number of grams of O in the product CuO will be the same as the number of grams of O in $Cu_xO_y$ plus the number of grams of O in $O_2$ from the air)

b. Setting up guided inquiry lab:

1. Before they start to work, have them draft some kind of data table to collect the information that their beginning question is likely to require (see below for sample data).

| Mass $Cu_xO_y$ | Mass CuO | Mass Cu | Moles Cu | Mass O | Moles O | Mole ratio Cu:O |
|---|---|---|---|---|---|---|
| Mass before reaction | Mass after reaction | | | | | |

2. Group them in pairs, but have each individual student perform the experiment. Students should all have a copy of the class data for reference.
3. Assign one of your better students to the job of copying the class data and entering it in the course database. Use the laptop located in the laboratory room for this purpose.

Calculations:

**For TA use. DO NOT GIVE THESE TO STUDENTS. GUIDE STUDENTS TO COMPLETE THESE CALCULATIONS.**

Mass Cu: $\text{mass CuO} \times \dfrac{\text{mole CuO}}{79.54 \text{ g CuO}} \times \dfrac{\text{mole Cu}}{\text{mole CuO}} \times \dfrac{63.54 \text{ g Cu}}{\text{mole Cu}}$ = g Cu in sample

Moles Cu: $\text{mass CuO} \times \dfrac{\text{mole CuO}}{79.54 \text{ g CuO}} \times \dfrac{\text{mole Cu}}{\text{mole CuO}}$ = mole Cu in sample

Mass O: Mass of product – mass Cu calculated above = mass O

Moles O: $\text{mass O} \times \dfrac{\text{mole O}}{16.00 \text{ g O}}$ = mole O in sample

Mole ratio Cu to O: $\dfrac{\text{mole Cu}}{\text{mole O}}$ =

TA tips

Students should find the actual mass of their empty crucible before adding the red copper powder to it. They should weigh again using the same balance after adding the powder. Finally, they should use the same balance to find the masses after heating. If they use the "tare" function, someone else will use the balance in between their readings and change their "tare" value. This has caused students to have problems with negative mass or very unusual data.

# Appendix C

## Sample Laboratory Reports Written in SWH Format

### Determining the Identity of a Chemical Reactant

## Question

What is the composition of the red powder
What effect does heating have on the red powder?
If it is a copper oxide, what is its empirical formula.
Does the beginning mass affect the composition

## Safety

Do not wear loose clothing & pull long hair back because we are using the bunsen burner.
Wear your goggles to prevent getting chemicals in the eye
Wash your hands after the experiment
Burn red powder in the hood - fumes are toxic

## Procedure

- Use porcelain evaporating dish to heat red powder in
- mass dish + powder

Burn dish in hood - 5 to 10 minutes

COOL + reweigh

Reheat + reweigh until mass of CuO = the mass of last weighing ± 1%

| SIGNATURE | DATE | WITNESS/TA | DATE |
|---|---|---|---|
| | | | |

| NAME | LAB PARTNER | LOCKER/DESK NO. | COURSE & SECTION NO. |
|---|---|---|---|
| | | | |

$Cu_xO_y + O_2 \rightarrow CuO$

1.5100g ? → 1.6302g

CuO
Cu 1 · 63.55g
O 1 · 16.00g
79.55 g CuO

CuO mass → moles → Cu moles → Cu mass

$1.6302g \cdot \frac{1 mol\ CuO}{79.55g\ CuO} \cdot \frac{1 mol\ Cu}{1 mol\ CuO} \cdot \frac{63.55g}{1 mol\ Cu} = 1.302g\ Cu$

~~Cu mass ⇔ Cu mass~~

Cu mass → moles + compare
O mass → moles ratio

$Cu_x\ O_y$

1.5100g $Cu_xO_y$
− 1.302 g Cu

1.302g .2077g $O_y$

$1.302g\ Cu_x \cdot \frac{1 mol\ Cu_x}{63.55g\ Cu_x} = .02049 mol\ Cu_x$

$.2077g\ O_y \cdot \frac{1 mol\ O_y}{16.00g\ O_y} = .01298 mol\ O_y$

$\frac{.02049 mol\ Cu_x}{.01298 mol\ O_y} = \frac{1.579 Cu_x}{1 mol O_y} \approx \frac{2.}{1}$

empirical formula for red powder
$Cu_2O$

balanced equation

$2Cu_2O(s) + O_{2(g)} \longrightarrow 4CuO(s)$

| SIGNATURE | DATE | WITNESS/TA | DATE |
|---|---|---|---|
| | | | |

| NAME | LAB PARTNER | LOCKER/DESK NO. | COURSE & SECTION NO. |
|---|---|---|---|
| | | | |

## Claims

Red Powder is not pure copper

Its empirical formula is $Cu_2O$ - law of multiple proportions

## Evidence

We knew our beginning mass and our end mass and composition. We can use $CuO$ and our ending mass to figure out % mass of the copper. Due to the law of conservation of mass we know that the total mass of materials present after a chemical reaction is the same as the total mass before the reaction, so the ending mass of Cu has to equal the beginning amount of Cu. Because the ending mass of copper does not equal the beginning mass of the red substance, we knew that something else had to be in the red powder. The red powder was not pure elemental copper. We assumed that the red powder was made up of Cu and oxygen because it seemed logical in the equation and it was hinted at in lab. We subtracted the ending Cu mass from the beginning red powder mass to find the mass of oxygen. We converted both the Cu mass + O mass to moles. We compared moles of Cu to Oxygen and found 1.579 moles Cu to 1 mol Oxgen. Due to the law of multiple proportions which states that when two elements A&B combine to form more than 1 compound, A&B are in the ratio of small whole numbers of moles. Taking into account experimental factors and this law, we decided that copper and oxygen form in a 2 mol Cu to 1 mol Oxygen ratio and, therefore, the empirical formula is $Cu_2O$.

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EXP. NUMBER | EXPERIMENT/SUBJECT emperical formula of oxide of Cu | DATE 9-15-03

NAME | LOCKER/DESK NO. | COURSE & SECTION NO.

What is the relationship between red and black copper oxide?
How does copper oxide and copper powder vary?
What type of affect does heating have on copper oxide (both red and black) and copper powder & how do the heated elements relate?

Safety: wear my goggles, tie my hair back, place burner in hood to take away gases, use fire safety, know where fire extinguishers are, read warning labels, don't inhale dust

Procedure: place 1 to 2 g red powder in a porcelain evaporating dish, set on clay triangle on ring stand, light burner so flame is 2cm (3/4 inch) from the triangle, place in the hood to take the fumes away, heat strongly for 5 to 10 min. allow dish to cool before weighing. Heat again for 5-10 min, cool and recheck mass. The mass should be within 1% of the previous weighing, if not continue to heat until two consecutive weights are within 1% of each other.

What is the composition of red powder?

* starting mass should not affect mole ratio
* different mass shouldn't have different results.

| | beginning mass: | ending mass: | Ratio: |
|---|---|---|---|
| 1.00 | 1.0000 / 1.0438 | 1.0950 / 1.084 | 1.765 : 1 |
| 1.25 | 1.2502 / 1.2502 | 1.3124 / 1.3755 | 2 : 1 |
| 1.50 | 1.5100 / 1.5020 | 1.6802 / 1.6420 | 1.73 : 1 |
| 1.75 | 1.7530 / 1.7530 | 1.9108 / 1.8822 | 1.695 : 1 / 1.5178 : 1 |
| 2.00 | 2.0051 / | 2.2059 | 1.82 : 1 |

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Observations during heating: Red powder turned black.

| min | mass dish & powder | mass powder |
|---|---|---|
| 0 | 15.7447g | 1.753g |
| 10 | 15.915 g | 1.923g |
| 20 | 15.9015 g | 1.9098g |
| 30 | 15.9035g | 1.9118g |
| 35 | 15.9025g | 1.9108g |

mass of dish: 13.9917g

$$1.9108\,g\,CuO\left(\frac{1\,mol\,CuO}{79.55\,g\,CuO}\right)\left(\frac{1\,mol\,Cu}{1\,mol\,CuO}\right)\left(\frac{63.55\,g\,Cu}{1\,mol\,Cu}\right) =$$

$$= 1.5264\,g\,Cu$$

$$Cu_xO_y + O_2 \Rightarrow CuO$$

| | |
|---|---|
| 1.9108g CuO | 1.7530 g $Cu_xO_y$ |
| 1.5264g Cu | .2266 g O |

$$1.5264\,g\,Cu\left(\frac{1\,mol\,Cu}{63.55\,g\,Cu}\right) = .0240\,mol\,Cu$$

$$.2266\,g\,O\left(\frac{1\,mol\,O}{16\,g\,O}\right) = .01416\,mol\,O$$

$Cu = .0240 / .01416 = 1.695$ Ratio $= 1.695:1$

$O = .01416 / .01416 = 1$

$$2Cu_2O + O_2 \Rightarrow 4CuO$$

Ratio of 2:1 because of the law of multiple proportions.

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| NAME | LAB PARTNER | LOCKER/DESK NO. | COURSE & SECTION NO. |
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Claims:

* because the mass went up we know we added more oxygen to it.
* since we started with a certain mass of Cu powder and ended with a smaller number of Cu we know that we started with something other than just Cu.

Evidence:

We started with 1.753 g of powder, but ended with 1.9108g after heating. we know we added oxygen to cause the mass to increase.

We started with 1.753 g of powder, but ended with 1.5264 g of Cu so we had to have started with something other than just Cu.

Reflection:

My ideas have changed because I never would have imagined there being a combination of Cu and O in the beginning powder and then adding more $O_2$ during heating.
Everyone in lab was a little confused by all this, so I think we were all on the same page. Talking with one fellow chemistry student we came to the same conclusion about this lab before starting and both of our ideas changed after the experiment.

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I will be investigating the composition of an unknown red powder.

1. What is the identity of the red powder?
2. Was the powder labled incorrectly, and if so, how did this happen?
3. Are there variations in physical properties of copper oxide?
4. How many different forms of Copper Oxide are known to exist?
7. I will be careful not to breathe in the dust, tie back my hair, and wear goggles
8. Procedure:

Use a porcelain evaporating dish to heat the red powder
Obtain a sample of the red powder weighing between 1 to 2g.
Set the evaporating dish on a clay-triangle, supported by an iron ring attached to a ringstand.
Set the burner so that the evaporating dish is 2 cm above the burner
light the burner and obtain a hot flame.
Set the ringstand in the hood
heat strongly for 5 to 10 minutes
allow to cool to room temperature before weighing
heat again for 5 to 10 minutes and recheck mass.

$Cu_{x(s)} + O_{2(g)} \rightarrow CuO_{(s)}$

Data & Observations

| | actual weight | ending weight |
|---|---|---|
| 1.00 g | 1.0000 / 1.0438 | a. 1.0950 / b. 1.084 |
| 1.25 g | 1.2502 / 1.2502 | c. 1.3124 / d. 1.3755 |
| 1.50 g | 1.5100 / 1.502 | e. 1.6302 / f. 1.6420 |
| 1.75 g | 1.753 / 1.753 | g. 1.9108 / h. 1.8822 |
| 2.00g | 2.0051 | i. 2.2059 |

RR what oxides of copper exist?
what are their properties?
is this consistent w/ the lab?
how do we properly dispense reagents?

2.0 g red powder
2.0051 g actual
13.2601 container

$$\begin{array}{r} 2.2059 \\ -2.0051 \\ \hline .2008 \end{array}$$

2nd wt. w/ container:

$$\begin{array}{r} 15.4612 \\ -13.2601 \\ \hline 2.2011 \end{array}$$

change: .2008

3rd wt w/container:

$$\begin{array}{r} 15.4660 \\ -13.2601 \\ \hline 2.2059 \end{array}$$

a.
b. 1.765:1
c.
d. 1.579:1
e. 1.73:1 heated for 10 min
f. 1.695:1 heated for 10 min
g. 1.5178:1 produced a green gas
h. turned black
i. 1.82:1

$CuO_{(s)} + O_{2(g)} \rightarrow CuO_{(s)}$

ending wt

$2.2059\text{ g CuO} \times \frac{1\text{ mol CuO}}{79.55\text{g CuO}} = .02773\text{ mol CuO}$

mass of Cu in original powder

$.02773\text{ mol CuO} \times \frac{1\text{ mol Cu}}{1\text{ mol CuO}} \times \frac{63.55\text{ g Cu}}{1\text{ mol}} = 1.7622\text{ g Cu}$

$$\begin{array}{r} 2.0051 \\ -\ 1.7622 \\ \hline .2429\text{ g O} \end{array}$$

mass of O in original powder

$1.7622\text{ g Cu} \times \frac{1\text{ mol Cu}}{63.55\text{g Cu}} = .02773\text{ mol Cu}$

$.2429\text{ g O} \times \frac{1\text{ mol O}}{16.00\text{g O}} = .0158\text{ mol O}$ $\boxed{\begin{array}{c} 1.82:1 \\ 2:1 \end{array}}$

$Cu_xO_y + O_2 \rightarrow CuO$

Copper (I) Oxide

$Cu_2O$

We can claim that the original, unknown powder ~~contained~~ was composed of copper (I) oxide ($Cu_2O$)

We can support this claim through the data gleaned from the experiment. In nine experiments conducted over five different masses the ratio of Cu to O was found to be approximately 2:1. This ratio is consistant with the composition of Copper (I) oxide ($Cu_2O$).

RR: - How do we properly dispense reagents?

To properly dispense reagents we first transfer some of the product to a separate container and obtain the desired sample from this - never putting anything removed from the original container back in it.

- What oxides of Copper exist?

$Cu_2O$ (cuprite) and CuO (tenorite) www.psigate.ac.uk/newsite/reference/plambeck/chem2/p.02262.htm

$Cu_2O$: brown-red → both properties are consistent with our lab observations.
CuO: gray/black

Claims: The mystery copper oxide has a composition of $Cu_2O$.

The heat energy causes a reaction where $Cu_2O$ reacts with oxygen gas to form $CuO$. It also changes the physical color from red to black..

Evidence: I know that the mystery copper oxide has a composition of $Cu_2O$, because I used the conservation of mass to find out how much copper was in the reactions, so I could distingwish that mass to the mass of oxgen. I then used the law of multiple proportions to find how many moles of each will react with each other.
After performing the experiment of our sample of the mystery powder, we saw that our sample gained .0950 g, withe the color change from red to black powder. To explain what was going on, we came up with the unbalanced equation:

$$\boxed{?}Cu_xO_y + \boxed{?}O_2 \rightarrow \boxed{?}CuO$$

Conservation of mass

After we had an idea of what was happening, we set off to try and balance the equation, and come up with the empiracle formula for our mystery powder. We knew that the mass of the copper (Cu) would be the same on the reactant side and the product side. We know this because copper can't make anything besides a solid, so it was the added oxygen that was changing the mass during the experiment. To get the amount of copper in the equation, we used the information that we already knew. Our product weighed 1.0950, a .0950 increase from the starting mass. We did a mole ratio to find the % composition of Cu and O in CuO.

$$\frac{1.09500g\,CuO}{} \left| \frac{1mol\,CuO}{79.55g\,CuO} \right| \frac{1mol\,Cu}{1mol\,CuO} \left| \frac{63.55g\,Cu}{1mol\,Cu} \right. = .875g\,Cu$$

From this, we know that there is .875g of Cu in CuO and in $Cu_xO_y$. Now we can find how much oxygen is in $Cu_xO_y$ by subtracting .875g from the 1.0000g of the mystery powder ($Cu_xO_y$) that we started with. There was .125g of oxygen in the starting reagent, and we now know that the mystery powder was an oxide and not straight copper powder, which was one theory of the class. If it was straight copper powder, the mass of the copper in CuO would have equalled ~~the mass of the starting reagent.~~

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Evidence: So we know that the starting powder was concentrated of
cont'd .875 g of Copper and .125 g of oxygen. To find out how these two masses proportion out, we need to find out how many moles each of them are.

$$\text{Copper: } \frac{.875\,g\,Cu}{} \cdot \frac{1\,mol\,Cu}{63.55\,g\,Cu} = .01377\,mol\,Cu$$

$$\text{oxygen} = \frac{.125\,g\,O}{} \cdot \frac{1\,mol\,O}{16.0\,g\,O} = .0078\,mol\,O$$

By using the law of multiple proportions, we took the larger number and put it over the smaller number to make a ratio.

$$\frac{.01377\,mol\,Cu}{.0078\,mol\,O} \approx \frac{2\,mol\,Cu}{1\,mol\,O}$$

We see that this ratio can be converted into a whole number ratio of 2 Cu : 1 O. This is the concentration for the mystery powder! Now we could balance the entire equation:

$$2Cu_2O_{(s)} + O_{2(g)} \rightarrow 4\,CuO_{(s)}$$

Reading/Reflections: My initial questions before the lab was to find the concentration of the mystery red powder and how heat energy affects the product. I found out the answers to all of these questions during the lab and by comparing them to the evidence from the other groups in my class. I was able to use the Chemistry textbook to learn about multiple proportions and the conservation of mass from the reagents to the products. I used the methods from class to find moles and use the information that we found out in the experiment to calculate the final composition of the red powder. My group's results were slightly off due to error in measuring and rounding. Example, when we were looking for the proportion of Cu to O, our answer came out to be 1.765 mol Cu : 1 mol O. We just rounded this up to 2 mol Cu : 1 mol O, because when we compared ours with the classes results, we implied that the slight error in each of our experiments would have had an effect on the result. The ≈ sign in this case means "close to" the ratio given. Our observations and calculating were able to answer all the questions on this lab, and by comparing the results w/ outside sources (the class), we ~~were pretty accurate~~

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beginning questions:

What affects does heat have on ~~[illegible]~~ Copper powder?

What affects does heat have on CuO?

What is the composition of the red powder

What are some properties of other copper oxides, i.e, what happens when it's heated, & color, ~~[illegible]~~

Safty:

Wear goggles at all times while in lab.

Read lables on powdered substances, follow carefully.

hair must be pulled back, using bunsen burners.

Be cautious when touching anything that had been heated.

procedure:

gather:
porcelian evaporating dish
1-2g of red powder
clay triangle
iron ring
ring stand
bunsen burner

1. Set evaporating dish on clay triangle, set triangle on ring, which should be attached to the ring-stand.
2. Set burner on the base of the stand, adjust ring to ~~[illegible]~~ have the dish be 2cm (3/4 inches) above burner.
3. Light burner, adjust gas and air for hot flame.
4. Be sure to have ring-stand in the hood.
5. Heat for 5 to 10 mins cool to room temp
6. Weigh dish
7. Heat again for 5-10 minutes, cool + recheck mass.

note: if new mass is within 1% of old then it's done. If not, then reheat + cool until two consecutive weightings give masses within 1%.

Data
powder
Starting mass should not affect mole ratio

mass should have different results

1.25 g of red powder heat for 5 mins

9:41 1.2502

| theoretical | actual | ending weight | ratio |
|---|---|---|---|
| 1.00 | 1.000 g | 1.0950 | 1.765:1 |
| | 1.0438 | 1.084 | |
| 1.25 | 1.2502 g | 1.3124 | ≈2:1 |
| | 1.2502 g | 1.3755 | |
| 1.50 | 1.5100 g | ~~1.6302~~ | ~~1.579:1~~ |
| | 1.502 g | 1.6420 | 1.73:1 |
| 1.75 | 1.753 g | ~~1.9015, 2.5019~~ 1.9108 | 1.695:1 |
| | 1.753 g | 1.8822 g | 1.51788:1 |
| 2.00 | 2.0051 g | 2.2059 | 1.82:1 |

$Cu_xO_y + O_2 \xrightarrow{\Delta} CuO$

final weight → 1.3124

x g CuO : 1.3124 g CuO × mol CuO / 79.55 g CuO × 1 mol Cu / 1 mol CuO × 63.55 g Cu / mol Cu

ratio .875 g : .01377 moles Cu

$\boxed{1.0484 \text{ g Cu}}$

CuO + $O_2$ → CuO .0011 g $O_2$
1.0484 g Cu in CuO

~~1.3135~~

1.3124 g CuO × mol CuO / 79.55 g CuO × mol O / mol CuO × 16 g O / mol O = .2639 g O

end wt / theory: 1.3124 / 1.25 % yield

start 1.2502 g
1.3500 g
1.3292 g
initial 1.3135 g
1.3124 final

new actual %

x mol O : .875 g Cu × mol Cu / 63.55 g .01377 mol Cu

Cu 1.3135 − 1.0484 = .2018 g O
mol O / mol Cu
.2018 g × 1 mol / 16.00 g = .0126 mol O
1.3135 g × 1 mol / 63.55 g = .0207 mol
.0207 mol Cu / .0126 = 1.64

$Cu_x + O_2 \rightarrow CuO$ mole ratio:

1.3135 + .0011 → 1.3124

$2Cu_2O_{(s)} + O_{2(g)} \rightarrow 4CuO$

conservation of mass! evidence

Start wt increase = final

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reading/reflection what oxides of Cu exist

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Claims:

As the actual weight of the red powder, the ending weight after being heated increased as well.

Because the mole ratio was about 2:1 we can assume the red powder is Copper (II) oxide, ~~[illegible]~~

Evidence:

Actual weights ranged from 1.00g - 1.0438, 1.2502, 1.5100 - 1.502, 1.753, 2.0015

where as the ending weights ranged from 1.0950 - 1.084, 1.3124 - 1.3755, 1.6302 - 1.6420, 1.9108 - 1.8822, 2.2059

Showing an increase in every trial.

Evidence con't:

We know it is more than copper powder because when heated the ending weight was more than the starting weight causing a 1.64:1 ratio.

We can't have partial moles according to laws of multiple porportions so it is allowed to apply rounding rule creating a 2:1 mole ratio.

Making it a Copper(II) oxide.

Reading/Reflections:

When heat is applied the Copper powder gains weight.

The composition of the red powder is $Cu^{2+}$.

Other oxides that exist are $Cu^+$. $Cu^+$ has 29 protons 36 neutron and 29 electrons

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