The effect of restructuring student writing in the general chemistry laboratory on student understanding of chemistry and on students' approach to the laboratory course

by

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CHAPTER 1

INTRODUCTION

Review of literature

From a theoretical standpoint, there is a need to understand what forms of student writing in science classes promote what types of learning outcomes (*1*). Written work in the science classroom has been found to address understandings of science concepts (*1-3*) and understandings of scientific inquiry, argumentative discourse (reasoning), epistemology (the nature of knowledge), and scientific discourse (communication) (*1*). However, research on student writing in the laboratory classroom has received little attention (*2, 4*). There is an assumption that the traditional journal article format for laboratory work will address the specific learning outcome of understanding science concepts (*5*). As Hart and co-workers observed, "Most laboratory work in school science follows a familiar rubric" that consists of an aim (the goal for the experiment, such as experimentally confirming Faraday's constant), hypothesis, method or procedure, observations and/or measurements, and questions that lead to the conclusion to be inferred from the experiment, and "Teachers assume that in following this rubric students will learn particular content" (*5*).

But what learning outcome(s) does this form of writing specifically address? Or as Pickering asks in practical assessment terms, "In many lab courses, grading does not emphasize the real goals of laboratory education … Does the grading system really reward what it is supposed to reward?" (*6*).

Traditional reporting of student laboratory work leaves students with the impression that writing is only a presentation of knowledge that one already possesses, and de-emphasizes or obscures opportunities for writing, such as research notes and drafts, in which initial understandings are developed (*3*). Traditional laboratory reports misrepresent science by this emphasis on knowledge presentation (scientific discourse) over knowledge development (scientific explanations) (*7*). In addition, writing in this style could be more harmful to students than just reading work that has been written in this style because students do not experience opportunities for learning how to generate their own initial understandings (*7*).

Students are not yet professional scientists and may have a weak understanding of how scientists develop explanations in the first place, and therefore, writing in the form scientists use to communicate with each other may not make much sense to students (*3*). Scientific explanations and models are considered to be complex forms of writing, and research has shown that students need practice and support on how to write such text structures (*3*). Even when students understand how to carry out experimental procedures, the resulting laboratory report may often be deficient due to a lack of interpretative skills associated with a scientist's ability to develop explanations (*2*). "In short, students' methodological or procedural activities are usually not consciously guided by the kinds of conceptual and theoretical ideas scientists use in their inquiries --- there is no active interplay between the thinking side ... and the doing side ... As a result, science laboratory work is often frustrating and/or meaningless" (*8*). Without a strong understanding of how scientists create their explanations, students may view scientific claims as originating from a mystical process rather than from a rational process (*5*).

In fact, many students appear to encounter unexpected difficulties in relating their laboratory experiences to understandings about science. Novak and Gowin noted, "... they proceed blindly to make records or manipulate apparatus with little purpose and little consequent enrichment of their understanding ..." (*8*). Similar observations have been reported by other researchers (*9-11*). The apparent barriers to learning from laboratory work have contributed to the current questions regarding the value of including laboratory instruction as part of chemistry education at the college level (*e.g., 12*). In addition, reviews of research on laboratory instruction have shown a lack of clear evidence for the value of this type of instruction.

In Domin's review in the *Journal of Chemical Education*, four categories of laboratory instructional styles were outlined (expository, inquiry, discovery, problem-based) in an attempt to promote more evaluative research in this field. The author stated, "The paucity of necessary research makes any conclusion tentative at best" (*13*). Lazarowitz and Tamir examined thirty-seven books, journals and technical reports that were themselves reviews of research on laboratory instruction (*7*). Four broad goals for laboratory instruction were identified (exposure to concrete experiences, use of microcomputers, development of logic and organization skills, and development of scientific values), and five factors which appear to facilitate successful instruction were discussed (curricula, resources, learning environments, teaching effectiveness, and assessment strategies). The authors stated, "The mix of studies performed at the present time will not lead us into the future. Well-structured studies ... will provide the needed answers about the role of laboratory work in science instruction" (*7*). Five variables in the laboratory environment (teacher attitude and behavior, content and nature of laboratory activities, instructional goals, social variables/learning environment, management) that needed further study were identified by Hofstein and Lunetta (*14*). Also, five student characteristics that needed further study were identified (student behavior, intellectual development, conceptual understanding, skill level, attitudes). The authors stated, "The research has failed to show simplistic relationships between experiences in the laboratory and student learning ... On the other hand, sufficient data do exist to suggest that laboratory instruction may play an important part in the achievement of some of these goals" (*14*).

Despite the number of factors that have been targeted for more research, there is a need for more discussion of the issue of student assessment. As Pickering noted, "It is important to see the lab from a 'student's eye view' ... Grading is important because it controls incentives. [R]eplacing experiment X with experiment Y will not fix the real malaise of the lab" (*6*). Although Lazarowitz and Tamir identified the factor of assessment strategies as contributing to successful instruction, the discussion was limited to the issue of using practical examinations to augment or replace standard pencil-and-paper tests. Assessing student work on individual laboratory activities was not discussed. Student work was briefly mentioned twice during the discussion of other factors. Under the goal of developing scientific values, it was suggested in a single sentence that allowing students "to write laboratory reports in the style preferred by the student" (*7*) would foster the development of personal meaning and scientific values. Under the factor of teaching effectiveness, Novak and Gowin's 1984 presentation (*8*) of concept maps and V-diagrams as potential tools for promoting knowledge construction was reiterated in two paragraphs. The issue of student assessment was not directly mentioned in the review by Domin (*13*) or the review by Hofstein and Lunetta (*14*).

How do we assess student work on individual laboratory activities? In practice the typical student assessment is the traditional laboratory report written in a format resembling a scientific journal article (*7*). The issue of assessment is important in education and research because how we assess students greatly determines what students will attempt to learn. As Phelps and co-workers observed, "Students are very efficient and most of them try to learn only what is necessary in order to achieve the grade they are seeking in the chemistry course ... In order to bring about real change in our chemistry classrooms, we must look not only at how and what we teach, but how we assess what we teach" (*15*). Studies have shown that the primary concern of many students during laboratory instruction is completing the task, not necessarily learning (*6, 16, 17*). Therefore, the issue of how students are assessed on individual laboratory activities needs serious consideration when studying the effectiveness of laboratory instruction.

The Science Writing Heuristic

A pedagogical tool designed to promote science learning from laboratory work and based upon constructivist theories of learning (*18-20*) is the Science Writing Heuristic (*3, 4*). Under the knowledge transforming model of writing of Bereiter and Scardamalia (*21*), the writing process is seen as a synthesis, between prior knowledge and incoming information, resulting in meaning construction and leading to knowledge development (*2, 4, 22*). Writing in science is consistent with this model, especially writing related to laboratory instruction, because the intention of such instruction is for students to generate new understandings by making inferences based upon their observations (*2*).

The Science Writing Heuristic (SWH) was designed in part to serve as a bridge between traditional forms of laboratory report writing and writing forms that promote the development of initial scientific understandings. The heuristic consists of two templates, an instructor template to aid in the design of inquiry-based laboratory activities and a student template to explicitly guide students in their thinking and writing to connect their laboratory work with their current scientific understandings. Students are initially directed to form a beginning question or idea to investigate, then to carry out some tests and procedures to try to answer the beginning question, and then to collect the observations that result from the tests and procedures. Students are then directed to create an explanation that addresses the beginning question by forming a knowledge claim that is supported by experimental evidence. Finally, students are directed to reflect on their learning from the laboratory activity.

Therefore, the SWH student template offers an avenue for altering the traditional student assessment on individual laboratory activities in order to redirect student effort in the laboratory class. To someone who is already at a high level of scientific understanding, the difference in using the SWH student template or a traditional article form as the laboratory report format may be minor, but to those with a novice level of understanding the difference is significant. The template explicitly promotes student learning of some of the thinking skills, such as posing questions to investigate and creating explanations supported by experimental evidence, that professional scientists use when developing scientific explanations of observable phenomena. Thus students learn how to make their laboratory work more meaningful and less frustrating, which in turn helps them to understand that science is a rational process not a mystical process.

Like other inquiry-based approaches to laboratory instruction, the SWH attempts to develop higher-order thinking skills such as inference, explanation, and evaluation. There has been widespread discussion that inquiry-based instruction emphasizes the development of such higher-order thinking skills and produces greater student interest in laboratory work whereas a traditional verification approach emphasizes the development of lower-order thinking skills by using a cookbook approach that trains students in how to confirm and verify rather than how to explain (*7, 11-13, 23-28*). However, there is not a convincing body of evidence for the superiority of inquiry approaches to laboratory instruction in chemistry (*7, 13, 14*), and the benefits of an inquiry approach over a verification approach have been demonstrated in only a few cases in chemistry (*29-32*).

A key feature of the SWH inquiry approach is that replacing the traditional laboratory report format with the SWH student template does not require significant up-front investment in time through in-house revisions and/or in money through adoption of commercially available materials. Some related attempts to improve laboratory instruction in chemistry by focusing on restructuring how students report on their laboratory work have been presented. Similar to the SWH student template, the Vee heuristic (*8*) was specifically designed to help students learn science and attempts to develop student thinking skills in how to relate scientific explanations to laboratory work. In one study (*11*) three volunteer freshmen students in a general chemistry course at a four-year university completed V-diagrams (contemporary term for Vee heuristic) for each laboratory activity although it was not clear if the diagrams were completed in addition to or in place of the traditional laboratory report. The students reported that completing the V-diagrams enabled them to learn chemistry material from their laboratory work whereas they believed that traditional laboratory reports could be successfully completed without learning or knowing the chemistry involved. They also reported increased confidence in knowing the purpose of their actions during laboratory work. Another implementation of the V-diagram (*33*) involved one class of 22 high school students, but there was no discussion of the impact of using V-diagrams.

The next set of developments extended traditional student laboratory writing to incorporate additional forms of communication used by professional scientists, and the discussion of students outcomes was limited to noting a positive reception from faculty and/or students or was absent. In place of weekly reports during the junior year, chemistry majors at a four-year university were required to write two or three reports each semester in the format for publications in the *Journal of the American Chemical Society*, the *Journal of Physical Chemistry*, *Inorganic Chemistry*, and the *Journal of Organic Chemistry* (*34*). In addition, a first draft of each report was required and was reviewed by writing consultants who were graduate students in the Department of Language, Literature, and Communication. In addition to weekly reports, chemistry majors at a four-year university (*35*) were required to report the results of a specified laboratory activity in one additional mode of scientific discourse (short technical report, poster session report, research article report, and original research proposal) in each semester from the end of the sophomore through the senior year. At the general chemistry level at a four-year university (*36*) students combined the experimental data from three laboratory sessions into a single report that was written in the publication format for the *Journal of the American Chemical Society*. In addition to the weekly reports, student in an environmental chemistry course at a four-year university (*37*) completed an Environmental Impact Statement (EIS) according to the professional format outlined by the Environmental Protection Agency. The EIS was completed as a class project in which pairs of students were responsible for preparing one or two elements of the EIS.

The lack of clear evidence in chemistry teaching laboratories for the effectiveness of these changes in student writing, for the effectiveness of inquiry-based instructional methods, and for the effectiveness of laboratory instruction in general indicates the importance of further research on laboratory instruction in chemistry courses.

General approach to assessment

The assessments used to measure the effectiveness of incorporating the SWH were student responses to test questions related to the concept of chemical equilibrium. The decision to assess student understanding of equilibrium was based upon the importance of this concept in general chemistry (*38-42*). Chemical equilibrium has been reported to be highly linked to other topics in chemistry (*43*) and important in understanding oxidation-reduction (*44*), acid-base (*45, 46*), and solubility processes (*47*). However, addressing the equilibrium concept creates difficulty for instructors and students (*38, 43, 45, 48, 49*).

Students have difficulty with general characteristics of equilibrium, such as the dynamic (*46, 50-52*) and reversible features (*48, 51, 53, 54*), the constancy of concentrations (*54*), and even identifying an equilibrium condition (*52*). Students often believe equilibrium means equal concentrations (*38, 51, 53*), and they confuse concentrations with amounts (*48, 54*) and rate of reaction with extent of reaction (*45, 46, 53-55*). Students demonstrate a poor understanding of the constancy of an equilibrium constant (*38, 46, 48, 52, 54*) and frequently misapply Le Chatelier's principle (*43, 45, 46, 54-57*). They show confusion regarding how concentrations change (*38, 48*) and how rates change (*38*) for a system to establish equilibrium. Students encounter difficulty when considering heterogeneous equilibria (*43, 47, 52, 56*), competing equilibria (*52, 54*), and the effect of catalysts on equilibria (*38, 52*).

Student confusion in the interpretation of terms and phrases related to equilibrium (*43, 48*) contributes to their conceptual difficulties.

The assessment issue is complicated by the fact that students often choose correct answers to test questions without possessing a scientifically acceptable understanding of the chemistry (*43, 48, 56, 58-63*). A two-tier format for test questions has been used to obtain a more comprehensive view of student understanding than a single answer. The two-tier format can consist of questions in which students select an answer from a multiple-choice set of answers and then either select a reason for their answer from a multiple-choice set of reasons (*43, 58, 64*) or explain their reasoning (*56*). The paired multiple-choice algorithmic and particulate nature of matter conceptual problems also utilize the two-tier approach (*59-63*).

We used test questions in which students were required to provide an answer and then support their answer with an explanation. This assessment method followed the two-tier answer-reason format, however students were not provided a preset list of possibilities. The use of written explanations was intended to yield additional insight into student understanding similar to the use of conceptual questions, such as particulate nature of matter problems (*59-63*). In addition, the use of written explanations as an assessment method was intended to match the methodology of comparing different types of student writing in the laboratory.

Organization of the dissertation

This dissertation is organized into five chapters and seven appendices, and the numbering for references, tables, figures, and boxes are self-contained within each chapter. Chapter one presents a general introduction to the dissertation. Chapter two is a paper in press in the *Journal of College Science Teaching* and presents a pilot study. Chapter three is a paper in press in the *Journal of Chemical Education* and presents a main study. Chapter four is a paper submitted to the *Journal of Chemical Education* and presents another main study. Chapter five presents conclusions, limitations, and implications of the dissertation.

The appendices present material that was not included in the papers for journal publication, and they are included in the dissertation because they were necessary to complete the research. Appendix A is the practice activity discussed in chapter two. Appendices B and D are the approval forms for human subjects research that were necessary to present the research discussed in chapters three and four, respectively. Appendices C and E are the student survey questions used for data collection for the research presented in chapters three and four, respectively. Appendices F and G are the two versions of the laboratory procedures discussed in chapter four.

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CHAPTER 2

RESHAPING THE GENERAL CHEMISTRY LABORATORY REPORT USING THE SCIENCE WRITING HEURISTIC

A paper in press in the *Journal of College Science Teaching*

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Abstract

Shifting students' attitudes from a procedural approach in writing laboratory reports to a more engaged learning experience is difficult. This paper describes the adoption of a Science Writing Heuristic to promote a more positive attitude and to promote better conceptual understanding in the introductory college chemistry laboratory.

Introduction and background

One difficulty we have experienced over the years is how to encourage students to develop connections between experimental work and the related chemistry. Students tend to focus their efforts during an experiment toward completing the procedures as quickly as possible, and rarely appear to be enthusiastic and highly engaged. Instead of striving to make quality observations and to think about the chemistry involved, they concentrate on completing the laboratory activity so that they can leave class. They then spend excessive time outside class preparing their laboratory reports, and despite their efforts, the quality of their discussions in their reports indicates that they often fail to link their observations and data with the chemistry that took place. Such efforts result in many students being unable to demonstrate the ability to apply their laboratory skills and chemical understanding toward solving transfer problems on the laboratory practical examination. They find the examination extremely difficult with the exam average being typically around fifty percent.

Why do students focus their mental efforts on simply developing efficient procedural skills? Why do they not focus on connecting the whole of experimental procedures, observations and data to relevant chemical concepts? In other words, why do students work so hard at following procedures and so weakly at developing their understanding of chemistry?

One possible explanation is that introductory college chemistry laboratory experiments and activities tend to focus on confirming concepts already taught rather than attempting to teach concepts, a format that does little to promote the development of conceptual understanding (Gunstone and Champagne 1990) or thought about the process of science itself (Lloyd and Spencer 1994; Spencer 1993-1994). A literature review of research which studied the educational effectiveness of science laboratories identified several goals when using laboratories to develop understandings about science, including the need to provide opportunities for students to identify and resolve their misconceptions, to develop skills in logical thinking and organization, and to develop an understanding of the nature of science (Lazarowitz and Tamir 1994). The achievement of these goals requires activities that are more open-ended, student-centered, and investigative in their approach. Science laboratories that emphasize the development of inquiry and other intellectual abilities in addition to the development of problem-solving and laboratory skills can teach science concepts more effectively than those that focus on verification activities (Hofstein and Lunetta 1982). Students can also learn science concepts from laboratory activities that ask them to determine the outcome of an investigative activity while writing their laboratory reports using a flexible format (Pickering 1987). In a chemistry laboratory that incorporated a modified guided-inquiry format (the MORE thinking frame) and written and oral reports, students had fewer misconceptions and better critical thinking skills than those in a standard chemistry laboratory (Tien, Rickey, and Stacy 1999). By comparison, laboratories that were heavily structured and teacher-centered and that emphasized a confirmatory approach to experimental work were less effective in promoting the understanding of science concepts, the development of problem-solving skills, or the acquisition of laboratory techniques (Lazarowitz and Tamir 1994)

Laboratory activities that use the Science Writing Heuristic (SWH) are effective in promoting development of conceptual understanding and logical thinking at the secondary level (Keys, Hand, Prain, and Collins 1999; Hand and Keys 1999). When complemented by a guided-inquiry laboratory format, the SWH provides opportunities for students to develop an understanding of science concepts by integrating science activities with peer discussion and writing that has personal meaning. In a standard laboratory report, students are generally asked to complete sections, such as Title, Purpose, Procedure, Data, Calculations, Results, and Discussion, which encourages them to verify science concepts already explained to them. By contrast, the SWH asks students to complete a laboratory report (see Figure 1) consisting of sections with more personal meaning as a way to encourage deeper thinking and understanding about science concepts (Hand and Keys 1999). We decided to try using the SWH as a means of promoting the development of conceptual understanding and other high level thinking skills for our introductory chemistry students.

Research design

We began our exploration of the effectiveness of the SWH with students enrolled in the first-semester chemistry course for science majors. We required that students in one laboratory section use the SWH format and in two other sections use the traditional format to complete their laboratory reports. Although we did not modify the experiments themselves or the laboratory manual, which contained the experimental procedures, we did complete some of the activities in the SWH section as group or class projects to allow time for student discussion. The same professor was the lecture instructor for all sections, and the same teaching assistant was the laboratory instructor for the three sections involved in this preliminary study.

The first class meeting

On the first day of class, the instructor briefly introduced the new report format and described the elements A-F of the SWH (see Figure 1).

Figure 1. The modified Science Writing Heuristic used in study

A. Beginning ideas and questions – What are my questions about this experiment?

B. Tests and procedures – What will I do to help answer my questions?

C. Observations – What did I see when I completed my tests and procedures?

D. Claims – What can I claim?

E. Evidence – What evidence do I have for my claims? How do I know? Why am I making these claims?

F. Reading and discussion – How do my ideas compare with others?

Immediately afterward, the class began with a demonstration in which zinc metal is placed into copper(II) sulfate solution. The instructor asked the students to write their beginning questions (A) and possible tests or procedures (B). Then the instructor asked what they had written, and several students offered "What's going to happen?" and "Put the zinc into the solution." A student volunteer conducted the demonstration, and everyone recorded their observations (C). The instructor then asked the students to work individually for 10 minutes writing claims about what they think happened (D) including evidence to support their claims (E).

The class then studied a demonstration in which liquid nitrogen is placed into the basin of a cryophorus, a glass device that has been evacuated and contains water (Baker 1950, Baker 1948). The students repeated the process of completing sections A-E, and then the instructor asked the students to work on their claims and evidence for both demonstrations in small groups of 3 or 4 as part of the social process of developing their understanding (F).

When the students worked individually to understand the demonstrations, their demeanor ranged from bored to respectful interest. However, when discussing in small groups, they became very animated and quite loud as they talked and argued with each other about the meaning of the demonstrations. The students were earnestly engaging in trying to understand what happened!

They used phrases such as "reaction between zinc and copper sulfate solution, possibly oxidation involved", "decomposition of zinc", "precipitate formed, possibly copper oxide", and "catalyst involved and breaking up copper sulfate" in reference to the zinc metal-copper(II) sulfate demonstration. Two students asked if they could do some additional work with the demonstration because they decided they needed more observations to strengthen their claims and evidence, but the tests they wanted to do were not in the lab manual. The students used phrases like "water vapor moved", "heat from the water transferred to the nitrogen so the water froze", "the liquid nitrogen boiled because it accepted heat from the water", and "nitrogen more easily reacted with the water than the surrounding air" in reference to the cryophorus demonstration. The students' initial use of the chemical terminology indicated apparent weaknesses in their understanding of several chemistry topics, such as chemical change and heat transfer. However, the students eagerly discussed their observations with each other, and in general, they succeeded in reviewing and clarifying their understanding of the relevant chemistry as demonstrated by their improved use of the chemical terminology.

Next, the instructor asked each group to decide on a single claim with evidence for each demonstration and then present their claims to the entire class. Starting with the zinc-copper(II) sulfate demonstration, the instructor summarized their statements on the board and asked the students to decide what parts of their statements represented claims and what parts represented evidence. As a class their claims were not sophisticated, and the students had difficulty distinguishing between claims and evidence. After working through this initial difficulty, however, the students were more prepared and readily distinguished between claims and evidence in the subsequent class discussion of the second demonstration.

The class period had now ended, but surprisingly, the students continued discussing the demonstrations. One group showed no signs of leaving and remained outside the classroom passionately discussing the chemistry they had initially encountered three hours ago, which perhaps was a first in a general laboratory course.

Mystery activity

After moving beyond simple demonstrations and onto more complex experiments, the students again had difficulty explaining their claims and evidence. To help them strengthen their understanding of the relationships between observations, claims and evidence, the instructor presented to them a mystery activity that was not complicated by the presence of chemical concepts. The instructor provided to the students the details of a possible crime scene with multiple potential outcomes and asked them to play the role of a detective investigating the scene. The instructor then asked the students to make a claim as to what happened and to provide evidence in support of their claim. The instructor found the students eager to work through this activity and summarized their statements on the board for class discussion.

Examples of student claims and evidence were:

(1) Mr. Xavier was dead. His dead body was found.

(2) Mr. Xavier was murdered. The knife with blood on it was the murder weapon, and the red stain under his body was from the fatal wound.

(3) Mr. Xavier died from a heart attack. The knife with blood was from his steak dinner, and the red stain was from a glass of spilled wine.

(4) The ground outside was wet. There was a storm.

The class agreed that the first example was of little value because it was merely a restatement of an observation given to them, which indicated to them that a claim with evidence is much different than an observation. The class agreed that statements (2) and (3) were equally possible based on the observations provided in the scene, which indicated the importance of observations in the context of a claim. The class agreed that statement (4) had some value, but it was less relevant to them in their role as detective. At which point the student that offered the statement said it would be very relevant if he was playing the role of estate gardener and had to decide whether to water the lawn, which indicated the importance of the beginning idea or question under investigation. Upon completion of the activity, the students agreed the experience was extremely helpful in clarifying all aspects of the SWH, especially claims and evidence.

An example of implementing the SWH: determination of empirical formula

The goal for the experiment following the mystery activity was the determination of the empirical formula of a compound of zinc and chloride. Students reacted various amounts of zinc with excess aqueous hydrochloric acid, and after isolating the solid product, they determined its empirical formula. The experiment itself was not revised, but the class procedure was modified in a few ways. Students worked with a partner to allow each of them time to write their observations and preliminary conclusions and to allow time for discussion with their partner and with other groups. Students completed a class data table on the board with each group indicating their initial zinc mass, product mass, and product appearance to provide a larger number of observations for them to use in making their claims. After the discussion between groups, a class discussion was held to allow groups of students to resolve any remaining differences in their understandings about how to determine the empirical formula of the product. The students then completed their laboratory reports in the SWH format before leaving class.

Although students had already received the lecture on empirical formula, many students were still in the initial stages of developing their understanding of this concept. The nature of their beginning questions reflected this initial level of understanding as well as their interest in trying to use the experiment to increase their understanding. Each student typically posed a few beginning questions regarding the qualitative and quantitative nature of product formation. For example,

Student 1: "What type of product will be formed? How much will we get (g) [grams]? What is its empirical formula?"

Student 2: "What products and what changes will take place? Will we be able to determine an empirical formula for the final product?"

Students recorded their preliminary observations during the course of the reaction. For example,

Student 1: "When HCl was added to zinc, the zinc started to dissolve. Bubbles. Continued to fizz and dissolve zinc. Zinc is gone, aqueous solution, ended up with a white fluffy substance."

Student 3: "Fizzing occurred when Zn(s) and HCl(aq) were mixed. A gas was released. Zinc metal was dissolved eventually. We evaporated too much and destroyed the product. It turned out to be a hard, glassy brown solid."

Students then constructed their claims and evidence. For example,

Student 1: "The empirical formula has the ratio of Zn:Cl that is 1:2. We started with 0.7381 g of Zn and ended with 1.6043 g of ZnCl compound, and minus beginning Zn gives g of Cl. Then we found the moles of Zn and Cl, divided Zn/Cl, and the ratio was 0.46 or approx. 1:2. $Zn(s) + 2HCl(l) \rightarrow ZnCl_2(aq) + H_2(g)$ [the student had already completed the necessary calculations at the end of the observations section]."

Student 4: "Hydrogen gas was given off in the reaction, and Zn and Cl combined. The evidence for this was the emergence of a colorless gas from the mixture when HCl was combined with Zn. Since a new, unidentified substance formed and the gas given off was hydrogen, the substance must contain some combination of Cl and Zn."

"The empirical formula for the substance is $ZnCl_2$ ... [the student shows the necessary calculations to determine moles of Zn and Cl] ... The ratio is 0.0085 mol of Zn to 0.0175 mol of Cl. Since 0.0085 is approximately half of 0.0175, the empirical formula is $ZnCl_2$. Balanced equation is Zn + 2HCl → $ZnCl_2(s)$ + $H_2(g)$ [followed by calculation of % yield]."

Student 5: "The empirical formula of the product formed is $ZnCl_2$. Since bubbles formed when the zinc dissolved, we know a gas formed ... We assumed it was H_2 ... Zn(s) + 2HCl(aq) → $ZnCl_x$ + $H_2(g)$. After finding the mass of Zn and Cl, we then found its ratio, which was close to 1 Zn to 2 Cl [the student had already completed the necessary calculations at the end of the observations section]. Zn(s) + 2HCl(aq) → $ZnCl_2(s)$ + $H_2(g)$ [followed by calculation of %yield]."

Results and discussion

A comparison of the discussion section of the traditional report with the claims and evidence sections of the SWH highlighted the differing pedagogical goals between the two formats. The traditional format encourages students to review concepts that have been previously explained in lecture and to report verifying, results, and unless the instructor intervenes and explicitly requires the students to explain how the experimental work relates to a concept, such as empirical formula, the discussions in traditional reports tend to focus on (1) the student's feelings regarding the experiment, e.g., "Overall the lab went well even though it was kind of boring. I learned a lot about determining empirical formulas", (2) numerical results, e.g., "We found the empirical formula to be 1 Zn to 2 Cl for a formula of $ZnCl_2$ and we calculated a percent yield of 95%", and (3) insignificant sources of error, e.g., "Human error could have occurred. We might not have been careful enough in weighing and transferring, or the balances could have been off."

In contrast, the SWH format encourages students to develop conceptual understanding by relating their results to their current level of understanding. The claims and evidence in the

SWH reports did deal more directly with chemical concepts than the discussions typically found in traditional reports. As shown in the previous empirical formula example, students using the SWH produced claims with evidence which clearly connected observations to the determination of an empirical formula *without* reminders from the instructor, and over the term of the course the students actively and consistently engaged in making these connections both in writing and in their group discussions.

Their overall class demeanor, however, depended on the nature of the laboratory activity. When students were more certain of the outcome of a laboratory activity, such as when their results were expected to confirm a concept from a previous lecture, they tended to revert to traditional behavior, expressing less interest in their laboratory work and racing through the procedures. One method of creating uncertain outcomes in an attempt to encourage more thoughtful laboratory work was to ask the class to divide the work among them. This modification encouraged students to be more responsible by allowing them to make important decisions, to value their results because they were working as a team, and to discuss the meaning of their results while they worked together. When the laboratory activities were successfully modified to create uncertainty in their minds about the outcome of their work and when they were allowed to resolve their uncertainty through group discussions and through the SWH, the more they expressed their internal motivation and passion for learning as they did in the first class meeting.

The students completed an end-of-semester feedback survey, and more than 90% of them expressed that the SWH format helped them relate their laboratory work to understanding chemistry. In interviews, students more clearly described how using the SWH encouraged their internal motivation and promoted the development of their understanding of chemistry.

Student 6: "I think that the claims were really important because they were the answers to your questions. They were the why ... I even understood the procedure more when I had some claims written down. And I knew what I was trying to accomplish with my procedure. I know that in [the previous semester's class], you just went in there and you followed the directions and you didn't learn anything while you were in there ... For this semester, I was actually learning stuff, ... and we were always adamant, 'Come here, Come look at this, You want to see this', wanting to be able to know what this is and recognize it. That was really, really new to me for this semester. It was something that really helped me to do much better in this lab than I did last semester."

"I think the biggest reason it was different was because it way my question that I was answering ... These were my questions, and I really cared about what the answer was because if I didn't care, I wouldn't have asked the question. I think that is the big difference, and it all goes back to the beginning ideas and then claiming it, evidence, proving it, and how it all really works together to make you understand it and give you more motivation to do it."

Student 7: "You were testing your own hypothesis so basically you were writing down what you did to [test the hypothesis], and so by answering your own questions, you don't have to rely on somebody else. And you are gaining your own knowledge, and you are using your own resources to gain that knowledge and answer those questions. It is not learning by reading and regurgitating it. It is actual learning and knowing what you are doing."

"A lot of times you can answer a question and not know why you know that answer. [With the SWH] you had to actually write down what you were doing, and you are trying to prove what you are doing was right. You had to know the why, you had to explain why. In [the previous semester's class], if you did something wrong, basically you took somebody else's data or wrote in your lab report, 'We did something wrong'. By doing this [the SWH], if you did it wrong, you had to explain why you were wrong and what you could do to make it right again. You actually learned the right way regardless of ... your outcome of the lab."

Although the SWH effectively encouraged students to engage in connecting their experimental work with the associated chemistry, a comparison of mean student performance on the end-of-semester laboratory practical examination did not yield conclusive results. The mean performance on the exam was 72.8% for students using the SWH (μ_1 =72.8, σ_1 =17.7, n_1 =16) and 63.0% for students using the traditional format (μ_2 = 63.0, σ_2 =22.5, n_2 =27). Although the result of a two-sample t-test comparing mean exam performance was not statistically significant at α=0.05 (t=1.59, df=37.6, p=0.121), the 95% confidence interval for the difference in mean exam performance indicated that students using the SWH would score as much as 22.4 percentage points higher or as much as 2.7 percentage points lower than students using the traditional format. In other words, at worst the mean performance for students using the SWH would be decreased only slightly (-2.7). However, this preliminary result also indicated that using the SWH could dramatically improve mean performance (+22.4).

In this initial exploration of incorporating the SWH into our introductory college chemistry laboratory course, we have found that the SWH does promote student engagement with their laboratory work and student development of their conceptual understanding through writing and discussion. We have also found preliminary evidence that replacing the traditional format with the SWH has the potential for significant improvement in preparing students to solve transfer problems. Currently we are investigating this aspect in more detail as well as how to modify laboratory activities to complement the pedagogical goals of the SWH.

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CHAPTER 3

USING THE SCIENCE WRITING HEURISTIC TO MOVE TOWARD AN INQUIRY-BASED LABORATORY CURRICULUM: AN EXAMPLE FROM PHYSICAL EQUILIBRIUM

A paper in press in the *Journal of Chemical Education*

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Abstract

Despite the importance placed on laboratory work in the undergraduate chemistry curriculum, there have been few research studies that have shown that chemistry laboratory experiments are an effective vehicle for promoting student understanding of chemistry. Laboratory activities that are inquiry-based have been reported as a potential method for improving the pedagogical value of laboratory work. This study compared the performance of general chemistry laboratory students who used the standard laboratory report format to students who used the Science Writing Heuristic (SWH) format on a lecture examination problem and on a laboratory practical examination task involving physical equilibrium. The standard laboratory reports had Title, Purpose, Procedure, Data & Observations, Calculations & Graphs, and Discussion sections. The Science Writing Heuristic reports had Beginning Questions & Ideas, Tests & Procedures, Observations, Claims, Evidence, and Reflection sections. Students in the SWH sections exhibited a better understanding of equilibrium when written explanations and equations were analyzed, performed slightly better on the equilibrium practical exam task, and spent less time completing the SWH laboratory reports than students in the standard sections. SWH instructors spent less time scoring reports of their students. The

SWH was shown to be a feasible mechanism for gradually modifying the laboratory curriculum to reflect inquiry-based learning.

Keywords: chemical education research – student centered learning, writing in chemistry, equilibrium, inquiry, and general chemistry

Introduction

Background

In an effort toward achieving the national goal of a population that is scientifically literate, the National Research Council (NRC) outlined specific goals and recommended numerous changes in educational practice to meet those goals in the *National Science Education Standards* (*1*). The recommendations clearly emphasize the view that "learning science is an inquiry-based process," and they specifically highlight in the teaching, professional development, and content standards the need for inquiry to be reflected in science teaching practice. The recommendations call for less emphasis on passive presentation and acquisition of information and more emphasis on active construction and communication of knowledge. In describing learning science as a process in which students construct explanations by establishing connections between their current knowledge and new information, the recommended shift toward inquiry is supported by constructivist theories of learning (*2-4*).

The NRC's recommendations also state that "hands-on" activities are not sufficient and call for more emphasis on "minds-on", inquiry-oriented investigations and less emphasis on "activities that demonstrate and verify science." The weaknesses of verification laboratory activities and the strengths of inquiry activities have been reported on repeated occasions (*5-14*). However, the lack of convincing studies regarding the effectiveness of inquiry laboratories (*5*) and laboratory work in general (*15*) very likely has impeded efforts to move toward the recommended changes, especially when the contemplated move would require a heavy initial investment in time through in-house curriculum and training revision and/or in money through purchasing commercially available laboratory manuals and supplemental materials.

An alternative to costly and large-scale changes with less than certain outcomes would be to make changes in small increments, such as a gradual restructuring of verification laboratory activities into inquiry-oriented investigations (*16*). We chose as our strategy for incremental change the gradual incorporation of the Science Writing Heuristic (SWH) (*17-18*) into our general chemistry laboratory curriculum. In addition to observing the qualitative impact of incorporating the SWH strategy, part of our strategy included undertaking some comparative evaluation to monitor and measure the effectiveness of using the SWH as we move toward inquiry-based laboratories.

Students often have difficulty relating their laboratory work to science concepts (*13*), and the SWH was specifically designed to facilitate the learning of science from laboratory activities through writing for construction of meaning (*17*). The SWH consists of a template to assist instructors in designing inquiry activities and a template to assist students in their thinking and writing in relation to these activities (Box 1).

Box 1. The Science Writing Heuristic (SWH) templates

Instructor template	Student template
1. Exploration of pre-instructional understanding	A. Beginning Questions or Ideas
2. Pre-laboratory activities	B. Tests and Procedures
3. Laboratory activity	C. Observations
4. Negotiation - individual writing	D. Claims
5. Negotiation - group discussion	E. Evidence
6. Negotiation - textbooks and other resources	F. Reading
7. Negotiation - individual writing	G. Reflection
8. Exploration of post-instructional understanding	

We believe that the standard laboratory report format (Box 2) currently in place in our curriculum does not particularly promote, and may actually discourage (*13*), both the development of connections among elements of a laboratory experiment and the development of meaning regarding chemistry concepts.

Box 2. Comparison of SWH student template with standard report format

Modified SWH student template			Standard report format*
I.	Beginning Questions or Ideas	similar to	Title, Purpose
II.	Tests and Procedures	similar to	Outline of procedure
III.	Observations	same as	Data and Observations
IV.	Claims	similar to	Discussion
V.	Evidence	similar to	Balanced Equations, Calculations, Graphs
VI.	Reflection		(no equivalent)

*Note that in the actual student laboratory reports the Balanced Equations, Calculations, and Graphs are completed and appear before the Discussion.

When comparing a modified version of the SWH student template with the standard report format (Box 2), the differences may appear subtle to someone who already possesses a strong understanding of the topic(s) under investigation during the laboratory activity. However to someone who is still forming basic understandings during the activity, the two approaches are different. Many of our students complete the standard report format by attempting to "fill in" isolated pieces of information, e.g., a stand-alone Balanced Equation or set of Calculations, and they spend limited effort toward making connections and drawing meaningful inferences. Their general lack of understanding of their laboratory work is evidenced by the poor quality of their discussions in their laboratory reports and by their poor performance on practical exams. In contrast, the SWH helped secondary school students connect the elements of questions, procedures, data, evidence, and knowledge claims from an investigative science activity and helped them develop meaning from that activity (*17*). Therefore, we wondered if the modified version of the SWH student template could be used as the laboratory report format to help undergraduate chemistry students make connections, draw inferences, and generate meaning from their laboratory work.

Pilot study

A quasi-experimental pilot study was conducted in which we simply replaced our standard laboratory report format with a modified version of the SWH student template (*19*). This incremental change also alleviated the necessity of up-front revisions of the laboratory experiments themselves. One laboratory section of students using the SWH as the report format was compared to two sections of students using the standard format, and the results were positive attitudinal changes and increased understandings about chemistry for SWH students. Specifically, for students using the SWH we observed a higher level of engagement with laboratory work, more sophisticated thinking as demonstrated in class and in the written reports, a greater amount of chemistry discussed in their reports, and the potential for considerable improvement in performance on the practical exams. These results indicated that an additional study was warranted.

Scope and intent of this study

Strong student understanding of physical and chemical equilibrium is crucial because the concept of equilibrium is an integral aspect of acid-base (*20, 21*), solubility (*22*), and redox processes (*23*). However, equilibrium is an area of general chemistry in which students experience great difficulty in understanding, and many student misconceptions have been identified (*20-30*), including an inability in distinguishing between physical and chemical processes (*25, 27*). Introducing the concept of equilibrium by starting with physical equilibrium is logical because removing the distractions of chemical changes and reaction stoichiometry can emphasize the equilibrium process. Indeed, many textbooks and teaching strategies introduce equilibrium with non-chemistry analogies (*31-34*).

We decided to look specifically at distribution equilibrium because this aspect of physical equilibrium is generally not discussed in textbooks, discussed in lecture, or covered by typical homework problems. Our purpose was to see the potential effect of laboratory work on student understanding of this type of physical equilibrium before we addressed equilibrium topics, such as acid-base and solubility processes, that receive more coverage in textbooks and lecture. Our research goals were (1) to determine if changing the report format would produce a measurable improvement in student understanding regarding physical equilibrium and (2) to investigate what metacognitive and practical factors might be causing potential improvements in understanding.

Design

Description and assignment of classes and instructors

This quasi-experimental study used five laboratory sections of 80 students co-enrolled in the second-semester general chemistry courses (lecture and laboratory) for science and engineering majors in the spring semester at a large midwestern state university. Two teaching assistants (TA) were assigned to these five sections. The first TA (TA1) was responsible for one section in which students wrote the weekly laboratory report using the standard report format and two sections in which students wrote the report using a modified version of the SWH student template (Box 2). The second TA (TA2) was responsible for one standard section and one SWH section. This design yielded four groups for the study based on the factors of assigned TA and assigned laboratory report format (Table 1).

Table 1. Description of the four groups involved in the study

Group	n	TA	Format	Mean composite scores (sd)	Mean diagnostic scores (sd)
1	17	1	standard	77.1 (6.2)	25.2 (5.7)
2	30	1	SWH	76.7 (8.0)	25.8(5.0)
3	17	2	standard	79.1 (8.0)	27.9(6.7)
4	16	2	SWH	82.2 (6.2)	26.1(5.6)
				ANOVA results	ANOVA results
				F(3,76) = 1.838	F(3,76) = 0.591
				p = 0.149*	p = 0.623*

*p < 0.05 was considered statistically significant

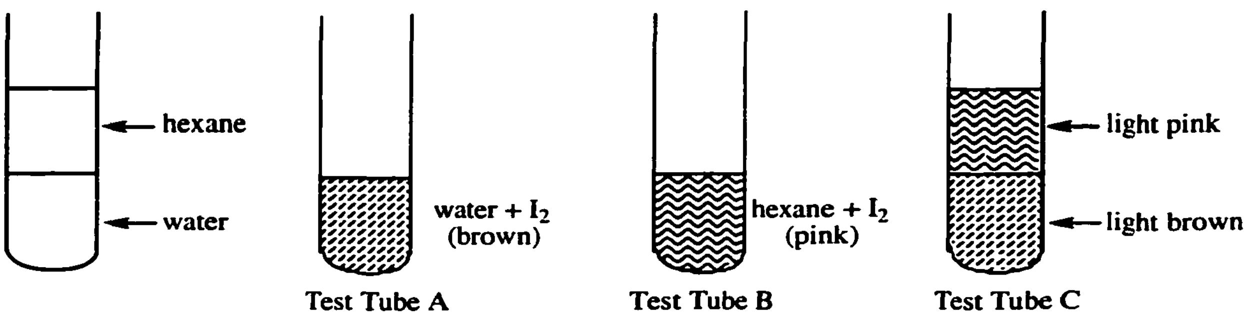
The 80 students involved in the study were similar in that (1) they had all passed the pre-requisite first-semester general chemistry courses in the fall semester prior to the study, (2) one professor taught the first-semester lecture course, and (3) during the study one professor taught the second-semester lecture course. The equivalency in baseline chemistry ability of the four groups was assessed to examine sample homogeneity by completing an ANOVA test on the mean composite scores in the pre-requisite general chemistry course and an ANOVA test on the mean scores on the ACS California Chemistry Diagnostic Exam (*35*) (Table 1). No statistical differences between groups were found on mean composite scores ($F(3,76) = 1.838$; $p = 0.149$) or on mean diagnostic scores ($F(3,76) = 0.591$; $p = 0.623$).

TA1 was an experienced TA and had previous experience with the SWH in the pilot study (*19*) whereas TA2 had been a TA for only one semester and had no experience with the SWH. Both TA's had a strong commitment to teaching and attempted to teach every laboratory section to the best of their ability. For practical reasons and in an attempt to maintain some instructional homogeneity, TA1 trained TA2 in the use of the SWH in a one-hour meeting. A follow-up 30-minute meeting was held after TA2 had additional questions after the first meeting. TA2 observed TA1 during the first laboratory session during the time when the SWH was introduced to the students. The TA's also met twice every week for about 15 minutes per meeting to discuss what was happening in both the standard and the SWH classes and to offer practical suggestions to each other. Additional information regarding implementation is provided in the supplemental material.

Assessments

To assess whether changing the report format produced a measurable improvement in student understanding of physical equilibrium in the lecture setting, student responses to a physical equilibrium problem (Box 3) on the first hour exam in the lecture course were analyzed using a multi-level scoring rubric (Box 4).

Box 3. Physical equilibrium problem on the hour lecture exam



Water and hexane are colorless liquids. Hexane, C_6H_{14}, does not dissolve in water.

A small amount of iodine, I_2, is dissolved in water creating a dilute aqueous solution of I_2 that has a brown color. This is test tube A.

A small amount of iodine, I_2, is dissolved in hexane, C_6H_{14}, creating a dilute hexane solution of I_2 that has a pink color. This is test tube B.

Pure hexane is added to the solution in test tube A and the contents are shaken vigorously. After a short time, a two-layer system is observed. The bottom layer has a light brown color, and the top layer has a light pink color. This is test tube C.

Briefly describe and explain what has happened when the pure hexane is added to the aqueous solution of I_2, shaken and allowed to stand for a few minutes. Include in your written explanation an appropriate equation.

Box 4. Scoring rubric used to categorize student responses on the lecture exam problem

A. Score and categories for written explanations with sample responses

5 Description of equilibrium process, including idea of equally opposing rates

"Because I_2 is soluble in both water and hexane, the I_2 is in equilibrium between the water and the hexane in test tube C. The net transfer of I_2 into and out of each of the layers is the same."

4 Use of equilibrium term, including idea of iodine partition

"The hexane and water do not mix, but the iodine does mix with each. Some of the iodine crosses the stratafication [sic] line into the hexane and eventually sets up an equilibrium."

3 Description of iodine solubility in both solvents, no use of equilibrium term

"The hexane is drawing out the I_2 from the water."

2 Focus on immiscibility of solvents

"The solution rises to the top and separates from the water. It is still soluble in the water."

1 Less acceptable or no answer

B. Score and categories for chemical equations with sample responses

5 Conventional symbolic notation for equilibrium process

"$I_2(aq) \rightleftharpoons I_2(hexane)$."

4 Unconventional symbolic notation for equilibrium process

"$H_2O(l) + I_2(aq) \rightleftharpoons C_6H_{14}(l) + I_2(aq)$."

3 Reaction equation: solvents as the reactants, and "equilibrium" as the product

"$H_2O + 2I_2 + C_6H_{14} \rightarrow (H_2O + I_2) + (C_6H_{14} + I_2)$."

2 Reaction of iodine with solvent

"$C_6H_{14} + I_2 \rightarrow C_6H_{14}I_2$."

1 Less acceptable or no answer

A chemistry professor from a four-year, private university who was not involved with the design of the study devised this rubric and categorized the student responses without knowledge of whether the response was written by a standard or SWH student. Responses were categorized into five levels of written explanation (Box 4A) and five levels of equation usage (Box 4B). The term "written" in this paper referred only to the use of words to describe the equilibrium to distinguish such work from a written chemical equation, which was considered a use of symbolic notation. A second rater also categorized the responses using the same rubric and without knowledge of whether the response was produced by a standard or SWH student. As a measure of inter-rater reliability, a Pearson's correlation coefficient was calculated between the two sets of ratings for written explanation and for equation usage. The coefficients were 0.88 for written explanation and 0.94 for equation usage, which indicated strong agreement between the two raters.

To assess for improvement in student understanding of physical equilibrium in the laboratory setting, each student's work on a physical equilibrium task (Box 5) on the first laboratory practical exam was analyzed using a scoring rubric that was devised again by the chemistry professor from the private university.

The student work was analyzed by a second rater using the same rubric and without knowledge of whether the work was produced by a standard or SWH student. As a measure of inter-rater reliability, a Pearson's correlation coefficient between the two sets of ratings was calculated and found to be 0.94, indicating strong agreement between raters. Finally, to investigate what factors might be influencing improvements in understanding of chemistry, a survey was given at the end of the semester to the SWH students.

Box 5. Physical equilibrium task on the laboratory practical exam

Imagine performing these two experiments. (I) You extract 2 mL of aqueous butyric acid with 2 mL of toluene. You completely separate the aqueous phase from the toluene phase. You then add 2 mL of toluene to the aqueous phase and extract the butyric acid from the aqueous phase a second time and separate the two phases. (II) You extract 2 mL of aqueous butyric acid with 4 mL of toluene. You completely separate the aqueous phase from the toluene phase.

a. PREDICT how the concentration of butyric acid (as determined by the number of drops of NaOH required to neutralize the acid) remaining in the aqueous phase will differ in these two experiments.

b. Explanation.

____________OBTAIN YOUR TA'S INITIALS BEFORE PROCEEDING TO PARTS C-F
TA initials

c. Perform any experiments to test your predictions. Experimental results:

d. Calculation of K_{eq}

e. Write the equilibrium equation for the system.

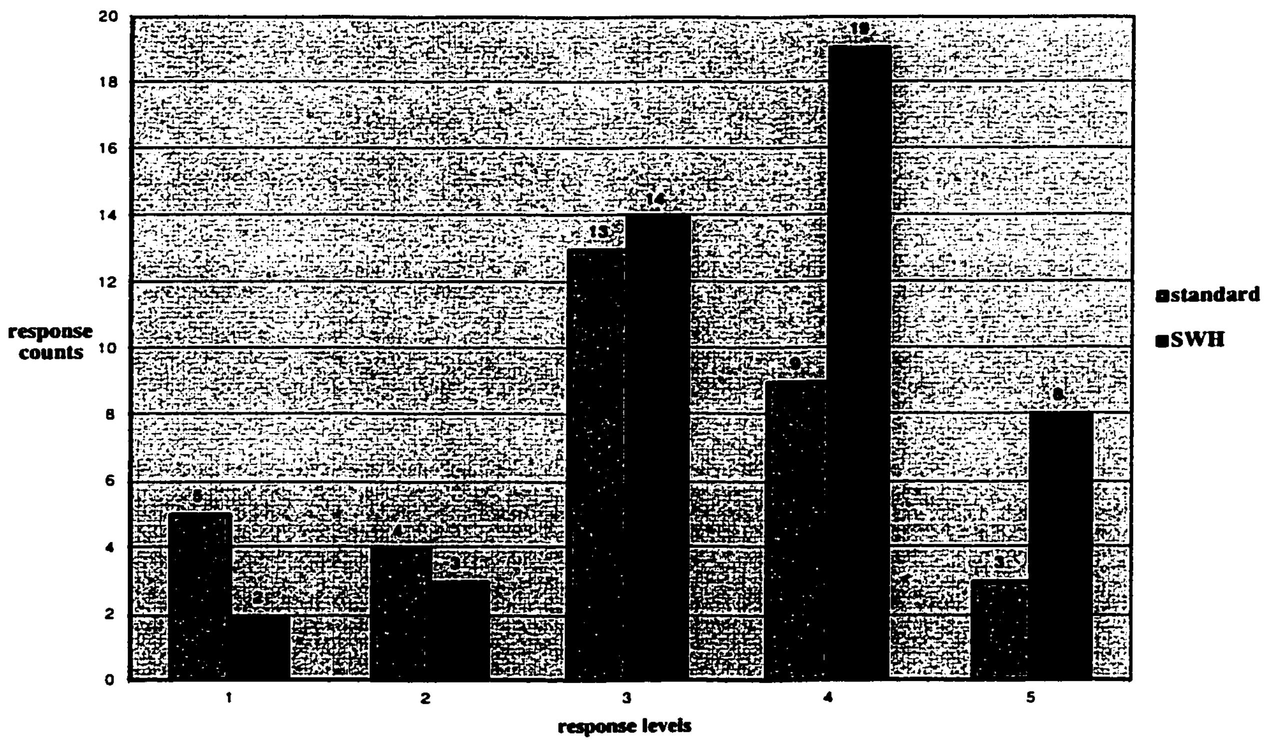
f. Is this a physical or chemical equilibrium?

Results and Discussion

Lecture exam problem on physical equilibrium

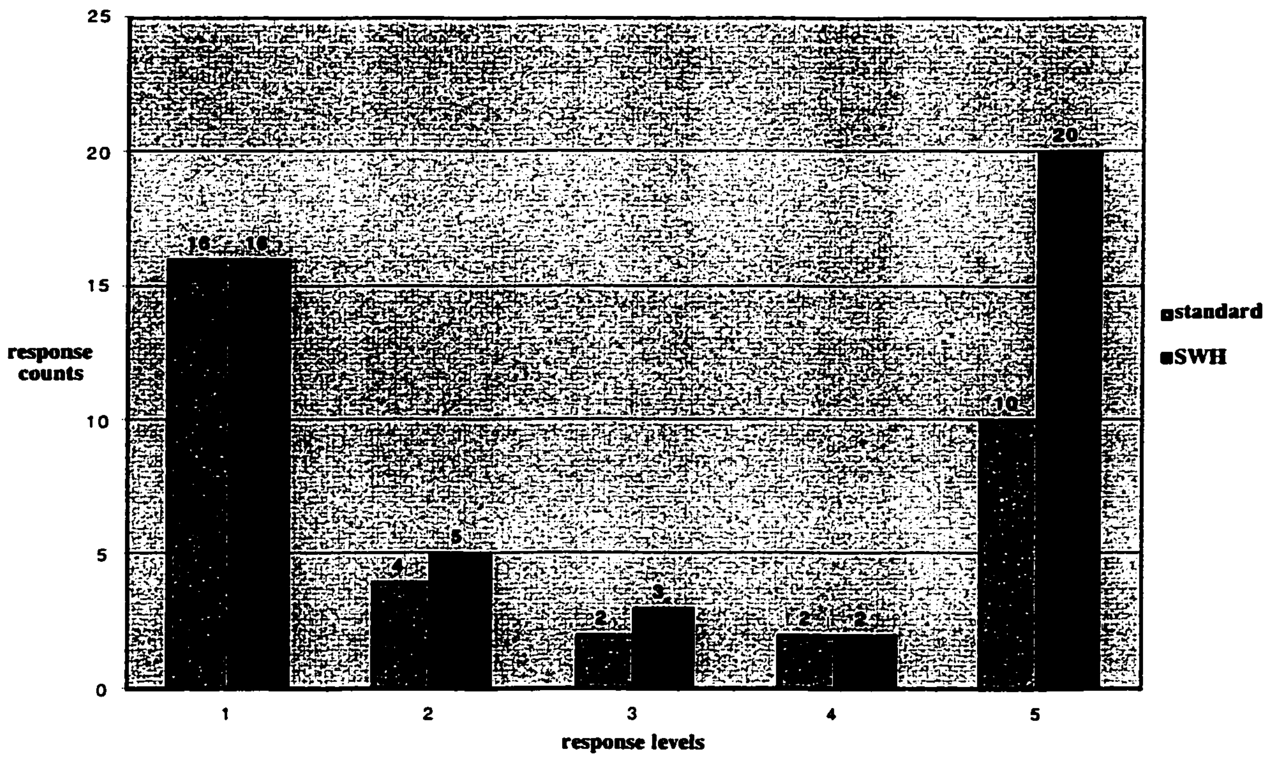
Both distributions of written responses were skewed (Figure 1). The median response for students using the standard format was a level 3 response whereas the median response for students using the SWH format was a level 4 response. An example level 3 student response was "The hexane is drawing out the I_2 from the water." An example level 4 student response was "The hexane and water do not mix, but the iodine does mix with each. Some of the iodine crosses the stratafication [sic] line into the hexane and eventually sets up an equilibrium." The shift in median response indicated that students using the SWH format more successfully explained in words the physical equilibrium than students using the standard format.

Figure 1. Distributions of written responses on the lecture exam problem



Both distributions of equation responses were bimodal (Figure 2). The most common responses were complete success (level 5) and complete failure (level 1) for all students. An example level 5 student response was "$I_2(aq) \rightleftharpoons I_2(hexane)$." Although all students generally either fully succeeded in producing an equation to represent the equilibrium or did not succeed at all, the ratio of complete success to complete failure was notably higher for students using the SWH format (1.25) than for students using the standard format (0.625).

Figure 2. Distributions of equation responses on the lecture exam problem



To statistically test for the effects of assigned format and assigned TA on the quality of written and equation responses, chi-square tests were completed using 2x2 contingency tables (Tables 2 and 3). Success was deemed to be a level 4 or higher response so failure was a level 3 or lower response. Level 4 and higher responses were considered successes because these responses specifically addressed equilibrium (Box 4).

Table 2. Counts and chi-square tests for treatment effects on written responses

A. Main effect of format on written responses

	Standard	SWH	
Success count (4-5)	12	27	
Failure count (1-3)	22	19	$\chi^2 = 4.29$
Total count	34	46	p = 0.038*

B. Main effect of TA on written responses

	TA1	TA2	
Success count (4-5)	23	16	
Failure count (1-3)	24	17	$\chi^2 = 0.00$
Total count	47	33	p = 0.968*

C. Simple effect of TA under standard format on written responses

	TA1	TA2	
Success count (4-5)	5	7	
Failure count (1-3)	12	10	$\chi^2 = 0.515$
Total count	17	17	p = 0.473*

D. Simple effect of TA under SWH format on written responses

	TA1	TA2	
Success count (4-5)	18	9	
Failure count (1-3)	12	7	$\chi^2 = 0.061$
Total count	30	16	p = 0.806*

*$p < 0.05$ was considered statistically significant

Table 3. Counts and chi-square tests for treatment effects on equation responses

A. Main effect of format on equation responses

	Standard	SWH	
Success count (4-5)	12	22	
Failure count (1-3)	22	24	$\chi^2 = 1.26$
Total count	34	46	p = 0.262*

B. Main effect of TA on equation responses

	TA1	TA2	
Success count (4-5)	19	15	
Failure count (1-3)	28	18	$\chi^2 = 0.201$
Total count	47	33	p = 0.654*

C. Simple effect of TA under standard format on equation responses

	TA1	TA2	
Success count (4-5)	5	7	
Failure count (1-3)	12	10	$\chi^2 = 0.515$
Total count	17	17	p = 0.473*

D. Simple effect of TA under SWH format on equation responses

	TA1	TA2	
Success count (4-5)	14	8	
Failure count (1-3)	16	8	$\chi^2 = 0.046$
Total count	30	16	p = 0.829*

*p < 0.05 was considered statistically significant

For written responses, the main effect of format (Table 2A) was statistically significant ($\chi^2 = 4.29$, p = 0.038) which meant that the type of format was related to student performance on written responses. As discussed in the descriptive results, the SWH format was associated with the shift in the median response from level 3 to level 4. The main effect of TA (Table 2B) was not statistically significant ($\chi^2 = 0.00$, p = 0.968) which meant that student performance was not related to which TA they were assigned. To check more closely this result, the simple effect of TA under each format condition was tested (Table 2C and 2D), and neither simple effect was statistically significant ($\chi^2 = 0.515$, p = 0.473 under standard format; $\chi^2 = 0.061$, p = 0.806 under SWH format). These tests further confirmed that the net effect of TA on student performance was statistically equivalent (which is not the same as each TA instructing in an identical manner).

For equation responses, neither main effect (Table 3A and 3B) was statistically significant ($\chi^2 = 1.26$, $p = 0.262$ for format, and $\chi^2 = 0.201$, $p = 0.654$ for TA). Again, the simple effect of TA under each format condition was tested (Table 3C and 3D), and neither simple effect was statistically significant ($\chi^2 = 0.515$, $p = 0.473$ under standard format; and $\chi^2 = 0.046$, $p = 0.829$ under SWH format). Neither the type of format nor the TA was statistically associated with student performance on the equation responses. However as discussed in the descriptive results, the ratio of complete success to complete failure was 0.625 for standard students and 1.25 for SWH students.

As compared to standard students, SWH students demonstrated a greater understanding of physical equilibrium by their better performance on the physical equilibrium problem on the lecture exam. This finding was evidence that the SWH format promoted the development of conceptual understanding from laboratory work to a greater extent than the standard format. A potential reason for the lack of a statistically significant result for the improvement in equation usage was that the assessment of equation usage was possibly more of a measure of skill in the conventions of symbolic representation and less of a measure of conceptual understanding. The SWH format does not explicitly address the conventions for symbolic representation within specific scientific disciplines so there would be no reason to expect any improvement in equation usage for SWH students.

Laboratory practical exam task on physical equilibrium

The results from the physical equilibrium task on the laboratory practical exam indicated a slight improvement for students using the SWH (Table 4). To statistically test for the effects of assigned format and assigned TA on student performance on the physical equilibrium task on the laboratory practical exam, a 2-factor ANCOVA test was completed using the composite score in the pre-requisite general chemistry course as the covariate. No statistical differences between groups were found (Table 4).

Table 4. Scores and ANCOVA results for treatment effect on laboratory exam task

Group	n	TA	Format	Mean scores (sd)	ANCOVA results		
1	16	1	standard	8.4 (2.0)	Effect	F (1,68)	p*
2	27	1	SWH	8.6 (2.0)	Format x TA	0.144	0.706
3	15	2	standard	8.7 (2.5)	Format	0.031	0.860
4	15	2	SWH	9.0 (2.5)	TA	0.072	0.789

*p < 0.05 was considered statistically significant

There was no interaction effect between type of format and assigned TA ($F(1,68) = 0.144$; $p = 0.706$) which meant that the effect on student performance of type of format was not related to the identity of the TA. There was no main effect of type of format ($F(1,68) = 0.031$; $p = 0.860$) or main effect of assigned TA ($F(1,68) = 0.072$; $p = 0.789$). In other words, neither factor was statistically related to student performance on the exam task despite the slight improvement in scores for SWH students.

A possible reason for the lack of a statistically significant result was that the structure of the assessment may not have placed sufficient emphasis on conceptual understanding which the SWH format was intended to develop. The completion of observations, the completion of a calculation and a chemical equation that were identical to the calculation and equation in the related laboratory activity, and the selection of whether the equilibrium was physical or chemical may have provided a limited opportunity for students to demonstrate their understanding of physical equilibrium. Therefore, the potential evidence for the greater effectiveness of the SWH format compared to the standard format in developing conceptual understanding was limited.

Survey results

The SWH students completed a survey at the end of the course in which they were asked to compare the SWH format to the standard format used in the pre-requisite course (Table 5).

Table 5. Survey results

A. Time spent completing reports using the SWH format as compared to the standard format

Less	same	more	n responding
23	13	5	41

B. Which format required an inappropriate amount of time

SWH	standard	both	neither	n responding
1	19	8	12	40

C. Which format was a better use of time

SWH	standard	n responding
40	3	43

D. Which format was preferred

SWH	standard	n responding
39	3	42

E. Why was the SWH format preferred

Learned more	Less busy work	More thinking	More self-direction	Less time	n responding
19	17	11	6	6	39

In response to "How much time did you spend on the SWH format as compared to the standard format?", 23 reported less time, 13 reported the same amount of time, and 5 reported more time when using the SWH. Thus 36 out of 41 SWH students spent equal or less time completing SWH reports than standard reports so any effects of using the SWH format were not due to more time spent completing the laboratory reports.

In response to "Was the time needed to complete the laboratory reports too much with the SWH format, the standard format, both formats, or neither format?", 1 said SWH, 19 said standard, 8 said both, and 12 said neither. In response to "Which format do you think was a better use of your time?", 40 said SWH and 3 said standard. Therefore, the general student perception was that using the SWH format in comparison to the standard format required equal or less time, required a more appropriate amount of time, and was a more efficient use of their time.

In response to the question "Which format do you prefer and why?", 39 out of 42 responses were "SWH." Within the 39 SWH responses, 19 indicated they learned more, 17 indicated there was less busy work, 11 indicated they did more thinking, 6 indicated there was the opportunity for more self-direction in their learning, and 5 indicated the reports took less time. Thus, only 5 of the 39 identified that less time was the reason they preferred the SWH. More importantly, nearly half of the students indicated that they believed they learned more and engaged in more thinking when using the SWH format. Also of these 39, 5 said they would have preferred more direction in use of the format.

Time spent by instructors

Finally, both TA's found that at the start of the semester the time required to score the SWH reports was greater than the time to score the standard reports. However, later in the semester TA1 found that the SWH reports took either the same amount or less time while TA2 found the SWH reports took significantly less time. Just as first-time TA's likely spend more time scoring reports at the start of the semester than at the end, some experience was needed to become accustomed to scoring the SWH reports. The end result was that eventually both students and instructors spent less time on the SWH reports than on the standard reports.

Conclusions and Implications

In this study, the incremental change of using the SWH as the laboratory report format in place of the standard format was considered a practical and successful first step in shifting our curriculum to inquiry-based laboratory work. For students using the SWH, the written explanation of a physical equilibrium was measurably better according to descriptive and statistical results, and the use of symbolic notation was measurably better according to descriptive results. Student performance on the physical equilibrium task was slightly better for students using the SWH according to descriptive results. Significantly, the simple implementation of the SWH student template (without additional changes to our laboratory curriculum) reduced time on task for students and instructors, and at the same time, SWH students exhibited better performance and attitudes.

In comparing the SWH with the standard report format, students indicated that they engaged in more thinking about their laboratory work and learned more from their laboratory work, which are goals the SWH was specifically designed to promote (*17*). The outcomes of this study augment the evidence from previous studies (*17, 31*) that the SWH does facilitate student effort toward connecting laboratory work to understandings about science. Therefore, the introduction of the SWH student template as a laboratory report format may be considered a useful and accessible method of incremental change for shifting toward an inquiry-based laboratory curriculum.

It is also important to note that distribution equilibrium did not receive much coverage in lecture. Only a single demonstration of a physical equilibrium system that was different from the laboratory activity was shown in lecture. Although the textbook for the lecture course did address physical equilibrium systems, only a few examples involving vapor pressure, boiling, and melting were presented. A substance in a mass-transport equilibrium between an organic solvent and an aqueous phase was not discussed. Therefore, this study provides some evidence that students can gain a better understanding of chemistry concepts from laboratory work if the laboratory activities are structured appropriately. The next change in our laboratory curriculum will be to revise the procedures for one or more laboratory activities to strengthen the opportunities for student inquiry in their laboratory work. Future research will assess the outcomes of these changes and will address major equilibrium topics.

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Supplemental Material

Description and example of implementation of the Science Writing Heuristic

The Science Writing Heuristic templates

The Science Writing Heuristic (SWH) consists of two templates, an instructor template to aid in the design of inquiry-based laboratory activities and a student template to provide a framework for student thinking about laboratory activities (*17, 18*) (Box 1). In this study, a modified version of the student template was used as the laboratory report format (Box 2), and there was no implementation of the instructor template. The student template was intended to show students a way to become more mentally engaged with the chemistry concepts related to the laboratory activity. To someone who is already at an expert level of understanding of the relevant concepts, the difference between using the SWH format and the standard report format may be minor, but to someone at a novice level of understanding, the SWH appears to promote stronger connections between actions, observations, and understandings in the laboratory.

Each step in the template explicitly directs students to consider the meaning of their actions and observations (see below for example activity and sample student report). The first step is the Beginning Questions or Ideas, and students are instructed to complete this step by thinking of it as "What do I want to know or already know?" Students are also instructed to prepare their questions or ideas before class by reading through the background and procedures provided in the laboratory manual. The next step is the Tests and Procedures, and students complete this step in terms of "What did I do to answer my questions or prove my idea?" Most often students simply reference the procedures provided in the laboratory manual. The Observations step is completed next by having students address the question "What did I observe from each test and procedure?" The Claims step is completed by addressing the question "What are the answers to my questions or the ideas that I claim?" The Evidence step is completed by interpreting the observations to justify each claim, i.e., "What evidence do I have that supports my claim?" The Reflection step is meant to solidify student understanding by instructing students to address the question "What have I learned from this activity?"

Example activity

The laboratory activity on physical equilibrium involved the calculation of the partition coefficients for the distribution of three organic acids between water and toluene. Aqueous solutions of acetic, butyric, and caproic (hexanoic) acids were shaken with pure toluene to set up the mass-transport equilibrium, and then the immiscible solvent layers were separated. The separated layers were titrated with a strong base solution to determine the concentrations of acid in each solvent, and then the partition coefficients were calculated. For acetic acid, the process was repeated but starting with a toluene solution of the acid that was then shaken with water.

Sample student report from the example activity

<u>Questions</u>

1. What is the equilibrium constant for the distribution of each acid between toluene and the aqueous layer?

2. Does it make a difference whether the acid was initially dissolved in the polar solvent or the non-polar solvent?

3. What happens to the equilibrium constant for the distribution of the acid between toluene and the aqueous layer as the non-polar portion of the molecule gets larger?

<u>Tests and Procedures</u>

(see lab manual for more detailed procedures)

[student outlined major steps]

Observations

[student recorded data and observations and made some preliminary calculations for each acid]

Claims

1. $K = [\text{organic acid}]_{toluene}/[\text{organic acid}]_{aqueous}$

$K_{acetic\ acid\ 1} = 0.017$, $K_{butyric\ acid} = 0.26$, $K_{caproic\ acid} = 5$, $K_{acetic\ acid\ 2} = 0.055$

2. It does not make a difference whether the acid was initially dissolved in the polar solvent or the non-polar solvent.

3. As the non-polar portion of the acidic molecule increases, the equilibrium constant K also increases.

Evidence

1. Upon separation of the aqueous and toluene layers, each layer was titrated. The equilibrium constants were calculated based on the ratio of (drops base used to titrate toluene layer) to (drops base used to titrate aqueous layer). The equation for the equilibrium constant was $K = [\text{organic acid}]_{toluene}/[\text{organic acid}]_{aqueous}$. The equation above was used based on the reactions that took place, for example, $CH_3COOH(aq) \rightleftharpoons CH_3COOH(toluene)$.

2. In the experiment where toluene was added to acetic acid, the equilibrium constant was 0.017. In the experiment where acetic acid was added to toluene and then mixed with water, the equilibrium constant was 0.055. The very small difference in the eq. constants (which was probably caused by small errors) was insignificant, which proved that it did not matter whether the acid was initially dissolved in the polar solvent or non-polar solvent.

3. Acetic acid had the smallest non-polar portion, followed by butyric and finally caproic acid. The equilibrium constants increased in the same order. Substances with similar intermolecular attractive forces tend to be soluble in one another ("like dissolves like"). Since water is extremely polar, it tends to dissolve polar molecules better than non-polar molecules. Or, in this case, the least non-polar (acetic acid) dissolved the easiest, which accounted for the lowest K value.

Reflection

The size of the equilibrium constant is affected by the solute-solvent interactions. The more non-polar the acid, the higher the K value. In this experiment, it was the acid that was in equilibrium. Acid molecules in the toluene layer were in equilibrium with acid molecules in the aqueous layer.

Training in the use of the SWH

The teaching assistants were trained in the use of the SWH by having the TA's read one of the reference articles (*18*) and by discussing the information presented in the article (in the same fashion as the discussion earlier in the Supplementary Material, but without a sample student report). Students were trained in the use of the SWH by having the same discussion at the beginning of the first class session and then by having them work through a practice activity. The implementation of the practice activity was presented in another article (*19*).

Scoring of the reports

Each report was worth 15 points: Questions (2), Tests and Procedures (1), Observations (2), Claims (3), Evidence (4), Reflection (3). Each TA scored the reports for their own sections which was standard procedure in the course. Additional examples of SWH implementation were presented in another article (*19*).

CHAPTER 4

USING THE SCIENCE WRITING HEURISTIC TO IMPROVE STUDENT UNDERSTANDING OF GENERAL EQUILIBRIUM

A paper submitted to the *Journal of Chemical Education*

James A. Rudd, II; Thomas J. Greenbowe; and Brian Hand

Abstract

As the next stage in the gradual incorporation of the Science Writing Heuristic (SWH) into a general chemistry laboratory curriculum, the activities covering the general equilibrium concept were restructured to enhance opportunities for student inquiry. This study compared the performance of students using the SWH approach and students using the standard laboratory curriculum on lecture exams and a laboratory exam. SWH students exhibited a better understanding of chemical equilibrium as shown by statistically greater success in overcoming the common confusion of interpreting equilibrium as equal concentrations and by statistically better performance when explaining aspects of chemical equilibrium. SWH students spent less time completing laboratory reports, and instructors spent less time scoring their reports. Written explanations were found to be a useful assessment tool, and laboratory instruction was shown to develop student understanding of general equilibrium. The SWH was considered to be an accessible inquiry-based approach for use with laboratory instruction.

Keywords: Chemical Education Research, CER Student-Centered Learning, Writing in Chemistry, Equilibrium, Inquiry-Based, and General Chemistry.

Introduction

Background

As part of ongoing curriculum development, we have been conducting field research to study the feasibility and potential benefits of a gradual revision of our general chemistry laboratory curriculum (*1, 2*). The need to improve laboratory instruction has been identified by some reviews of research on laboratory instruction (*3-5*) which have indicated the benefits of such instruction are not clearly evident. In addition, the National Research Council has recommended that laboratory instruction employ an approach that incorporates more student inquiry (*6*).

We have been studying the feasibility of incorporating the Science Writing Heuristic inquiry-based approach to laboratory activities into our curriculum because recent studies have shown the potential for student learning using this inquiry approach (*7, 8*), including a study we completed as part of an initial assessment of the suitability of the approach at our institution (*1*). Following the success of that study, we undertook a larger investigation (*2*) in which we examined the effect of simply replacing the student laboratory report format, which followed a standard report format that was in the style of a journal article, with a version of the Science Writing Heuristic (SWH) template for student thinking (Box 1). The results of that quasi-experimental study indicated that students using the SWH report format produced better explanations to an exam problem on physical equilibrium than students using the standard report format. In comparing the standard report format to the SWH format, students indicated a clear preference for the SWH format, and their preference was based on their belief that they were thinking and learning more when using the SWH format. In addition, students reported spending less time completing each report when using the SWH format, and instructors noted spending less time scoring each report submitted in the SWH format.

Box 1. Comparison of SWH student template with standard report format

Modified SWH student template		Standard report format*
I. Beginning Questions or Ideas	similar to	Title, Purpose
II. Tests and Procedures	similar to	Outline of procedure
III. Observations	same as	Data and Observations
IV. Claims	similar to	Discussion
V. Evidence	similar to	Balanced Equations, Calculations, Graphs
VI. Reflection		(no equivalent)

*Note that in the actual student laboratory reports the Balanced Equations, Calculations, and Graphs are completed and appear before the Discussion.

The SWH approach is consistent with constructivist theories of learning as applied to the writing process. Under a knowledge transforming model of writing (*9*), the composition process is seen as a synthesis between prior knowledge and incoming information resulting in meaning construction which leads to knowledge development (*7, 10, 11*). Writing in science is consistent with this model, especially writing related to laboratory instruction because the intention of such instruction is for students to generate new understandings by making inferences based upon their observations (*10*). The SWH was developed to promote knowledge construction from laboratory activities and in part to guide students in their writing and thinking to connect their actions and observations with their scientific understandings.

Scope and intent of this study

The assessments used in this study were student responses to test questions related to the concept of chemical equilibrium, and the decision to assess student understanding of equilibrium was based upon the importance of this concept in general chemistry (*12-16*). Chemical equilibrium has been reported to be highly linked to other topics in chemistry (*17*) and important in understanding oxidation-reduction (*18*), acid-base (*19, 20*), and solubility processes (*21*). However, addressing the equilibrium concept creates difficulty for instructors and students (*12, 17, 19, 22, 23*).

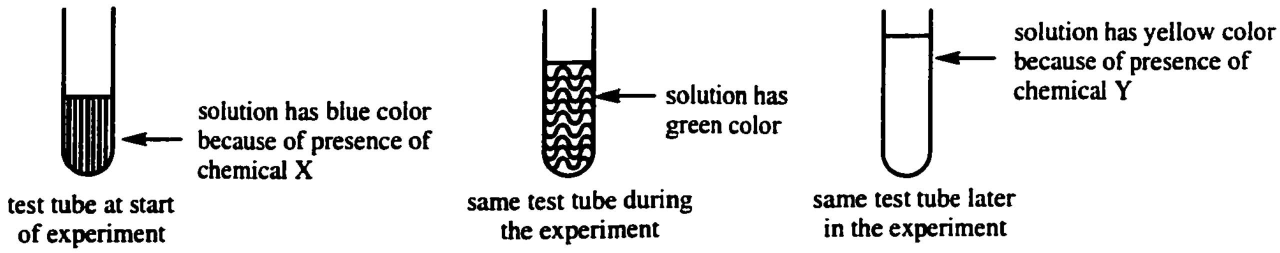
Students have difficulty with general characteristics of equilibrium, such as the dynamic (*20, 24-26*) and reversible features (*22, 25, 27, 28*), the constancy of concentrations (*28*), and even identifying an equilibrium condition (*26*). Students often believe equilibrium means equal concentrations (*12, 25, 27*), and they confuse concentrations with amounts (*22, 28*) and rate of reaction with extent of reaction (*19, 20, 27-29*). Students demonstrate a poor understanding of the constancy of an equilibrium constant (*12, 20, 22, 26, 28*) and frequently misapply Le Chatelier's principle (*17, 19, 20, 28-31*). They show confusion regarding how concentrations change (*12, 22*) and how rates change (*12*) for a system to establish equilibrium. Students exhibit difficulty when considering heterogeneous equilibria (*17, 21, 26, 30*), competing equilibria (*26, 28*), and the effect of catalysts on equilibria (*12, 26*). Student confusion in the interpretation of terms and phrases related to equilibrium (*17, 22*) contributes to their conceptual difficulties.

Further complicating the assessment of student understanding is that students often choose correct answers to test questions using scientifically unacceptable reasoning processes (*17, 22, 30, 32*). To achieve a deeper assessment of student understanding, a two-tier format for test questions could be utilized. The two-tier format consists of questions in which students select an answer from a multiple-choice set of answers and then either select a reason for their answer from a multiple-choice set of reasons (*17, 32, 33*) or explain their reasoning (*30*). We used a question format in which students were required to provide an answer and then support their answer with an explanation (Boxes 2 and 3). This format followed the two-tier answer-reason format, however students were not provided a preset list of possibilities.

In this study we began the process of structuring the laboratory activities to be more oriented toward student inquiry. The main set of research goals was to compare the performance of students using the standard laboratory format to the performance of students using the SWH laboratory format on (1) a general equilibrium problem on a lecture exam, (2) a general equilibrium task on a laboratory practical exam, (3) a subset of general equilibrium problems on an ACS exam, (4) a subset of general equilibrium problems on the final exam in the lecture course. A second set of research goals was (1) to compare the time spent by students and instructors using the different laboratory formats and (2) to examine student reaction to the SWH format. Finally, one curriculum goal was to create a new laboratory activity for introducing the equilibrium concept.

Box 2. Equilibrium problem on the first hour exam in the lecture course

The figures refer to the experiment described below.



i. An aqueous solution in a test tube has a blue color because of the presence of an unknown chemical X.

ii. Adding a small amount of chemical A causes the solution to turn yellow initially on top. After the contents of the tube are mixed more thoroughly, the solution becomes completely green and remains green indefinitely. Adding another small amount of A causes the solution to turn completely yellow after mixing and remain yellow indefinitely. The yellow color is due to the presence of an unknown chemical Y in the solution.

iii. Next, adding a small amount of chemical B to the same tube causes the yellow solution to turn blue initially on top. After the contents of the tube are mixed more thoroughly, the solution becomes completely green again and remains green indefinitely. Adding another small amount of B causes the solution to turn completely blue after mixing and remain blue indefinitely. The color is now the same blue color as at the start of this experiment, and unknown chemical X is again present in the solution.

iv. This process of changing the color of the solution to blue, green, or yellow can be repeated an infinite number of times by adding more A or more B.

a. (12 pts) Indicate the point(s) in this experiment when equilibrium is achieved. Then discuss why the point(s) demonstrate(s) equilibrium. **Include in your discussion** a description of relative concentrations, relative rates of reaction, and any appropriate reaction equation(s).

b. (4 pts) How would you describe what is happening in the solution during the time that the solution color is changing from blue to green? **Include in your answer** a description of relative concentrations and relative rates of reaction.

Box 3. Equilibrium task on the first laboratory practical exam in the laboratory course

The orange dichromate anion $Cr_2O_7^{2-}$ and the yellow chromate anion CrO_4^{2-} can achieve equilibrium in water according to the reaction

$$Cr_2O_7^{2-}(aq) + H_2O(l) \rightleftharpoons 2CrO_4^{2-}(aq) + 2H^+(aq).$$

Starting from a solution that is orange in color, what reagent(s) can be added to change the color of the solution to yellow (aside from adding more CrO_4^{2-} anion)?

Place 2 drops of the 0.2 M dichromate solution in a small test tube. Change the color of the solution in your test tube to a definite yellow color. Your TA has a reference solution that has an acceptable yellow color. The color of the final solution does not have to exactly match the reference color, but it must be reasonably close. **Use only one reagent, and use the smallest amount of that reagent as possible.** Do not add anymore reagent than is necessary to achieve the reference color. Add the reagent by drops, and keep track of the number of drops required to change the solution color to the reference color. The variance in drop sizes will not affect your results. When you are finished, show the solution to your TA for evaluation. TA initials:______________

Experimental results:

Reagent used to change the color of the solution:____________________________

Number of drops required to change the color of the solution:__________________

Explain how this reagent changed the color of the solution. Include any appropriate chemical equation(s).

Experimental design

Description and assignment of classes

The study involved 93 students enrolled in a second-semester general chemistry course (lecture and laboratory) for science and engineering majors in the spring semester at a midwestern university. The data analysis was limited to the 84 students that had passed the first-semester general chemistry course (lecture and laboratory) in the fall semester prior to the study. The first-semester course was taught by two professors, and the second-semester course was taught by another professor. The total student enrollment was 402 in the lecture course and 306 in the laboratory course. Human subjects research approval was obtained from the Institutional Review Board at the university where the study was conducted.

For the laboratory course, there were 11 teaching assistants (TAs) assigned to 19 laboratory sections. Two TAs were assigned to four laboratory sections which were directly participating in the study, and one TA was assigned to two sections which were used as an internal standard and not directly involved in the study. The two TAs involved in the study were each assigned one laboratory section in which students completed their work using the standard laboratory format for the course and one section in which students completed their work using the SWH laboratory format. All other sections in the course, including the two monitor sections, used the standard laboratory format. This assignment yielded a quasi-experimental design with four sections directly participating in the study (Table 1).

Table 1. Class assignment and pre-study mean ACS scores and mean composite scores

Section	n	TA	Format	Mean ACS score (sd)	Mean composite score (sd)
1	14	1	standard	28.3 (6.3)	79.0 (6.1)
2	15	1	SWH	25.8 (5.6)	71.9 (9.5)
3	8	2	standard	23.6 (5.3)	77.6 (6.5)
4	15	2	SWH	25.3 (7.1)	72.6 (6.7)
5*	15	3	standard	27.4 (4.8)	82.0 (8.6)
6*	17	3	standard	27.0 (7.8)	75.3 (9.4)

*No direct participation in the study

Pre-study comparison of classes

The ACS California Chemistry Diagnostic Exam (*34*) was given at the start of the fall semester as part of the first-semester course. The mean scores on this measure did not show meaningful differences between the participating sections (1-4) and the monitor sections (5 and 6) (Table 1). The composite score was the weighted average of the scores on the hour exams (3 x 100 points) and the final exam (150 points) in the first-semester course. This score served as a measure of baseline chemistry ability because it was considered to be a recent, comprehensive measure of chemistry ability. The mean composite scores for the SWH sections (2 and 4) were the lowest while the mean composite score for section 5 was the highest.

Because the composite scores for the standard and SWH sections in the study were similar regardless of TA (79.0 vs. 71.9 for TA1, and 77.6 vs. 72.6 for TA2), the data were combined to examine the general difference between sections using different laboratory formats (Table 2).

Table 2. Comparison of composite scores from the four sections participating in the study

Section	n	Format	Mean composite score (sd)
1 + 3	22	standard	78.5 (6.2)
2 + 4	30	SWH	72.3 (8.1)

Comparing the mean scores (78.5 vs. 72.3) using a two-sample t-test yielded a statistically significant result ($t = 3.160$, 2-sided $p = 0.003$, $p < 0.05$ was considered statistically significant). Typically, a five percent difference between composite scores for a course would be a half-letter grade difference when assigning course grades. Thus, the average initial chemistry ability was lower in the two SWH sections as compared to the two standard sections participating in the study.

Methods

Laboratory formats

The weekly laboratory reports were completed in the standard sections according to a format commonly used in practice (*2*) and were completed in the SWH sections according to a version of the SWH student template (Box 1). However, for this study the laboratory activities were structured differently. The laboratory manual that contained the background and procedures for each activity was identical for all students, except for the experiment that was revised as a course goal and served as an introduction to equilibrium. This activity was based upon published procedures for student activities for the qualitative study of equilibrium systems (*35, 36*). The background, reagents, and manipulations for the activity were identical for all students, however the SWH sections received a version that used different wording and language to enhance the inquiry approach.

In the SWH sections, the laboratory activities were restructured into class projects to provide time for group and class discussion to generate and share interpretations of the data in the form of initial Claims and Evidence. This was in line with one element of the SWH instructor template (*7, 8*), the negotiation phase between individuals. Students in the SWH sections were required to prepare for each activity by coming to class with a set of Beginning Questions to investigate. After the instructor introduced the activity, a set of Beginning Questions related to the activity and derived from questions produced by students in the previous study (*2*) was provided to the class. The main purpose for providing questions was to provide examples so that students would have an idea of what types of questions would be most useful to investigate in subsequent activities. Another purpose was to give students additional ideas to consider during their laboratory work, especially those students who had difficulty generating their own questions. Students were not required to use any of the provided questions, and most were able to produce their own and did not need the provided set. Students in the standard sections were required to prepare for each activity by coming to class with the title, purpose and procedures sections of the report already completed. Also, the laboratory manual provided all students in the course with discussion questions for each activity.

General equilibrium laboratory activities

The first equilibrium activity was a qualitative introduction to equilibrium using the aqueous cobalt (II) chloride system and the aqueous iron (III) monothiocyanate system. Students studied the effect of additional chloride or water on the cobalt (II) system, the effect of temperature changes on the cobalt (II) system, and the effect of additional iron (III) or thiocyanate on the iron (III) system. The second equilibrium activity was an examination of the distribution of three organic acids between water and toluene. Students determined the partition coefficients for each acid by separating the immiscible solvent layers and titrating each layer with a strong base solution.

Lecture assessments as part of field research

The study was conducted as field research, and the assessments reflect the realistic setting of the research. Two quizzes on general equilibrium were given as part of the lecture course after the material had been covered in lecture and before the related laboratory activity was undertaken. The quizzes consisted of typical end-of-chapter questions from textbooks over limited aspects of equilibrium (write an equilibrium expression, calculate a reaction quotient, predict the direction of the shift in the equilibrium, etc.). From the mean performance on the quizzes, the participating sections did not appear to be unusually different from the monitor sections (Table 3). It was noted that section 5 consistently performed at a very high level on all assessments in the courses, and this high level of performance may likely be related to high overall starting chemistry ability as demonstrated by mean performance in the first-semester course (82.0% from Table 1).

Table 3. Performance on general equilibrium lecture quizzes for all sections in the study

Section	n	TA	Format	n for quiz 1	Quiz 1 mean %(sd)	n for quiz 2	Quiz 2 mean %(sd)
1	14	1	standard	14	57.1 (44.3)	13	85.4 (18.5)
2	15	1	SWH	14	58.9 (27.0)	13	75.4 (17.1)
3	8	2	standard	8	59.4 (42.1)	7	88.6 (15.7)
4	15	2	SWH	15	70.0 (36.8)	14	69.3 (30.0)
5*	15	3	standard	13	84.6 (24.0)	15	88.0 (19.7)
6*	17	3	standard	15	60.0 (32.5)	15	84.0 (17.2)

*No direct participation in the study

Two experienced chemistry instructors cooperatively devised the scoring rubrics for student responses on the quizzes, the lecture exam problem, and the laboratory exam task. Additional information is provided in the supplemental material. The two instructors and third chemistry instructor scored the students' anonymous responses using these rubrics. For the second quiz, the lecture exam problem, and the laboratory exam task, only a random selection of half of the responses were scored by the second and third raters, and as a measure of inter-rater reliability, an intraclass correlation (*37*) was calculated for the common set of scores. The values of 0.96 for both quizzes, 0.99 for the lecture exam problem, and 0.92 for the laboratory exam task indicated strong agreement among the three raters. The high level of agreement was not unexpected for experienced chemistry instructors using a common rubric.

Post-laboratory instruction assessments used to address research questions

Student understanding of general aspects of equilibrium was examined broadly in two settings. The first hour exam in the lecture course contained a problem that described an experiment and then asked students to identify the equilibrium points in the experiment and explain aspects of the identified equilibrium points (Box 2). The problem directed students to explain the equilibrium condition in terms of rates and concentrations and what happens to rates and concentrations when re-establishing equilibrium. The problem was reviewed prior to the exam by three tenured chemistry professors who previously served as instructors for this general chemistry course sequence. Revisions to the problem were made based upon their suggestions.

The first laboratory practical exam contained a practical task involving the chromate-dichromate equilibrium in which students were required to shift the position of the equilibrium (Box 3). Students were asked to select an appropriate reagent and then explain how the reagent was able to alter the equilibrium position. The task directed students to explain how the addition of the reagent altered the equilibrium position of the system in order to probe their use of Le Chatelier's principle and their underlying understanding of the reaction equation.

Results and Discussion

Lecture exam problem on general equilibrium

The equilibrium problem on the first hour exam in lecture (Box 2) elicited a wide variety of student responses (Box 4).

Box 4. Sample student responses from the lecture exam problem

High response

a. "Equilibrium is achieved in all three cases, the reason for the change in color is the differing concentration of chemicals in each case. X(aq) + A(aq) $\rightleftharpoons$ Y(aq) + B(aq) is the equilibrium equation for this experiment. When A is added to X, X remains in the solution, but the concentration of Y is increased so if it equals X, the solution will be green. But if [Y] is greater than [X], the solution will be yellow. The reaction is still at equilibrium because the rate at which the forward and reverse reactions are occurring are still equal, the concentration of Y is just larger than that of X, so the solution expresses the presence of Y by turning yellow. The same happens when B is added. The concentration of X > [Y], but equilibrium is still established. X is just dominant in concentration causing Y's presence to be shielded by the blue color."

b. "When the solution is changing from blue to green the concentration of X is being lowered by A being added to the solution which causes [X] = [Y], resulting in a green colored solution. The rate at which X(aq) + A(aq) $\rightarrow$ Y(aq) + B(aq) is sped up until equilibrium is established because A was added to the system causing the reaction to shift to the right."

More typical response

a. "X + A $\rightleftharpoons$ B + Y. The system is at equilibrium when the solution is green in color. It is at equilibrium because the forward rate equals the reverse rate. The relative concentrations of X and Y should be close to equal. The reason the blue and yellow solutions are not at equilibrium is because they are pure (either pure chemical X or Y). But when the solution is green, both are interacting to form the green solution. And when you can't turn the solution back to yellow or blue w/o adding more A or B, the system is at equilibrium. At equilibrium (green sol.) there are both chemical X and Y present. When the solution is at blue or yellow, pure X or Y are present. The concentration of X and Y are weaker in the green state than in the blue/yellow state."

b. "Chemical Y is reacting with chemical B and is beginning to form chemical X. The system is changing from blue to green because of the addition of B. Also, the concentration of Y is decreasing w/ the addition of B --- forming chemical X, whose concentration is increasing."

Identification of equilibrium on lecture exam problem

For the identification of the equilibrium points, the counts of incorrect and correct responses indicated that descriptively the SWH sections were the two highest performing despite having the lowest baseline chemistry ability (Table 4). Descriptively, standard section 1 performed at nearly the same level as the monitor sections 5 and 6 whereas standard section 3 performed the worst of all six sections. For the four sections participating in the study, the SWH section descriptively performed better than the standard section for each TA.

Table 4. Counts of incorrect and correct responses on the lecture exam problem for all sections in the study

			Identification		Reaction equation	
Section	TA	Format	Incorrect (%)	Correct (%)	Incorrect (%)	Correct (%)
1	1	standard	7 (50)	7 (50)	6 (43)	8 (57)
2	1	SWH	4 (27)	11 (73)	13 (87)	2 (13)
3	2	standard	7 (88)	1 (12)	3 (38)	5 (62)
4	2	SWH	4 (27)	11 (73)	9 (60)	6 (40)
5*	3	standard	8 (53)	7 (47)	8 (53)	7 (47)
6*	3	standard	9 (53)	8 (47)	12 (71)	5 (29)

*No direct participation in the study

Based upon the main research interest being the laboratory format, the direction of the difference in performance between standard and SWH section being the same for each TA, and the small number of observations, the data were combined to test statistically for a relationship between laboratory format and performance on the identification of equilibrium points (Table 5). A two-sample z-test (*38*) was completed to compare the proportions of success in these four sections, and the test yielded a statistically significant result ($z = 2.666$, 2-sided $p = 0.008$, $p < 0.05$ was considered statistically significant). In other words, the SWH format was associated with the increase in the success rate in the identification of the equilibrium points.

Table 5. Counts of incorrect and correct responses on the lecture exam problem from the four sections participating in the study

		Identification		Reaction equation	
Section	Format	Incorrect (%)	Correct (%)	Incorrect (%)	Correct (%)
1 + 3	standard	14 (64)	8 (36)	9 (41)	13 (59)
2 + 4	SWH	8 (27)	22 (73)	22 (73)	8 (27)

Students that incorrectly identified the equilibrium points almost exclusively identified the green solutions as being equilibrium points. Despite the similar laboratory activity with the cobalt (II) equilibrium and the emphasis from TA's and the lecture instructor that equilibrium is not defined by equal concentrations, 50% or more of the students in the standard sections (1, 3, 5, and 6) still possessed this confusion. The authors found it interesting to hear TA's comments during and after the grading session for this exam on how students were specifically told in class that equilibrium did not mean equal concentrations, and yet these students still incorrectly responded to the exam problem. The students were apparently similar to other students who have difficulty identifying an equilibrium (*26*) and confuse equilibrium with equal concentrations (*12, 25, 27*) and whose understandings are resistant to relevant instruction (*39*). However, the students in the SWH sections were more successful at overcoming these difficulties despite their lower baseline chemistry ability.

Inclusion of an equilibrium equation on the lecture exam problem

For the inclusion of an equilibrium reaction equation, the counts of incorrect and correct responses indicated that descriptively the sections 1 and 3 were the two highest performing (Table 4). The proportions of success in these two sections were higher than in the monitor standard sections (5 and 6) and the SWH sections with SWH section 2 having the least success. For the four sections participating in the study, the SWH section had weaker performance than the standard section for each TA.

For the same reasons stated earlier regarding interest in laboratory format, same direction of effect, and few observations, the data were combined to test statistically for a relationship between laboratory format and performance on inclusion of a correct reaction equation (Table 5). A two-sample z-test was completed, and the test yielded a statistically significant result ($z = 2.354$, 2-sided $p = 0.019$, $p < 0.05$ was considered statistically significant). In other words, the standard format was statistically associated with the increase in the success rate in providing a correct equilibrium reaction equation.

Although the SWH sections had weaker performance than the standard sections, the SWH sections also had the lowest baseline chemistry ability. Based upon baseline chemistry ability, the SWH sections would be expected to be the worst performing sections with section 2 being the worst and section 4 being the next worst. Section 2 was the worst, however section 6, not section 4, was the next worst. Thus, it was possible that the SWH format benefited section 4 without negatively affecting section 2.

These results conflicted with the results from the previous study (*2*) in which the SWH format used in that study was associated with better equation usage on a physical equilibrium exam problem. Also, student skill with the equilibrium equation in this study was not necessarily an indicator of a well-developed conceptual understanding of equilibrium. Students who were able to provide a correct equation frequently identified equilibrium as equal concentrations (see Box 4 for example). Other studies have also indicated that successful manipulation of reaction equations by students does not necessarily reflect a well-developed understanding of chemistry (*40-45*).

Explanation on the lecture exam problem

For the explanation part of the lecture exam problem, the mean raw explanation scores for the standard sections followed the order of their baseline chemistry ability (Table 6). The mean scores on the explanation for the SWH sections did not follow this order in that the scores were higher than expected based upon baseline chemistry ability.

Table 6. Raw score, percent score, and change score for student explanations on the lecture exam problem for all sections involved in study (sd in parentheses)

Section	TA	Format	Explanation	Composite score	% explanation	Change score
1	1	standard	3.46 (1.33)	79.0 (6.1)	31.5 (12.1)	47.5 (10.2)
2	1	SWH	4.10 (1.90)	71.9 (9.5)	37.3 (17.3)	34.6 (15.4)
3	2	standard	3.31 (3.05)	77.6 (6.5)	30.1 (27.7)	47.1 (27.6)
4	2	SWH	3.83 (2.27)	72.6 (6.7)	34.8 (20.6)	37.8 (21.0)
5*	3	standard	3.97 (1.64)	82.0 (8.6)	36.1 (14.9)	46.0 (15.4)
6*	3	standard	3.18 (1.94)	75.3 (9.4)	28.9 (17.6)	46.5 (19.3)

*No direct participation in the study

The data did not meet the assumptions for an analysis of covariance (see Note on p. 80), and so in order to account for differences in starting chemistry ability, a change score (*37, 46*) was calculated by subtracting the percent explanation score from the composite score (Table 6). This difference was considered to be a measure of the learning gains and losses by students. Because the composite score was used to assign course grades in the first-semester course and because of the difficulty of the exam question, the composite score was higher than the explanation percent score in almost every case. Therefore, the change score was calculated as composite score minus percent explanation score to yield positive values for the mean change scores. When calculated in this manner, a smaller change score indicated a smaller difference between initial performance and final performance, which would be favored by a higher percent score on the explanation. In other words, smaller change scores were considered to be an indication of greater learning gains. For example, a student with an initial score of 70% and an explanation score of 30% would have a change score of 40%. A second student with an initial score of 60% and an explanation score of 30% would have a change score of 30%, and this second student therefore would be considered to have demonstrated a greater learning gain than the first student.

Although standard sections with higher baseline ability did score higher on the explanation (Table 7), the change scores indicated that sections using the standard laboratory format had nearly equal learning gains (47.5, 47.1, 46.0, 46.5). The change scores indicated that sections using the SWH format had similar learning gains (34.6, 37.8), and the gains were descriptively greater in the SWH sections than in the standard sections. For the same reasons stated earlier (format interest, same direction of effect, few observations), the data were combined to test statistically for a relationship between laboratory format and learning gains (Table 7). A two-sample t-test (*38*) on the mean change scores yielded a statistically significant result ($t = 2.219$, 2-sided $p = 0.031$, $p < 0.05$ was considered statistically significant). The greater learning gains were associated with the SWH format.

Table 7. Raw score, percent score, and change score for student explanations on the lecture exam problem from the four sections participating in the study (sd in parentheses)

Section	Format	Explanation	Composite score	% explanation	Change score
1 + 3	standard	3.41 (2.05)	78.5 (6.2)	31.0 (18.6)	47.4 (17.8)
2 + 4	SWH	3.97 (2.06)	72.3 (8.1)	36.1 (18.7)	36.2 (18.2)

Therefore, the SWH sections demonstrated a greater ability to identify the equilibrium condition and to explain aspects of equilibrium than standard sections despite the lower baseline chemistry ability of the SWH sections. The correlation between better explanations and better identification of the equilibrium condition was important because the explanations provided evidence to support the conclusion that a correct answer (the identification) regarding basic aspects of the equilibrium concept was indeed an indicator of better conceptual understanding. This finding was significant because the ability of a student to provide a correct answer does not necessarily indicate well-developed understanding (*17, 22, 30, 32, 41, 43-45, 47*). Thus, the use of written explanations provided additional insight into student understanding similar to the use of conceptual questions, such as particulate nature of matter problems (*41, 43-45, 47*), to obtain a more comprehensive view of student understanding.

Laboratory practical exam task on general equilibrium

The equilibrium task on the first laboratory practical exam (Box 3) also produced a wide variety of student responses (Box 5).

Box 5. Sample student responses from the laboratory practical exam task

High response

"We can see that if we add water to the $Cr_2O_7^{2-}$ that we shift the equilibrium to the right creating more $2CrO_4^{2-}$(aq) and $2H^+$(aq). The CrO_4^{2-} is yellow in color. So by adding water we shifted the equilibrium to the right. We now have mostly CrO_4^{2-} instead of the orange $Cr_2O_7^{2-}$."

More typical response

"When adding water to the $Cr_2O_7^{2-}$, you are forming more CrO_4^{2-}, which is yellow in color. Therefore, the orange $Cr_2O_7^{2-}$ is going to react into CrO_4^{2-}(yellow) and H^+ because of the H_2O added."

Selection of reagent on the laboratory exam task

Students overwhelming selected water as the reagent to alter the equilibrium position of the reaction, and as a result there was little distinction in performance between sections. There was descriptive evidence for a higher percent of students selecting a viable reagent in the SWH sections as compared to the standard sections (79% standard section 1 vs. 87%

SWH section 2 for TA1, and 88% standard section 3 vs. 93% SWH section 4 for TA2) despite the lower baseline chemistry ability of the SWH sections. However, there was no statistical evidence to support a relationship between laboratory format and student performance in selecting a reagent. Further information is supplied in the supplemental material.

Explanation on the laboratory exam task

For the explanation part of the laboratory exam task, the mean raw explanation scores were similar to the order of baseline chemistry ability for the standard sections and were again higher than expected for the SWH sections based upon baseline chemistry ability. (Table 8). The data did not meet the assumptions for an analysis of covariance (see Note p. 80) so change scores were again calculated (Table 8), and the scores indicated that the learning gains were similar for all sections using the standard laboratory format (49.6, 44.6, 46.5, 50.2). The change scores for sections using the SWH format were again similar (33.7, 31.2) and again descriptively indicated greater learning gains for the SWH sections.

Table 8. Raw score, percent score, and change score for student explanations on the laboratory exam task for all sections in the study (sd in parentheses)

Section	n	TA	Format	Explanation	Composite score	% explanation	Change score
1	14	1	standard	2.64 (1.57)	79.0 (6.1)	29.4 (17.5)	49.6 (19.5)
2	15	1	SWH	3.43 (2.38)	71.9 (9.5)	38.1 (26.5)	33.7 (27.9)
3	8	2	standard	2.94 (2.16)	77.6 (6.5)	32.6 (24.0)	44.6 (23.7)
4	15	2	SWH	3.73 (1.56)	72.6 (6.7)	41.5 (17.3)	31.2 (17.3)
5*	15	3	standard	3.20 (1.67)	82.0 (8.6)	35.6 (18.5)	46.5 (20.7)
6*	17	3	standard	2.27 (1.42)	75.3 (9.4)	25.2 (15.7)	50.2 (15.6)

*No direct participation in the study

For the same reasons stated earlier, the data were combined for the statistical analysis (Table 9). A two-sample t-test comparing the mean change scores yielded a statistically significant result ($t = 2.534$, p (2-sided) = 0.015, $p < 0.05$ was considered statistically significant).

Table 9. Raw score, percent score, and change score for student explanations on the laboratory exam task from the four sections participating in the study

Section	Format	Explanation	Composite score	% explanation	Change score
1 + 3	standard	2.75 (1.76)	78.5 (6.2)	30.6 (19.6)	47.8 (20.7)
2 + 4	SWH	3.58 (1.98)	72.3 (8.1)	39.8 (22.0)	32.4 (22.8)

The greater learning gains were associated with the SWH format. Thus, the SWH sections demonstrated a greater ability to explain how the equilibrium was altered in terms of changing concentrations, and the better explanations indicated a stronger understanding of the relationship between reactants and products that is described by a reaction equation. The results were evidence that SWH sections were more successful at overcoming some of the known student confusion regarding how concentrations change in an equilibrium process when establishing the equilibrium condition (*12, 22*).

Time on task by students and teaching assistants

The approximate amount of time spent by students in class was recorded for the four sections participating in the study, and the amount of time spent by students outside of class preparing the laboratory report was estimated from a survey (Table 10).

Table 10. Average time spent by students on the laboratory course in minutes

Section	TA	Format	Time in class	Time per report (sd)
1	1	standard	133	146 (31)
2	1	SWH	132	121 (29)
3	2	standard	111	131 (32)
4	2	SWH	123	104 (31)
5*	3	standard	n/r	151 (45)
6*	3	standard	n/r	142 (30)

*No direct participation in the study

The sections assigned to TA1 spent nearly the same amount of time in class. For the sections assigned to TA2, the standard section spent approximately 12 minutes less in each class than the SWH section. It is possible that the decreased time in class was a result of the much lower enrollment in the standard section as compared to the SWH section which would allow TA2 to address individual student needs faster in the standard section.

The time spent outside of class on the laboratory report by students was estimated from a student survey in which students reported the amount of time they typically spent completing one laboratory report (Table 10). From the results of the survey, the SWH sections spent the least amount of time outside of class on their laboratory work. The four standard sections appeared to have spent similar amounts of time outside of class.

For the four sections participating in the study, the SWH section descriptively spent less time on each report than the standard section for each TA. For the same reasons stated earlier, the data were combined for a statistical analysis (Table 11).

Table 11. Average time spent by students on each laboratory report in minutes

Section	Format	time per report (sd)
1 + 3	standard	140 (31)
2 + 4	SWH	113 (31)

A two-sample t-test comparing the time spent on each report yielded a statistically significant result ($t = 3.200$, 2-sided $p = 0.003$, $p < 0.05$ was considered statistically significant). The SWH format was statistically associated with less time spent each week on the laboratory report.

The time spent scoring the laboratory reports was recorded by the two TA's involved in the study (Table 12). For TA1 there was a general decrease in time spent scoring each report from weeks 1 and 2 to weeks 5 and 6, and the decrease may have resulted from the TA becoming more familiar with student hand-writing and the students becoming more familiar with the TA's expectations. For TA2, the time spent scoring each report was greatest in weeks 3 and 4 and then decreased.

Table 12. Average time spent by TA's on each laboratory report in minutes

Section	TA	Format	weeks 1 and 2	weeks 3 and 4	weeks 5 and 6	average
1	1	standard	10.0	8.0	6.3	8.1
2	1	SWH	9.1	7.5	5.2	7.2
3	2	standard	7.0	9.0	7.5	7.6
4	2	SWH	7.2	7.5	3.1	5.9

On average, each TA spent less time scoring SWH reports than standard reports (7.2 minutes vs. 8.1 minutes for TA1, and 5.9 minutes vs. 7.6 minutes for TA2). TA1 consistently spent about one minute less on each SWH report as compared to a standard report, which may have resulted from the TA possessing two semesters of prior experience in scoring SWH reports. TA2 initially spent slightly more time scoring each SWH report (7.2 minutes) as compared to a standard report (7.0 minutes) but eventually spent much less time on each SWH report (3.1 minutes vs. 7.5 minutes for a standard report). Perhaps some time was necessary for TA2 to become familiar with scoring SWH reports (much like the time needed to become familiar with scoring standard reports when first learning how to do so). Overall, both TA's spent less time on an SWH report than on a standard report.

Student reaction to the SWH laboratory format

On the same survey in which students estimated the time spent on each report, students were asked about their preference of laboratory report format (Table 13).

Table 13. Preferred laboratory report format and reasons why

Preferred format	n responses*	Reasons cited	n responses
SWH	18	More learning	6
		More understanding	7
		More thinking	5
		Less busywork	2
		Less time	2
standard	4	Familiarity with the report expectations	4
both	1	(see discussion)	

*total n responding was 23

In response to the question "Do you prefer the laboratory report format used in Chemistry 177L [the first-semester laboratory] or the format being used in Chemistry 178L [the laboratory in the study]? Why?", 18 out of 25 collected responses indicated the SWH format was preferred, four indicated the standard format, one indicated both formats, and two chose not to respond.

The reasons cited for the preference of the SWH format were increased learning (cited by 6 students), increased understanding (7), increased thinking (5), less busywork (2), and less time needed to complete a report (2). The theme that emerged was that students generally preferred the SWH format because they believed they were learning more, understanding more, and thinking more when using the SWH format as compared to the standard format. Of particular interest was that two students who said they learned more still preferred the SWH format despite their belief that they would have earned more points on their reports using the standard format.

The reason cited for the preference of the standard format was greater familiarity and confidence in completing the standard report (cited by all four students). However, one of these four also indicated that they were learning more with the SWH format despite the lack of confidence in completing the SWH report. The student citing a preference for both formats stated, "Chem 178L [i.e., SWH format] for learning, Chem 177L [i.e., standard format] for simplicity" which may have essentially summarized the general trends in reasons cited for preference of format.

Limitations of this study

In conducting field research, the use of intact classes as research samples resulted in two limitations of the study. First, the non-random selection of students from the course population meant that the research sample was not necessarily representative of students enrolled in the course or any other population of general chemistry students. Generalization to student populations that closely resemble the research samples would be most appropriate. Second, the use of intact classes resulted in the non-random assignment of students to the two laboratory formats. Therefore, the evidence for student outcomes being related to the type of laboratory format does not necessarily prove a cause-and-effect relationship.

Also, with the use of the new laboratory activity by all sections (standard and SWH) in the course, there was the possibility that students participating in the study and using the standard format would benefit more than past students that used the standard laboratory format. This potential effect might have decreased the observable differences in performance between standard and SWH sections in this study. However, it was necessary to produce the new activity for our teaching laboratory and was another practical aspect of conducting field research.

Conclusions and Implications

The gradual incorporation of the SWH inquiry approach into our general chemistry laboratory curriculum has yielded encouraging results. SWH students were more successful than standard students in the identification of an equilibrium condition according to the descriptive and statistical evidence. SWH students were descriptively more successful than standard students at explaining equilibrium processes in the lecture and laboratory courses, and they statistically demonstrated greater learning gains than standard students on these equilibrium explanations. Students and instructors spent less time on reports in the SWH format, and most students preferred the SWH format because in general they believed the format increased their level of learning, understanding, and thinking. Another important finding was that the use of a written explanation as an assessment tool elicited a more comprehensive view of student understanding of chemistry.

The outcomes of our study demonstrated that appropriately structured laboratory instruction has the potential to address student difficulties in understanding chemical equilibrium, including their strongly held confusion that equilibrium is defined by equal concentrations. More broadly, the outcomes are evidence that having students engage with science concepts in a laboratory setting can provide measurable benefits to their understanding of the concept(s) specifically addressed by the laboratory activity. To date, there have few experimental studies demonstrating a connection between laboratory activities and a measurable development in student understanding of science concepts (*3-5*).

All of the general conclusions from this study (better identification and explanation of an equilibrium process with the SWH format, less time with the SWH format, and student preference for the SWH format because of increased mental engagement with laboratory activities) matched the conclusions from the previous study (*2*). Thus, the SWH approach was successful with verification activities and with more inquiry-oriented activities. However, the strength of an inquiry approach to laboratory instruction over a verification approach has been demonstrated (*48-50*). The SWH inquiry approach, especially the use of the student template as the report format, provided guidance to students which increased their ability to pose questions to investigate, to relate laboratory actions and observations to science concepts, and to refine their understandings by writing scientific knowledge claims supported by experimental evidence.

The small steps we have taken to improve our general chemistry laboratory curriculum have been successful, and the success of gradually incorporating elements of the SWH inquiry approach has given us the flexibility to adapt the approach to our specific situation. The flexible implementation of the SWH approach has also given us an accessible way of addressing the National Research Council's recommendations for more inquiry-based instruction in science. We intend to continue the process of modifying laboratory activities to strengthen the opportunities for student inquiry in our courses.

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Note

To account statistically for differences in starting ability on student scores, one possibility was to do an analysis of covariance (ANCOVA) with the composite score (starting ability) as the covariate, the laboratory format as the categorical predictor variable, and the explanation or subtotal score as the response variable. However, without the random assignment of students to the laboratory formats, it was difficult to meet the assumptions that justify the ANCOVA test (*37, 46*). The assumption of equal covariate means was not met as a result of the inequality in the mean composite scores (78.5 for the standard sections, and

72.3 for the SWH sections from Table 2). The assumption of equal regression coefficients (equal slopes) was not met as was found by completing a least-squares regression analysis on the response variables and the potential covariate variable.

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Supplemental Material

Scoring rubrics, additional student responses, and example scoring of student responses

Box 6. Scoring rubric for the lecture exam problem

A. Identification of equilibrium points as all points at which the solution's color remains indefinitely (correct or incorrect).

B. Reaction equation (correct or incorrect).

$$X + A \rightleftharpoons Y + B \quad \text{or} \quad X \underset{B}{\overset{A}{\rightleftharpoons}} Y \quad \text{considered correct}$$

C. Explanation of equilibrium and change in equilibrium (0 – 11 with half-points possible).

Equilibrium condition

		scoring codes*
Rates are equal	+1	+r
Concentrations are constant	+1	+cc
Reaction is reversible	+1	+rev

Equilibrium concentrations

Linking blue color to chemical X and yellow colors chemical Y	+1	+color
Blue solution is the result of [X] > [Y]	+1	+b
Green solution is the result of [X] = [Y]	+1	+g
Yellow solution is the result of [X] < [Y]	+1	+y

Establishing equilibrium

Additional reactant stresses or shifts the equilibrium.	+1	+s
The reactions is not at equilibrium (will re-establish equilibrium)	+1	+ne
The forward rate becomes faster than the reverse rate	+1	+Δr
[X] decreasing and [Y] increasing	+1	+Δc

*scoring codes used to mark student responses

Box 7. Sample low level student response from the lecture exam problem, and the scoring for the three sample responses

Low response

a. "The points when equilibrium is achieved is when the test tube turned green. The tube turned green because there was an equal amount of the blue solution and yellow solution in the test tube. The rate at which the blue solution crossed the line to join the yellow solution equaled the rate at which the yellow solution crossed the line to join the blue solution in the test tube. The reaction equation for this would be: $X + A \rightleftharpoons B + Y$."

b. "The time when the color is changing from blue to green, there is dissociation going on."

Scoring for high response (see Box 4)
Correct identification of equilibrium points
Correct presentation of equilibrium equation
8.5 explanation score

a. +g, +y, +r, +1/2color, +b, +1/2color = 5
b. +1/2Δc, +Δr, +ne, +s = 3.5

Scoring for more typical response (see Box 4)
Incorrect identification of equilibrium points
Correct presentation of equilibrium equation
3 explanation score

a. +r, +g, +color = 3

Scoring for low response
Incorrect identification of equilibrium points
Correct presentation of equilibrium equation
0.5 explanation score

a. +1/2r = 0.5

Box 8. Scoring rubric for the laboratory practical exam task

A. Selection of reagent (poor, good, best).

Acidic solutions, acidic salts, neutral salts	poor
Water, solutions of weak base, basic salts	good
Hydroxide solutions	best

B. Explanation (0 – 9 with half-points possible).

Explanation based on Le Chaterlier's principle (0 – 3.5)

		scoring codes*
Identifying system is initially at equilibrium	+1/2	+1/2init
Identifying what happens (direction of shift)	+1	+dir
Identifying why it happens (stress applied)	+1	+stress
Inferring that equilibrium will be re-established	+1	+rest

Explanation based on reaction equation (0 – 3.5, note *, #, and $)

Identifying a viable reagent that was added	+1	+rg
Indicating what the added reagent reacts with (dichromate)	+1	+rc
Identifying the product(s) of the reaction (chromate)	+1*	+pd

*To earn full credit for identifying the product(s), the previous steps in mechanism (identifying the added reagent and the reactant) must be correctly described. If the steps are incorrect, then no credit. If the steps are missing, then +1/2 only.

#A chemical equation can be used to identify reactant and product(s) if the equation is a natural extension of an initial written explanation. This was rarely observed.

$The use of hydroxide as the reagent can earn additional +1/2 if the titration reactant (H^+) and product (H_2O) are identified (again, an equation that is a natural extension of a written explanation can earn credit). This was rarely observed.

Explanation of color (0 – 2)

Attributing orange and yellow color to dichromate and chromate	+1	+color
Attributing yellow solution to $[CrO_4^{2-}] > [Cr_2O_7^{2-}]$	+1	+y

*scoring codes used to mark student responses

Box 9. Sample low level student response from the laboratory exam task, and the scoring for the three sample responses

Low response

"Added more reactant (H_2O) so equilibrium shifted to the right so more product was formed and the solution turned yellow."

<u>Scoring for high response (see Box 5)</u>
Correct reagent
6 = +1 rg, +rc, +dir, +pd, +1/2color, +y, +1/2color

<u>Scoring for more typical response (see Box 5)</u>
Correct reagent
4 = +rg, +rc, +pd, +color

<u>Scoring for low response</u>
Correct reagent
2 = +rg, +dir

Additional results and discussion

Selection of reagent on the laboratory exam task

The reagent selected to alter the equilibrium position was categorized as a poor, good, or best selection (Table 14).

Table 14. Counts of responses for the selection of a reagent on the laboratory practical exam for all sections in the study

Section	TA	Format	Poor (%)	Good (%)	Best (%)	Incorrect (%)	Correct (%)
1	1	standard	3 (21)	8 (57)	3 (21)	3 (21)	11 (79)
2	1	SWH	2 (13)	11 (73)	2 (13)	2 (13)	13 (87)
3	2	standard	1 (12)	5 (62)	2 (25)	1 (12)	7 (88)
4	2	SWH	1 (7)	13 (86)	1 (7)	1 (7)	14 (93)
5*	3	standard	1 (7)	12 (80)	2 (13)	1 (7)	14 (93)
6*	3	standard	3 (17)	10 (59)	4 (24)	3 (17)	14 (83)

*No direct participation in the study

Acidic solutions and acidic or neutral salts were considered poor selections. Water, solutions of weak bases, and basic salts were considered good selections. Solutions of hydroxide were considered the best selections. The overwhelming choice of reagent was water, and no section appeared especially unique in terms of the distribution of reagents chosen in each section.

To simplify the analysis, the data was collapsed into selection of an incorrect reagent (poor selections) or a correct reagent (good or best selections)(Table 14). There did not appear to be strong evidence for a relationship between laboratory format and choice of reagent. Descriptively, the SWH sections performed slightly better than the standard sections in the study despite the lower baseline chemistry ability of the SWH sections. For the same reasons as stated earlier, the data were combined to test statistically for a relationship between laboratory format and correct reagent selection (Table 15).

Table 15. Counts of responses for the selection of a reagent on the laboratory practical exam from the four sections participating in the study

Section	n	Format	Incorrect (%)	Correct (%)
1 + 3	22	standard	4 (18)	18 (82)
2 + 4	30	SWH	3 (10)	27 (90)

A two-sample z-test comparing the proportions of success did not yield a statistically significant result ($z = 0.854$, 2-sided $p = 0.393$, $p < 0.05$ was considered statistically significant). There was no statistical evidence that selecting a correct reagent was related to type of laboratory format. However, SWH sections did demonstrate a slightly better ability to choose a correct reagent according to the descriptive results despite having lower baseline chemistry ability.

ACS exam and final exam in the lecture course

At the end of the semester, an ACS second-semester general chemistry exam (*51*) was given as a method for students to improve their final grade in the lecture course. Scores above 50% on the multiple-choice exam improved the course grade. Other scores did not alter the course grade, and students were not required to take the exam. Forty-four of the 52 students participating in the study chose to take the exam.

For the four multiple-choice problems on the exam that addressed general equilibrium, the counts of the subtotals were determined for each section (Table 16). The mean subtotals for the four problems on the ACS exam were determined for each section (Table 17).

Table 16. Counts of subtotals for equilibrium problems on the ACS and final exams

			ACS exam subtotals						Final exam subtotals							
Section	TA	Format	n	0	1	2	3	4	n	0	1	2	3	4	5	6
1	1	standard	12	0	1	4	3	4	14	0	0	1	5	2	5	1
2	1	SWH	13	0	0	7	6	0	15	0	0	0	9	1	3	2
3	2	standard	6	0	1	3	1	1	8	0	0	0	1	2	4	1
4	2	SWH	13	0	0	3	8	2	15	0	0	1	5	2	6	1
5*	3	standard	14	0	1	1	3	9	15	0	0	0	1	5	4	5
6*	3	standard	17	2	2	3	7	3	17	0	0	1	5	4	7	0

*No direct participation in the study

Table 17. Subtotals and change scores for the four equilibrium problems on the ACS exam (sd in parentheses)

Section	n	TA	Format	Subtotal	Composite score	% subtotal	Change score
1	12	1	standard	2.83 (1.03)	79.0 (6.1)	70.8 (25.7)	7.3 (23.7)
2	13	1	SWH	2.46 (0.52)	71.9 (9.5)	61.5 (13.0)	12.4 (16.6)
3	6	2	standard	2.33 (1.03)	77.6 (6.5)	58.3 (25.8)	22.4 (26.4)
4	13	2	SWH	2.92 (0.94)	72.6 (6.7)	73.1 (16.0)	-0.2 (14.1)
5*	14	3	standard	3.43 (0.94)	82.0 (8.6)	85.7 (23.4)	-3.5 (24.0)
6*	17	3	standard	2.41 (1.28)	75.3 (9.4)	60.3 (31.9)	15.0 (27.8)

*No direct participation in the study

Section 5 was the highest scoring section (3.43) which was consistent with past performance by students in this section, and section 3 was the lowest (2.33). The data did not meet the assumptions for an analysis of covariance so change scores were again calculated for a statistical analysis (Table 17). The mean change score was highest in section 5 (-3.5) and lowest in section 3 (22.4). For sections 1 and 2 assigned to TA1, the scores descriptively indicated greater learning gains for the standard section. For sections 3 and 4 assigned to TA2, the scores descriptively indicated greater learning gains for the SWH section. Because the differences were in opposite directions for the two TA's, the data could not be collapsed across the factor of TA. Instead, the data were analyzed separately for each TA.

In order to compare statistically the mean change scores with so few observations for each TA, a non-parametric Mann-Whitney (Wilcoxon) test (*37, 38*) was completed because of the limited nature of the data. The test comparing the scores for sections 1 and 2 yielded no statistical evidence for a relationship between laboratory format and change scores ($z = -0.761$, 2-sided $p = 0.446$, $p < 0.05$ was considered statistically significant). The test comparing the scores for sections 3 and 4 yielded statistical evidence for a relationship between laboratory format and change scores ($z = -2.105$, 2-sided $p = 0.035$, $p < 0.05$ was considered statistically significant). In other words, the greater learning gain was statistically associated with the SWH laboratory format for TA2.

On the final exam in the lecture course, the subtotals for the six multiple-choice problems addressing general equilibrium were determined (Table 16), and the mean subtotals were determined (Table 18).

Table 18. Subtotals and change scores for the six equilibrium problems on the final exam (sd in parentheses)

Section	n	TA	Format	Subtotal	Composite score	% subtotal	Change score
1	14	1	standard	4.00 (1.18)	79.0 (6.1)	66.7 (19.6)	12.3 (17.0)
2	15	1	SWH	3.87 (1.19)	71.9 (9.5)	64.4 (19.8)	7.4 (18.2)
3	8	2	standard	4.63 (0.92)	77.6 (6.5)	77.1 (15.3)	0.5 (12.2)
4	15	2	SWH	4.07 (1.16)	72.6 (6.7)	67.8 (19.4)	4.9 (17.3)
5*	15	3	standard	4.87 (0.99)	82.0 (8.6)	81.1 (16.5)	0.9 (13.3)
6*	17	3	standard	4.00 (1.00)	75.3 (9.4)	66.7 (16.7)	8.7 (11.0)

*No direct participation in the study

Section 5 was again the highest scoring section (4.87), and section 2 was the lowest (3.87). The data did not meet the assumptions for an analysis of covariance so the change scores were again calculated (Table 18). The mean change score was highest in section 3 (0.5) and lowest in section 1 (12.3). For sections 1 and 2 assigned to TA1, the scores descriptively indicated greater learning gains for the SWH section. For sections 3 and 4 assigned to TA2, the scores descriptively indicated greater learning gains for the standard section.

The data were again analyzed separately for each TA because of the differential relationship, and the Mann-Whitney (Wilcoxon) test was completed to test statistically for a relationship between laboratory format and change scores because of the limited data for each TA. The test comparing the scores for sections 1 and 2 yielded no statistical evidence for a relationship between laboratory format and change scores ($z = -0.611$, 2-sided $p = 0.541$, $p < 0.05$ was considered statistically significant). The test comparing the scores for sections 3 and 4 yielded no statistical evidence for a relationship between laboratory format and change scores ($z = -0.452$, 2-sided $p = 0.651$, $p < 0.05$ was considered statistically significant). There was no evidence for a relationship between learning gains and laboratory format for either TA.

Overall, the results from the ACS exam and the final exam presented a series of inconsistent findings. From the ACS exam (Table 17), there was descriptive evidence for standard section 1 demonstrating better performance than SWH section 2, and there was descriptive and statistical evidence for standard section 3 demonstrating worse performance than SWH section 4. From the final exam, this trend was reversed (Table 18). There was descriptive evidence for standard section 1 demonstrating worse performance than SWH section 2, and there was descriptive evidence for standard section 3 demonstrating better performance than SWH section 4. Therefore, the evidence was contradictory within a given exam and contradictory between the exams.

In addition, the change scores across the two SWH sections and across the four standard sections were not consistent within a given exam: 12.4 and –0.2 for SWH sections and 7.3, 22.4, -3.5, and 15.0 for standard sections on the ACS exam (Table 17), and 7.4 and 4.9 for SWH sections and 12.3, 0.5, 0.9, and 8.7 for standard sections on the final exam (Table 18). Finally, the change scores were not consistent between the exams either. Section

3 had the lowest score on the ACS exam (22.4) but the highest on the final exam (0.5). One somewhat consistent result was that section 5 scored highly on both exams (-3.5 for ACS, and 0.9 on final).

The inconsistent outcomes may have resulted from attempting an analysis of a subtotal score on multiple-choice problems because a small number of such problems may have been an insufficiently refined measure of student understanding. As mentioned in the introduction, the selection of a correct answer from a list of possible answers may not be representative of strong understanding. In addition, the restricted range in possible subtotals may have created limited distinctions in student performance by categorizing student understanding into too few groups. For example, with four multiple-choice problems, there were only five possible groupings (0 – 4 with only integers) whereas with the explanation part of the lecture exam problem, there were 23 categories (0 – 11 with half-points allowed). Therefore, the analysis of a small number of multiple-choice problems for differences between sections did not provide conclusive evidence for a relationship between laboratory format and student performance. Further investigation of this issue is needed.

Additional reference

51. ACS Second-Term General Chemistry Exam. Form 1998. ACS DivCHED Examinations Institute, Clemson University, Clemson, SC.

CHAPTER 5

CONCLUSIONS

Conclusions

Students using the SWH approach demonstrated a better understanding of the equilibrium concept and reported a greater level of mental engagement with their laboratory work. Thus the research produced evidence supporting the conclusion that laboratory instruction enhances student understanding of science and the conclusion that an inquiry approach to laboratory instruction can successfully benefit student understanding and attitudes toward laboratory work in chemistry. In addition, it was found that students and instructors spent less time on task with the SWH approach. It was also found that the use of written explanations as an assessment tool for obtaining a more comprehensive view of student understanding of chemistry was successful.

From a practical and local standpoint, using the SWH approach offers the potential for meaningful improvement in the general chemistry laboratory program at ISU. With the standard verification approach currently in use, students generally have unexpected difficulty in engaging with the chemistry concepts in their laboratory work and in connecting such work to the topics discussed in lecture. Teaching assistants have difficulty in shifting student attention away from a narrow focus on procedures and experimental results toward a consideration of the meaning of the results that have been obtained.

However the results of this research indicate that the SWH approach can more successfully address these difficulties in the Chemistry 178L laboratory course. The SWH approach apparently promotes student ability in making sense of laboratory work and relating such work to lecture topics. In turn, the demands placed upon on an individual TA's ability to encourage students to engage with the relevant chemistry are less, which allows TA's to spend more effort on actually discussing chemistry. Therefore, the SWH approach offers the potential for an improvement in student and TA attitude because the focus of laboratory discussions would be shifted toward discussing chemistry topics presented in lecture. In addition, the potential improvement in attitudes and learning outcomes would be augmented by the reduced time spent on laboratory reports by students and TA's. Lastly, the research produced an additional laboratory activity for addressing equilibrium, and the activity was successfully field-tested in Chemistry 178L.

Limitations of the studies

The nature of field research required the use of intact classes as research samples and resulted in several limitations in the research. Although control and treatment sections were compared, the research experiments were quasi-experiments, not true experiments. The non-random selection of students from each course meant that the research samples were not necessarily representative of students enrolled in the course or any other population of general chemistry students. Generalization to student populations that closely resemble the research samples would be most appropriate. The non-random assignment of students to the two laboratory formats meant that evidence for student outcomes being related to the type of laboratory format were not proof of a cause-and-effect relationship.

Another set of limitations resulted from the narrow scope of the investigations. Although the research produced theoretically general results using multiple teaching assistants, the practical generality, i.e., that similar results could be successfully obtained when implementing the SWH laboratory format in a larger number of laboratory sections, was not necessarily demonstrated. There may be some practical issues which were not brought out by the research. The potential effectiveness of the SWH format on developing student understanding of chemistry concepts was essentially limited to the equilibrium concept only, and although the potential benefits are possibly general to other chemistry concepts, it was not necessarily demonstrated by the research.

Implications

With a view toward course-wide implementation of the SWH, one possible research goal would be to increase the number of laboratory sections using the SWH to uncover some of the factors involved in larger scale implementation. A related goal would be to investigate the effectiveness of the SWH with additional chemistry concepts. Also, the modification of additional laboratory activities to reflect more opportunities for student inquiry could be carried out in conjunction with this investigation.

The Calibrated Peer Review (CPR) element of the Molecular Science Project NSF systemic reform initiative offers the potential for greatly enhancing the effectiveness and breadth of SWH implementation (*1*). CPR is an on-line method for incorporating written assignments into any curriculum and is based upon the peer review process used to evaluate manuscripts submitted for publication in scientific journals. Students enter their written work into the CPR program and then evaluate and score three assignments authored by their classmates. CPR therefore increases the amount of feedback a student receives on a given written assignment and the number of exposures to the relevant material. The main student discomfort with the SWH approach is a lack of confidence regarding the expectations for the laboratory report, and submission of the laboratory report in conjunction with CPR (in addition to submission of the report to the instructor) would increase the amount of feedback to students and provide some feedback at a student level of communication. In addition, students would be practicing critical evaluation of their peers' scientific explanations. Students would therefore have additional opportunities to mentally engage with the relevant concept(s) and with the process of producing scientific explanations.

The inconclusive evidence regarding equation usage by SWH students leads to the possibility of discipline-specific tailoring of the SWH student template. Perhaps for specific laboratory activities students would be required to complete an additional report section or another claim in which students would provide a reaction equation and the experimental evidence that supports the applicability of the equation. Students would hopefully be engaging in more meaningful practice with writing reaction equations and would thus develop a better understanding of the meaning of such symbolic representation. Incorporation of this additional section or claim would be for a limited number of points in order to maintain the assessment focus on the creation of scientific claims supported by evidence.

Further investigation of some of the qualitative factors underlying the potential effectiveness of the SWH approach would be useful. For example, the SWH student template is meant to help students develop some of the thinking skills used by professional scientists in laboratory work and to help students understand the rational process of science. Although students have indicated greater mental engagement with their laboratory work, there was little specific evidence that SWH students possessed better thinking skills or a better understanding of the process of science. Specific investigations would examine more closely student work on laboratory practical exams and/or student interviews regarding how exactly the SWH helped to increase mental engagement with laboratory work.

A related research goal would be a longitudinal study regarding the effect of the SWH approach on student participation in undergraduate research experiences. It has come to the attention of one of the instructors involved in this research (James Rudd) that five students enrolled in laboratory sections that were assigned to this instructor are currently involved in undergraduate research at ISU. Three students are associated with the Chemistry department, one student with the MSE department, and one with the Genetics program. The students involved in chemistry and genetics research were enrolled in SWH laboratory sections while the remaining student is an honors student who was enrolled in a standard section. Although the evidence is strictly anecdotal, perhaps the SWH inquiry approach does in fact promote better understandings about the scientific process and a greater appreciation for scientific endeavors which translates into encouraging more students to pursue scientific research. The specific investigation would study whether or not the SWH approach was associated with an increased rate of participation in undergraduate research in general and an increased rate specifically in chemistry.

Another research goal would be to study whether using the SWH would be related to the ability to produce better written communication in the style used by professional scientists. Perhaps 2-3 reports written in the style of a journal article could be assigned each semester and then compared to see if SWH students produce better reports. These assignments could also be evaluated on-line using the CPR program.

Reference

1. Russell, A. A.; Chapman, O. L.; Wegner, P. A. *J. Chem. Educ.* **1998**, *75*, 578-579.

APPENDIX A

PRACTICE ACTIVITY USED TO INTRODUCE THE SWH LABORATORY REPORT FORMAT FROM CHAPTER 2

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.

Based on these preliminary observations, please work with your partner to draw initial conclusions about what happened. Please provide as much evidence as you can to support each conclusion you make.

<u>A. Beginning Questions or Ideas. What do I want to know or already know?</u>
What has happened to Mr. Xavier?

<u>B. Tests and procedures. What did I do to investigate my questions or ideas?</u>
Observed the scene of the incident.

<u>C. Observations. What did my tests and procedures produce?</u>
[students complete this section during practice activity]

<u>D. Claims. What is my answer or statement for what happened?</u>
[students complete this section during practice activity]

<u>E. Evidence. What can I say that justifies and supports my claim(s)?</u>
[students complete this section during practice activity]

<u>F. Reflection. What have I learned from this activity?</u>
[students complete this section after practice activity]

APPENDIX B

HUMAN SUBJECTS RESEARCH APPROVAL FOR RESEARCH PRESENTED IN CHAPTER 3

Information for Review of Research Involving Human Subjects
Iowa State University
(Please type and use the attached instructions for completing this form)

1. Title of Project Implementation of new laboratory procedures in general chemistry laboratory courses

2. I agree to provide the proper surveillance of this project to insure that the rights and welfare of the human subjects are protected. I will report any adverse reactions to the committee. Additions to or changes in research procedures after the project has been approved will be submitted to the committee for review. I agree to request renewal of approval for any project continuing more than one year.

James A. Rudd. II — Typed name of principal investigator
14 Jan 2000 — Date
James A. Rudd, II — Signature of principal investigator

Chemistry — Department
1605 Gilman Chemistry Department — Campus address

294-7718 — Phone number to report results

JAN 19 2000 ISU

3. Signatures of other investigators | Date | Relationship to principal investigator

Signatures of other investigators	Date	Relationship to principal investigator
Thomas J. Greenbowe	14 Jan 2000	Major professor Chemistry Department
[signature]	14 Jan 2000	Co-investigator Curriculum and Instruction Department

4. Principal investigator(s) (check all that apply)
X Faculty _ Staff X Graduate student _ Undergraduate student

5. Project (check all that apply)
X Research X Thesis or dissertation _ Class project _ Independent Study (490, 590, Honors project)

6. Number of subjects (complete all that apply)
\# adults, non-students: ____ # minors under 14: ____ # minors 14 - 17: ____
\# ISU students: 60 other (explain): ____

7. Brief description of proposed research involving human subjects: (See instructions, item 7. Use an additional page if needed.)

A. The project is a course evaluation and will study the effect of changing the laboratory procedures in Chemistry 178L. Chemistry achievement will be measured by scoring subject responses on a set of questions related to the course material (see attached).

B. Two or three laboratory sections from the course will be selected to participate in the project, and the subjects will be the students enrolled in those sections. Subjects will be predominately first-year students. These students will be informed of the implementation of the new laboratory procedures and will be informed that their participation is voluntary. Students may transfer to a non-participating section to decline participation.

(Please do not send research, thesis, or dissertation proposals.)

8. Informed Consent: _ Signed informed consent will be obtained. (Attach a copy of your form.)
X Modified informed consent will be obtained. (See instructions, item 8.)
_ Not applicable to this project.

9. Confidentiality of Data: Describe below the methods you will use to ensure the confidentiality of data obtained. (See instructions, item 9.)

Access to student responses to course-related questions will be restricted to the instructors and to the investigators involved in the proposed project. All persons receiving access to the responses will be reminded of the need to maintain confidentiality.

10. What risks or discomfort will be part of the study? Will subjects in the research be placed at risk or incur discomfort? Describe any risks to the subjects and precautions that will be taken to minimize them. (The concept of risk goes beyond physical risk and includes risks to subjects' dignity and self-respect as well as psychological or emotional risk. See instructions, item 10.)

No foreseeable risks or discomfort to subjects.

11. **CHECK ALL** of the following that apply to your research:

- ☐ A. Medical clearance necessary before subjects can participate
- ☐ B. Administration of substances (foods, drugs, etc.) to subjects
- ☐ C. Physical exercise or conditioning for subjects
- ☐ D. Samples (blood, tissue, etc.) from subjects
- ☐ E. Administration of infectious agents or recombinant DNA
- ☐ F. Deception of subjects
- ☐ G. Subjects under 14 years of age and/or ☐ Subjects 14 - 17 years of age
- ☐ H. Subjects in institutions (nursing homes, prisons, etc.)
- ☐ I. Research must be approved by another institution or agency (Attach letters of approval)

If you checked any of the items in 11, please complete the following in the space below (include any attachments):

Items A–E Describe the procedures and note the proposed safety precautions.

Items D–E The principal investigator should send a copy of this form to Environmental Health and Safety, 118 Agronomy Lab for review.

Item F Describe how subjects will be deceived; justify the deception; indicate the debriefing procedure, including the timing and information to be presented to subjects.

Item G For subjects under the age of 14, indicate how informed consent will be obtained from parents or legally authorized representatives as well as from subjects.

Items H–I Specify the agency or institution that must approve the project. If subjects in any outside agency or institution are involved, approval must be obtained prior to beginning the research, and the letter of approval should be filed.

Last name of Principal Investigator Rudd

Checklist for Attachments and Time Schedule

The following are attached (please check):

12. x Letter or written statement to subjects indicating clearly:
    a) the purpose of the research
    b) the use of any identifier codes (names, #'s), how they will be used, and when they will be removed (see item 17)
    c) an estimate of time needed for participation in the research
    d) if applicable, the location of the research activity
    e) how you will ensure confidentiality
    f) in a longitudinal study, when and how you will contact subjects later
    g) that participation is voluntary; nonparticipation will not affect evaluations of the subject

13. _ Signed consent form (if applicable)

14. _ Letter of approval for research from cooperating organizations or institutions (if applicable)

15. x Data-gathering instruments

16. Anticipated dates for contact with subjects:

First contact	Last contact
2/14/00	4/17/00
Month/Day/Year	Month/Day/Year

17. If applicable: anticipated date that identifiers will be removed from completed survey instruments and/or audio or visual tapes will be erased:

Month/Day/Year

18. Signature of Departmental Executive Officer — Date — Department or Administrative Unit

Gordon J Miller — 1/19/00 — Chemistry

19. Decision of the University Human Subjects Review Committee:

☐ Project approved ☐ Project not approved ☐ No action required

Name of Human Subjects in Research Committee Chair	Date	Signature of Committee Chair
Patricia M. Keith		

Attachment 12. Informed consent letter to be read to subjects indicating purpose and nature of project.

The chemistry department continually works to improve the quality of the chemistry courses that are offered at Iowa State University, and this semester we need to evaluate the effectiveness of some new laboratory procedures for the Chemistry 178 laboratory course. This laboratory section has been selected to participate in the evaluation process, and the students enrolled in this section will be using the new procedures. Participating in the project has no foreseeable discomfort or risks to you, and you may find the course experience more valuable to you with the new procedures than with the standard procedures. In addition, you would be helping to improve the quality of the course experience for future students. Your participation is voluntary, and you may decline to participate by transferring to a section that is not involved with the project. We are willing to discuss any concerns you may have about being involved in this course evaluation, and we thank you in advance for your participation.

Attachment 15. Data-gathering instrument composed of a set of questions related to course material.

A chemical system at equilibrium can be represented by the following general equation.

$$A_2(g) + B_2(g) \rightleftharpoons 2\,AB(g)$$

1. Which statement is *always* true about a reaction at equilibrium?

   1) The number of product molecules equals the number of reactant molecules.
   2) The concentration of products equals the concentration of reactants.
   3) The pressure of products equals the pressure of reactants.
   4) The rate of forming products equals the rate of forming reactants.
   5) I don't know the answer to this question.

2. The equilibrium constant expression for the reaction below is:

$$2\,BrF_5(g) \rightleftharpoons Br_2(g) + 5\,F_2(g)$$

   1) $K_{eq} = \dfrac{[Br_2]\,[F_2]}{[BrF_5]}$
   2) $K_{eq} = \dfrac{[Br_2]\,[F_2]^5}{[BrF_5]^2}$
   3) $K_{eq} = \dfrac{[Br_2]\,[F_2]^2}{[BrF_5]^5}$
   4) $K_{eq} = \dfrac{[BrF_5]^2}{[Br_2F_2]^5}$
   5) $K_{eq} = \dfrac{2[BrF_5]^2}{[Br_2 \times 5F_2]^5}$

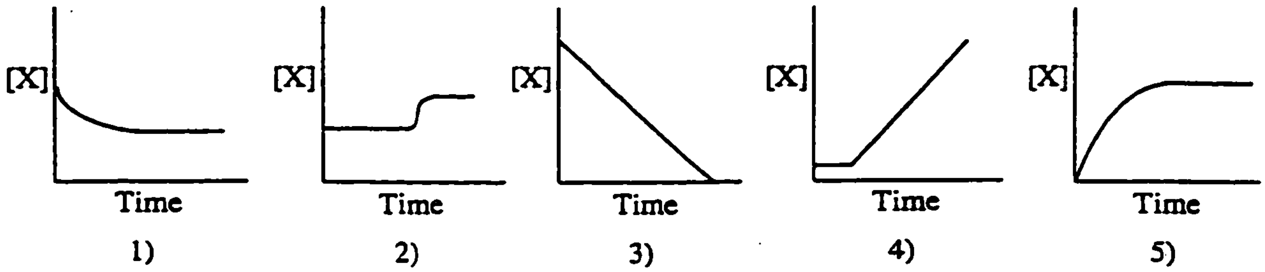
3. An equilibrium constant with a large magnitude ($K_{eq} > 1 \times 10^{10}$) indicates that a system favors ___ when its reaches equilibrium.

   1) reactants
   2) products
   3) equally reactants and products
   4) the magnitude of K_{eq} does not affect the system
   5) I don't know.

4. Chemical equilibrium is the *result* of

   1) a decrease in speed of reaction.
   2) the unavailability of one of the reactants.
   3) a stoppage of further reaction.
   4) opposing reactions attaining equal speeds.
   5) formation of products equal in mass to the reactants.
   6) I don't know.

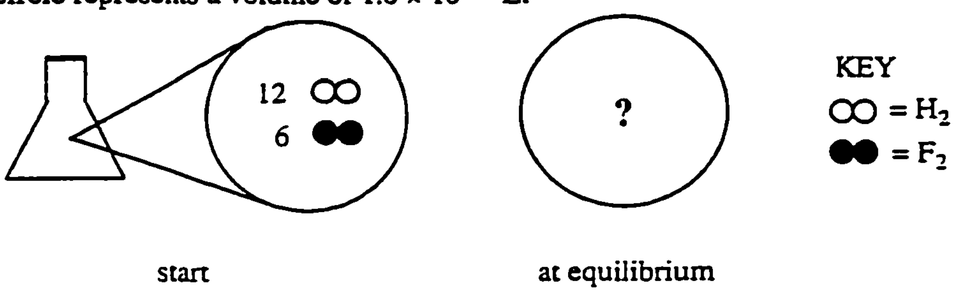
5. X is a reactant in a reaction mixture. Initially, 0.100 mol of X and 0.100 mole of Y are injected into a sealed flask. X reacts with Y to produce XY. Which graph describes the change in concentration of X as the mixture comes to equilibrium?

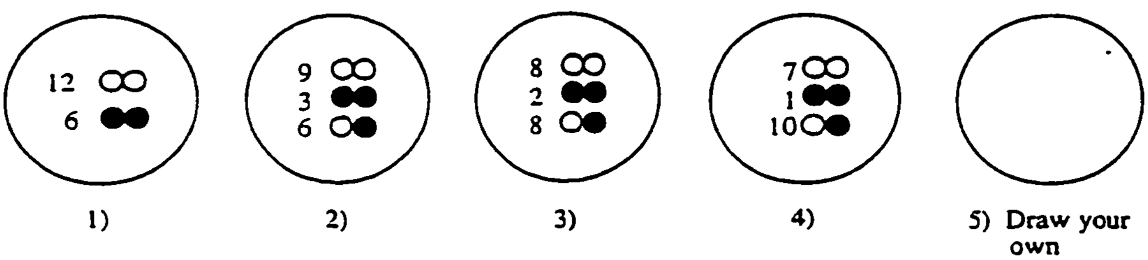


6. Hydrogen gas can react with fluorine gas at a certain temperature to form HF gas.

$$H_2(g) + F_2(g) \rightleftharpoons 2\,HF(g) \qquad K_{eq} = 4 \quad \text{at this temperature}$$

The following diagram shows the initial conditions before the reaction takes place. Which molecular picture shows what the system looks like when it reaches equilibrium. Be sure to conserve atoms and molecules. Assume each circle represents a volume of 1.0×10^{-21} L.





7. At 400°C, $K_c = 64$ for the equilibrium:

$$H_2(g) + I_2(g) \rightleftharpoons 2\,HI(g)$$

If 3.00 mol H_2 and 3.00 mol I_2 are introduced into an empty 4.0 L vessel, calculate the equilibrium concentration of HI at 400°C.

1) 0.15 2) 1.2 3) 2.4 4) 4.8 5) 5.8 6) I don't know

8. The following reaction system is at equilibrium: $CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(g)$
The result of removing some CH_4 from the system is:

1) H_2O is consumed 2) more CH_4 and H_2O are produced 3) K_{eq} decreases 4) more CO is produced
5) no change occurs 6) I don't know how to answer this question.

9. A sample of lemon juice was found to have a pH of 2.45. What is the $[H_3O^+]$ in the juice?

1) 3.5×10^{-3} M 2) 8.6×10^{-2} M 3) 11.6 M 4) 8.0×10^{-3} M 5) 2.80×10^{2} M 6) I don't know

10. If the pH of an acid rain storm is approximately 3.0, how many time greater is the $[H_3O^+]$ in the rain than in a cup of milk with a pH of 6.0?

1) 2 2) 30 3) 100 4) 1,000 5) none of these 6) I don't know

11. Which has the smallest concentration of hydroxide ions?

1) 1 M NaOH
2) 1 M HCl
3) 1 M NH_3(aq)
4) 0.0001 M NaOH
5) pure water
6) I don't know.

12. Take a 10.0 mL solution of HCl at pH = 2.00 and a 10.0 mL solution of HCl at pH = 6.00 and mix them. The resulting pH will be

1) 2.0 2) 2.3 3 4.0 4) 6.0 5) 8.0 6) I don't know

13. Which is a strong acid?

1) HF 2) HBr 3) HNO_2 4) H_2SO_3 5) I don't know.

Questions 14 through 17 pertain to the table below.

<u>Acid</u>	$HO-\overset{\overset{O}{\|}}{C}-CH_3$	HN_3	$HO-\overset{\overset{O}{\|}}{C}-H$	HOCl
$\underline{K_a}$	1.8×10^{-5}	1.9×10^{-5}	1.8×10^{-4}	3.0×10^{-8}

14. Which acid listed in the above table is the weakest acid?

1) $HO-\overset{\overset{O}{\|}}{C}-CH_3$ 2) HN_3 3) $HO-\overset{\overset{O}{\|}}{C}-H$ 4) HOCl 5) I don't know.

15. Which 0.010 M solution of the above acids would have the lowest pH?

1) $HO-\overset{\overset{O}{\|}}{C}-CH_3$ 2) HN_3 3) $HO-\overset{\overset{O}{\|}}{C}-H$ 4) HOCl 5) I don't know.

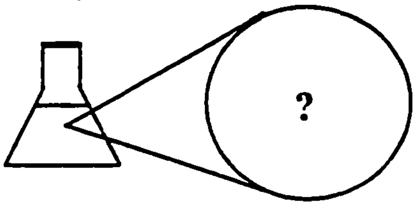
16. The pH of 0.010 M HBr(aq) is ____ the pH of a 0.010 M $CH_3\overset{\overset{O}{\|}}{C}-OH$, acetic acid

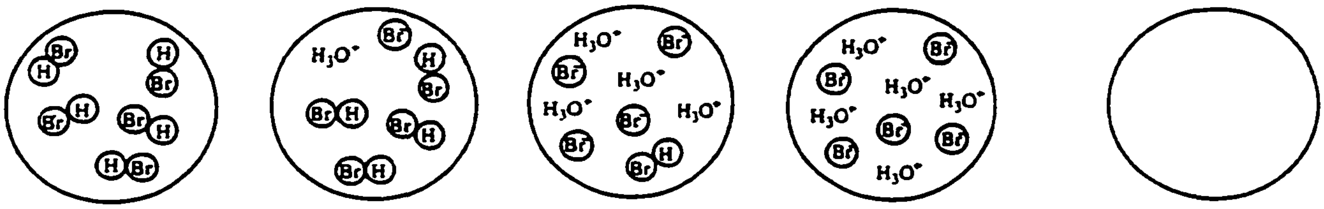
1) higher than 2) the same as 3) lower than 4) I don't know

17. In which solution is acetic acid ionized most extensively?

1) 18 M 2) 0.1 M 3) 0.01 M 4) 10^{-5} M 5) I don't know

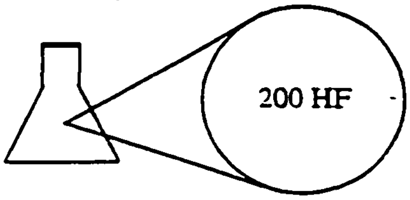
18. Which representation best illustrates a small volume of hydrobromic acid, $HBr_{(aq)}$, solution? (Water molecules are not shown and only major species are shown.)





1) 2) 3) 4) 5) Draw your own

19. Which diagram best represents a small volume of a 0.30 M HF solution. Water molecules have been omitted for clarity, only major species are shown. Explain.



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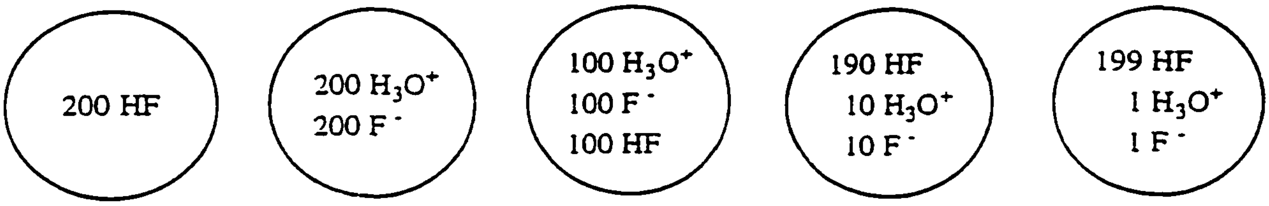


1) 2) 3) 4) 5)

20. K_a for HF is 6.8×10^{-4}. What is the pH of a 0.35 M solution of HF?

1) 3.17 2) 1.81 3) 3.62 4) 0.46 5) I don't know.

21. Which compound will produce an acidic solution when dissolved in H_2O?

1) NaF 2) $Ca(CN)_2$ 3) $K^{\oplus}, {}^{\ominus}O-C(=O)-CH_3$ 4) NH_3 5) NH_4Cl 6) I don't know.

22. The addition of sodium acetate to a solution of acetic acid would

1) decrease the total acetate ion concentration.
2) decrease the acidity of the solution.
3) increase the ionization of the acetic acid.
4) increase the hydronium ion concentration.
5) decrease the ionization constant of acetic acid.
6) I don't know.

23. The following 1.0 M aqueous solutions are available for mixing:

$HCl(aq)$ $HC_2H_3O_2(aq)$ $NaOH(aq)$ $NH_4Cl(aq)$ $NaC_2H_3O_2(aq)$ $NaCl(aq)$ $NH_3(aq)$

Select two solutions that when mixed will form an alkaline buffer solution that is mildly basic.

1) HCl and NaOH
2) NaOH and NH_3
3) NH_3 and NH_4Cl
4) $NaC_2H_3O_2$ and NH_4Cl
5) none of these
6) I don't know.

24. Calculate the pH of a buffer solution which contains 0.25 M benzoic acid ($C_6H_5CO_2H$) and 0.15 M sodium benzoate ($NaC_6H_5CO_2$). Given $K_a = 6.5 \times 10^{-5}$, for benzoic acid.

1) 3.97 2) 4.83 3) 4.19 4) 3.40 5) 4.41 6) I don't know.

25. If 10 mL of 0.01 M HCl is added to the buffer solution in the previous problem (#24), the pH of the solution will ________________.

1) not change at all
2) increase slightly
3) noticeably increase
4) decrease slightly
5) noticeably decrease
6) I don't know.

26. The reason for your answer in the previous question (# 25)
"...because the HCl reacts with the ________________ present in the solution."

1) OH^- ions 2) H_3O^+ ions 3) benzoate ions 4) benzoic acid 5) none of these
6) I don't know.

27. 50 mL of a benzoic acid/sodium benzoate buffer solution at pH = 4.78 is needed. How many mL of a 0.1 molar sodium benzoate solution should be mixed with how many mL of a 0.1 M benzoic acid solution in order to create a buffer solution of pH = 4.78? Given for benzoic acid $K_a = 6.5 \times 10^{-5}$, $pK_a = 4.18$.

	0.1 M sodium bezoate	0.1 M benzoic acid
1)	10 mL	40 mL
2)	22 mL	28 mL
3)	25 mL	25 mL
4)	28 mL	22 mL
5)	40 mL	10 mL
6)	none of these	
7)	I don't know	

APPENDIX C

SURVEY QUESTIONS USED FOR DATA COLLECTION FOR RESEARCH PRESENTED IN CHAPTER 3

Please provide some feedback to us about the new laboratory report format so we can learn how to give better advice and direction. Please try to provide as many specific comments as you can. Thank-you.

Time issues

1. Compared to the previous lab report format, how much time did you spend on writing up a lab report under the new format after the lab experiment was finished? If the amount of time was different, by how many hours?

2. Which format do you think was a better use of your time?

3. Do you think the time needed to complete the lab reports is too much with the previous format, the new format or both formats?

Learning issues

3. Compared to the previous format, what do you think is more useful about the new format? And what do you think is less useful about the new format?

4. Compared to the previous lab format, how well do you feel you learned chemistry by using the new report format?

Lab procedures

5. How do you think the standard lab procedures fit (or did not fit) the new report format?

6. Please discuss how you think the modified procedures on conjugate acid-base pairs (Exp 3A and 3B) compared to more typical lab manual procedures.

Other issues

7. Which format do you prefer and why?

8. Please offer any comments that might be used to improve any other aspects of the course (for example, the lab practical exams, the lab procedures, the lab room, etc.).

APPENDIX D

HUMAN SUBJECTS RESEARCH APPROVAL FOR RESEARCH PRESENTED IN CHAPTER 4

OFFICE USE ONLY
Project ID# ___________ Project Category: ___________ IRB Approval Date: ___________
Oracle ID# ___________ IRB Expiration Date: ___________

Iowa State University
Human Subjects Review Form

(Please type and use the attached instructions for completing this form)

1. Title of Project: Incorporation of the Science Writing Heuristic and Inquiry-based Procedures in the Chem 178L Course, General Chemistry Laboratory for Science and Engineering Majors

2. I agree to provide the proper surveillance of this project to insure that the rights and welfare of the human subjects are protected. I will report any adverse reactions to the committee. Additions to or changes in research procedures after the project has been approved will be submitted to the committee for review. I agree that all key personnel involved in conducting human subjects research will receive training in the protection of human subjects. I agree to request renewal of approval for any project continuing more than one year.

James A. Rudd, II	12/18/00	James A. Rudd, II
Typed name of principal investigator	Date	Signature of principal investigator
Chemistry	3051 Gilman Hall	Thomas J. Greenbowe
Department	Campus Address	

294-7718, jarudd@iastate.edu
Phone number and email

2a. Principal investigator
☐ Faculty ☐ Staff ☐ Postdoctoral ☒ Graduate Student ☐ Undergraduate Student

3. Typed name of co-principal investigator(s)	Date	Signature of co-principal investigator(s)
Thomas J. Greenbowe, Ph.D.	12/18/00	Thomas J. Greenbowe
Brian M. Hand, Ph.D.	12/18/00	[signature]

3a. Co-Principal investigator(s) (check all that apply)
☒ Faculty ☐ Staff ☐ Postdoctoral ☐ Graduate Student ☐ Undergraduate Student

3b. Typed name of major professor or supervisor (if not a co-principal investigator) | Date | Signature of major professor or supervising faculty member

4. Typed names of other key personnel who will directly interact with human subjects.

5. Project (check all that apply)
☒ Research ☒ Thesis or dissertation ☐ Class project ☐ Independent Study (490, 590, Honors project)

6. Number of subjects (complete all that apply)
\# adults, non-students 260 # ISU students # minors under 14 # other (explain)
\# minors 14-17

7. Status of project submission through Office of Sponsored Programs Administration (check one)
☐ Has been submitted ☐ Will be submitted ☒ Will not be submitted

7a. Funding Source: none

8. Brief description of proposed research involving human subjects: (See instructions, item 8. Use an additional page

if needed.) **(Include one copy of the complete proposal if submitting to a Federal sponsor.)**

Students enrolled in introductory undergraduate chemistry courses often are able to generate numerical answers to examination problems by memorizing and applying algorithms and formulas, but they exhibit a distinct lack of conceptual understanding of the topic. The Science Writing Heuristic has been shown to enhance students conceptual understanding of science topics when used in place of the standard laboratory report format. This project will compare the performance of students in Science Writing Heuristic Chem 178L laboratory sections with students in standard Chem 178L sections on the Chem 178L practical examinations (mid-term and final), the Chem 178 hour examinations, and on the Chem 178L pre-lab quizzes. These assessments are a normal part of course administration, and therefore, no extra work will be required of students. In addition, copies of twenty student laboratory reports from the SWH group and twenty from the standard group will be analyzed for accuracy of chemistry content and for effectiveness and completeness of writing. Submitting laboratory reports is a normal part of the Chem 178L course, and again, no extra work will be required of students. In the last week of the semester during laboratory check-out, students will be asked to complete a short survey to determine how much time they spent completing laboratory reports, how their reports helped with their understanding of chemistry, and how the experiments affected their attitudes about learning chemistry. It is anticipated that students will spend 5-8 minutes completing the survey.

Two Chem 178L sections are taught at each class meeting time. Four laboratory sections will be selected at random to use the SWH procedures, and the other section that meets at the same time will use the standard laboratory procedures. Four chemistry graduate students who have experience teaching introductory chemistry laboratory sections and who have been trained in the SWH and inquiry techniques will be assigned as teaching assistants in Chem 178L. Each of the four TA's will have an SWH section and a standard section.

The subjects of this study will be ISU undergraduate students enrolled in Chem 178L during the spring 2001 semester. Students enrolled in Chem 178L are predominately freshmen college students, and the range of ages for this group of students is 18-21. It is anticipated that there will be an equal number of male and female students in the SWH group and the standard group. Students in the eight sections of this study will be informed of the procedures of the study. Students in the SWH group will be informed that their participation is voluntary and that they may transfer to a standard lab section if they choose to decline participation.

9. Informed Consent: ☐ Signed informed consent will be obtained. (Attach a copy of your form.)
☒ Modified informed consent will be obtained. (See instructions, item 9.)

10. Confidentiality of Data: Describe below the methods you will use to ensure the confidentiality of data obtained. (See instructions, item 10.)

Access to copies of the laboratory reports and to copies of answers to the exams and quizzes will be restricted to the class instructors, to the teaching assistants, and to the investigators involved in the project. All investigators involved have received certification for participation in Human Subjects Research Assurance Training. The principal investigator will remind all project personnel of the need to maintain confidentiality of the data. The principal investigator and his major professor will maintain records in such a manner as to ensure that the names of the students will not be associated with data that is analyzed or displayed in subsequent research reports, presentations, or manuscripts submitted for publication.

11. Will subjects in the research be placed at risk or incur discomfort? Describe any risks to the subjects and precautions that will be taken to minimize them. (The concept of risk goes beyond physical risk and includes risks to subjects' dignity and self-respect as well as psychological or emotional risk. See instructions, item 11.)

There are no risks or discomforts to subjects as a result of this study.

12. **CHECK ALL** of the following that apply to your research:

- ☐ A. Medical clearance necessary before subjects can participate
- ☐ B. Administration of substances (foods, drugs, etc.) to subjects
- ☐ C. Physical exercise or conditioning for subjects
- ☐ D. Samples (blood, tissue, etc.) from subjects
- ☐ E. Administration of infectious agents or recombinant DNA
- ☐ F. Application of external stimuli
- ☐ G. Application of noxious or potentially noxious stimuli
- ☐ H. Deception of subjects
- ☐ I. Subjects under 14 years of age and/or
  - ☐ Subjects 14-17 years of age
- ☐ J. Subjects in institutions (nursing homes, mental health facilities, prisons, etc.)
- ☐ K. Pregnant women
- ☐ L. Research must be approved by another institution or agency (attach letters of approval)

If you checked any of the items in 12, please complete the following in the space below (include any attachments):

Items A-G Describe the procedures and note the proposed safety precautions.

Items D-E The principal investigator should send a copy of this form to Environmental Health and Safety, 118 Agronomy Lab for review.

Item H Describe how subjects will be deceived; justify the deception; indicate the debriefing procedure, including the timing and information to be presented to subjects.

Item I For subjects under the age of 14, indicate how informed consent will be obtained from parents or legally authorized representatives as well as from subjects.

Items J-K Explain what actions would be taken to insure minimal risk.

Item L Specify the agency or institution that must approve the project. If subjects in any outside agency or institution are involved, approval must be obtained prior to beginning the research, and the letter of approval should be filed.

OFFICE USE ONLY
EXPEDITED ____ FULL COMMITTEE____ ID#________

PI Name: **Title of Project:**

Checklist for Attachments

The following are attached (please check):

13. ☒ Letter or written statement to subjects indicating clearly:
    a) the purpose of the research
    b) the use of any identifier codes (names, #'s), how they will be used, and when they will be removed (see item 18)
    c) an estimate of time needed for participation in the research
    d) if applicable, the location of the research activity
    e) how you will ensure confidentiality
    f) in a longitudinal study, when and how you will contact subjects later
    g) that participation is voluntary; nonparticipation will not affect evaluations of the subject
14. ☐ A copy of the consent form (if applicable)
15. ☐ Letter of approval for research from cooperating organizations or institutions (if applicable)
16. ☒ Data-gathering instruments

17. Anticipated dates for contact with subjects:

First contact	**Last contact**
1/8/01	5/20/01
Month/Day/Year	Month/Day/Year

18. If applicable: anticipated date that identifiers will be removed from completed survey instruments and/or audio or visual tapes will be erased:

    6/20/01
    Month/Day/Year

19. Signature of Departmental Executive Officer — Date — Department or Administrative Unit

    P. Thiel ____________ 12/19/00

20. Initial action by the Institutional Review Board (IRB):

    ☐ Project approved ________ Date ☐ Pending Further Review ________ Date ☐ Project not approved ________ Date

    ☐ No action required ________ Date

21. Follow-up action by the IRB:

    Project approved ________ Date Project not approved ________ Date Project not resubmitted ________ Date

Patricia M. Keith ________________ ____________ ________________________
Name of IRB Chairperson Date Signature of IRB Chairperson

Attachment 12. Informed consent letters to be read and given to students

(standard letter followed by SWH letter)

We are working to improve the Chemistry 178L course by modifying the laboratory procedures to try to increase active student interest and involvement. As part of the evaluation of these modifications, we need to collect copies of your laboratory reports and copies of your answers to exams and quizzes. We will also need you to complete an anonymous survey during the semester. On the survey you will be asked to answer anonymously a few questions about how well the labs have helped you to learn chemistry. We will also be asking to interview a few of you to help us understand in more detail how well you feel the labs helped your learning. Your identity and name will remain confidential during the entire collection process, and all identifiers will be removed before we analyze the work we collect. We will code all the work we collect and remove your name so that everyone's identity will remain anonymous during the analysis process. Your chemistry teaching assistant or other chemistry instructors might see a summary of the data, but they will not see results containing anyone's identity. If the results of this project are significant, the anonymous data may be included as part of the data set in various publications or presentations.

The work we collect will not add or subtract points from your scores on lab reports, exams or quizzes in Chemistry 178 or 178L, and you will not have to do any extra work as part of this course evaluation. Also, students in a particular lab section are not at a greater advantage or disadvantage over students in another lab section as a result of this course evaluation. There are no known discomforts or risks to you, other than the normal discomforts and risks associated with taking any college chemistry course.

If you prefer not to have the results from the confidential analysis of your work be included in publications or presentations, please indicate this preference by marking the checkbox on this form, printing your name clearly below the checkbox, and returning this form to your instructor.

This project is part of our curriculum development process, and if you have any questions or need further information, please contact us at 294-7718 or by e-mail at tgreenbo@iastate.edu. Thank you.

Professor Thomas J. Greenbowe
Department of Chemistry, Iowa State University

☐ I do not want the analysis of my work to be included in publications or presentations.

____

We are working to improve the Chemistry 178L course by modifying the laboratory procedures to try to increase active student interest and involvement. As part of the evaluation of these modifications, we need to collect copies of your laboratory reports and copies of your answers to exams and quizzes. We will also need you to complete an anonymous survey during the semester. On the survey you will be asked to answer anonymously a few questions about how well the labs have helped you to learn chemistry. We will also be asking to interview a few of you to help us understand in more detail how well you feel the labs helped your learning. Your identity and name will remain confidential during the entire collection process, and all identifiers will be removed before we analyze the work we collect. We will code all the work we collect and remove your name so that everyone's identity will remain anonymous during the analysis process. Your chemistry teaching assistant or other chemistry instructors might see a summary of the data, but they will not see results containing anyone's identity. If the results of this project are significant, the anonymous data may be included as part of the data set in various publications or presentations.

The work we collect will not add or subtract points from your scores on lab reports, exams or quizzes in Chemistry 178 or 178L, and you will not have to do any extra work as part of this course evaluation. Also, students in a particular lab section are not at a greater advantage or disadvantage over students in another lab section as a result of this course evaluation. There are no known discomforts or risks to you, other than the normal discomforts and risks associated with taking any college chemistry course.

Most students have found that this course improvement has helped them to gain a better understanding of chemistry and to make better use of their time, but your participation in this course evaluation is optional. You may switch to the other lab section that is meeting at this class time or to another section that fits your schedule at any point in the semester as long as advance notice is given to your course instructor and teaching assistant.

This project is part of our curriculum development process, and if you have any questions or need further information, please contact us at 294-7718 or by e-mail at tgreenbo@iastate.edu. Thank you.

Professor Thomas J. Greenbowe
Department of Chemistry, Iowa State University

Attachment 16. Data-gathering instruments

I. Chem 178L pre-lab quiz

II. Chem 178L practical examination

III. Chem 178 hour examination

IV. Student survey

Chemistry 178L pre-lab quiz

Name: ___________
SS#: ___________
Lab section: _______

Table 1. Dissociation constants for acids and bases

Chemical name	Chemical formula	K_{a1}	K_{a2}
hydrofluoric acid	HF	6.8×10^{-4}	
propionic acid	CH_3CH_2COOH	1.3×10^{-5}	
sulfuric acid	H_2SO_4	greater than 1	1.2×10^{-2}

Chemical name	Chemical formula	K_b
ammonia	NH_3	1.8×10^{-5}
aniline	$C_6H_5NH_2$	4.3×10^{-10}

$$pH = pK_a + \log[A^-]/[HA]$$

1. A 0.1 M solution of sodium propionate $NaCH_3CH_2COO$ is
(a) acidic (b) basic (c) neutral (d) I don't know

Explain your reasoning.

2. Compare a 0.1 M solution of sodium propionate $NaCH_3CH_2COO$ to a 0.1 M solution of potassium fluoride KF. Which solution has a pH that is closest to 7 (is more neutral)?
(a) $NaCH_3CH_2COO$ (b) KF (c) I don't know

Explain your reasoning.

3. You have an aqueous solution of ammonia NH_3. When solid ammonium nitrate NH_4NO_3 is added,
(a) the solution will become more acidic (b) the solution will become more basic
(c) the solution will have no change in pH (d) I don't know

Explain your reasoning.

4. Which pair of 0.1 M aqueous solutions will form a buffer that is **basic** when they are mixed in approximately equal amounts?
(a) HCl and NaOH
(b) CH_3CH_2COOH and NaOH
(c) CH_3CH_2COOH and $NaCH_3CH_2COO$
(d) $C_6H_5NH_2$ and NaOH
(e) $C_6H_5NH_2$ and $C_6H_5NH_3Cl$
(f) none of these
(g) I don't know

Explain your reasoning.

5. Calculate the pH of a buffer that contains 0.25 M HF and 0.15 M KF. See Table 1 for K_a for HF.
(a) 1.74 (b) 2.95 (c) 3.17 (d) 3.39 (e) 4.59 (f) I don't know

Explain your reasoning.

6. An aqueous solution of Na_2SO_4 is
(a) acidic (b) basic (c) neutral

Explain your reasoning.

DR. MILLER/DR. GREENBOWE **CHEMISTRY 178L** **NAME________________**
SPRING 2000 **LABORATORY EXAM, PART I (48 POINTS)**
SOC. SEC. #______________

THIS IS AN EXAM! YOU MUST WORK ON YOUR OWN TO COMPLETE THE TASK. **LAB SECTION NUMBER___**

ALL THE EQUIPMENT YOU WILL NEED TO USE IS LOCATED IN YOUR PERSONAL LOCKER OR ON THE BENCH. USE THIS EXAM BOOKLET TO RECORD EXPERIMENT NOTES, RESULTS AND EXPLANATIONS. SHOW ALL OF YOUR WORK FOR FULL CREDIT!

PART I OF THIS EXAM CONSISTS OF <u>FOUR</u> TASKS ON <u>FOUR</u> PAGES. THE ESTIMATED TIME TO COMPLETE EACH TASK IS 15 TO 20 MINUTES. (MAXIMUM TIME FOR PART I IS 2 HOURS)

YOU WILL BE GIVEN PART II OF THIS EXAM DURING THE LAST HOUR OF THE LABORATORY PERIOD. (MAXIMUM TIME FOR PART II IS 1 HOUR)

Task 1. You will be given two samples in vials. The samples are 0.10 M acids, bases, or salts.
12 points Classify each sample. Write an explanation to support your claim. You must do at least
20 minutes two different experiments for each sample.

(2 pts.) Sample number ________________

(2 pts.) Procedure and evidence:

___ strong acid ____weak acid

___ strong base ____weak base

___ salt of a weak base ____salt of a weak acid

(2 pts.) Explanation

****

(2 pts.) Sample number ________________

(2 pts.) Procedure and evidence:

___ strong acid ____weak acid

___ strong base ____weak base

___ salt of a weak base ____salt of a weak acid

(2 pts.) Explanation

Task 2.
12 points
30 minutes

Prepare 50 mL of a buffer which will maintain a pH within your assigned range when up to 5 drops of 0.10 M H_3O^+ or 0.10 M OH^- are added to it. The reagents you will have available are: acetic acid ($pK_a = 4.74$), ammonia ($pK_b=4.74$), ammonium nitrate, hydrochloric acid, sodium acetate, sodium chloride, and sodium hydroxide, all 0.10 M.

If the last 2 digits of your social security number are within the range:
00 to 24 your assigned pH range is 4.4 to 4.8
25 to 49 your assigned pH range is 9.2 to 9.6
50 to 74 your assigned pH range is 8.8 to 9.2
75 to 99 your assigned pH range is 4.8 to 5.2

My target pH range is ___________

a.) (4 pts) Write a brief description of <u>your method</u> for preparing the buffer. <u>Justify why</u> you choose the solutions that you did.

Complete the table below showing the reagents used to prepare the buffer.

Reagent used	Quantity used

b.) (2 pts) Write the equilibrium equation for your buffer solution.

c. (3 pts) Results: You must mix the two solutions in the presence of your TA. TA initials ______

	pH
pH of the buffer (as measured by the TA)	______
pH of the buffer after adding some acid	______
or	
pH of the buffer after adding some base	______

d.) (3 pts) Explain the workings of your buffer system when a small amount of acid or base is added. Your written explanation should also include an equation(s).

e.) If your experimental pH did not match the target pH range, explain why and tell how you would revise your preparation so this new buffer would match the target pH range.

Task 3. Identify 2 solid salts as acidic, neutral, or basic.
12 points The tables of acid and base dissociation constants, posted at your lab bench, show the formula of
20 minutes the acid or base and the ions which result when the acid or base dissociates.

1st salt formula ________

a.) (2 pts) Predict if a solution of the salt in water will be acidic, neutral or basic before doing any experimentation. ____________

b.) (3 pts) Write an equation to support your prediction of the salt solution being acidic, neutral, or basic. Write a written explanation.

TA initials _______Pick up your salt after your TA initials your predicted pH and equation.

c.) (1 pt) Perform any experiments you wish to use to confirm your prediction.

d.) You may modify your prediction, but you must support it with an equation.

****

2nd salt formula ________

a.) (2 pts) Predict if a solution of the salt in water will be acidic, neutral or basic before doing any experimentation. ____________

b.) (3 pts) Write an equation to support your prediction of the salt solution being acidic, neutral, or basic. Write a written explanation.

TA initials _______Pick up your salt after your TA initials your predicted pH and equation.

c.) (1 pt) Perform any experiments you wish to use to confirm your prediction.

d.) You may modify your prediction, but you must support it with an equation.

Task 4.
12 points
30 minutes

Imagine performing these two experiments.

(I) You extract 2 mL of aqueous butyric acid with 2 mL of toluene. You completely separate the aqueous phase from the toluene phase. You then add 2 mL of toluene to the aqueous phase and extract the butyric acid from the aqueous phase a second time and separate the two phases.

(II) You extract 2 mL of aqueous butyric acid with 4 mL of toluene. You completely separate the aqueous phase from the toluene phase.

a. (2 pts.) PREDICT how the concentration of butyric acid (as determined by the number of drops of NaOH required to neutralize the acid) remaining in the aqueous phase will differ in these two experiments.

b. (2 pts.) Explanation.

____________OBTAIN YOUR TA'S INITIALS BEFORE PROCEEDING TO PARTS C-F
TA initials

****
c. (2 pts.) Perform any experiments to test your predictions. Experimental results:

d. (2 pts.) Calculation of K_{eq}

e. (2 pts.) Write the equilibrium equation for the system.

f. (2 pts.) Is this a physical or chemical equilibrium?

PROF. KEITH WOO
SPRING 2000

CHEMISTRY 178
HOUR EXAM II

NAME__________________

RECIT. INSTR.____________

RECIT. SECT.____________

THIS EXAM CONSISTS OF 6 QUESTIONS ON 6 PAGES

GRADING

QUESTION	POINTS	SCORE
I.	44 pts	______
II.	9 pts	______
III.	12 pts	______
IV	2 pts	______
V.	25 pts	______
VI.	8 pts	______
TOTAL	100 pts	______

NOTE: SHOW ALL OF YOUR WORK ON THESE EXAM PAGES. NUMERICAL ANSWERS SHOULD BE GIVEN IN THE CORRECT NUMBER OF SIGNIFICANT FIGURES. PUT YOUR ANSWERS IN THE ANSWER SPACES. THE LAST PAGE CONTAINS A **PERIODIC TABLE**, AND **USEFUL INFORMATION**. THIS MAY BE REMOVED AND USED FOR REFERENCE AND SCRATCH PAPER. DO NOT PUT ANSWERS ON THE TEAR AWAY PAGE.

Teaching Assistants and Recitation Sections

Name	Sections	Time
Guilong Cheng	12, 20	10:00, 3:10
Pramit Chowdhury	14, 15, 16	1:10, 3:10, 9:00
Tony Fischer	18	1:10
Nenad Grubor	1, 10	8:00, 12:10
Nick Keppel	4, 9	11:00, 9:00
Ying Liu	7, 8	2:10, 9:00
Heather Netzloff	19	2:10
Un-Mei Pan	17	12:10
Ling Xiao	5	12:10
Tijana Zarkovic	3, 6, 13	11:00, 1:10, 12:10
Dazhi Zhang	2, 11	8:00, 10:00

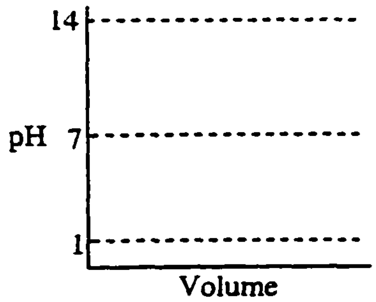
DO NOT BEGIN THIS EXAM UNTIL INSTRUCTED TO DO SO

THE ANSWER KEY TO THIS EXAM WILL BE POSTED ON BULLETIN BOARD #7 IN THE HALLWAY EAST OF ROOM 1002 GILMAN AND ON THE CHEM 178 WWW SITE.

CHEM 178 GROUP FINAL EXAM
MONDAY, MAY 1
7:00 - 9:00 P.M.

I. (44 pts) Multiple choice and short answer questions.

1. On the axes below, draw the titration curve for the titration of 0.10 M HF with 0.10 M KOH. Clearly label the equivalence point. Also indicate whether the pH of the equivalence point is 7, > 7, or < 7.



The pH at the equivalence point is (7, >7, <7) _________.

2. What is the molarity of an HOAc solution if 25.5 mL of this solution required 37.5 mL of 0.175 M NaOH to reach the equivalence point?

a) 0.119 b) 1.83×10^{-4} c) 0.257 d) 0.365

3. Which one of the following pairs could be used to make a buffer solution?

a) NH_3, CH_3CO_2Na
b) $NaNO_3$, NH_4Cl
c) CH_3CO_2H, NaOH
d) NaOH, NaCl

4. Calculate the molar concentration of bromide ions in a saturated solution of $HgBr_2$, $K_{sp} = 8.0 \times 10^{-20}$.

a) 1.4×10^{-10} M
b) 2.0×10^{-20} M
c) 5.4×10^{-7} M
d) 2.7×10^{-7} M

5. Consider the following table of K_{sp} values.

Compound	K_{sp}
CdS	8.0×10^{-27}
CuS	6.3×10^{-36}
PbS	8.0×10^{-28}
$MnCO_3$	1.8×10^{-11}

Which one of the compounds shown in the table is the least soluble?

a) CdS b) CuS c) PbS d) $MnCO_3$

6. A one-liter buffer is made from 0.25 moles of CH_3CO_2H and 0.25 moles of CH_3CO_2Na so that the pH = 4.74. If 10 mL of 0.10 M HCl is added to the buffer solution, the pH will:

a) not change at all
b) increase slightly
c) noticeably increase
d) decrease slightly
e) noticeably decrease

7. The reason for your answer in the previous question is
"...because the HCl reacts with the __________ present in the solution."

a) H_2O c) acetate ions e) none of these
b) H_3O^+ ions d) acidic acid

8. What is the pH at the equivalence point in the titration of 100 mL of 0.10 M HCl with 0.10 M NaOH?

a) 1.0 b) 6.0 c) 7.0 d) 8.0 e) 13.0

9. When a reaction is found by thermodynamics to be spontaneous,

a) it will be very rapid as written
b) it is possible for it to proceed as written without outside intervention
c) it is also spontaneous in the reverse direction
d) the equilibrium position lies very far to the left

10. Which one of the following can be determined exactly?

a) G b) H c) S d) all of these e) none of these

11. Which equation represents a reaction that is <u>decreasing</u> in entropy as the reaction proceeds?

a) $CaCO_3(s) \longrightarrow CaO(s) + CO_2(g)$
b) $2\ C(s) + O_2(g) \longrightarrow 2\ CO(g)$
c) $2\ Na(s) + 2\ H_2O(R) \longrightarrow 2\ NaOH(aq) + H_2(g)$
d) $2\ H_2(g) + O_2(g) \longrightarrow 2\ H_2O(R)$

II. (9 pts) Predict whether the following salts will form an acidic, basic, or neutral solution on dissolving in water. Write the net ionic equation to show the reaction of the salt with water.

a) $NaNO_2$ 1) acidic 2) basic 3) neutral

b) NH_4Br 1) acidic 2) basic 3) neutral

c) $LiNO_3$ 1) acidic 2) basic 3) neutral

III. (12 pts) Complete the table.

	ΔG^o	ΔH^o	ΔS^o
a) $Ag^+(aq) + Cl^-(aq) \rightleftharpoons AgCl(s)$ Reaction (a) is spontaneous.	_____	_____	_____
b) $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$ Reaction (b) is nonspontaneous	_____	_____	_____

IV. (2 pts) Write a balanced chemical reaction which produces H_2.

V. (25 pts) Given the following table of thermodynamic data compute ΔH^o, ΔS^o, and ΔG^o for the reaction at 25 °C.

$$3\ NO_2(g) + H_2O(R) \longrightarrow 2\ HNO_3(R) + NO(g)$$

	ΔH_f^o (kJ/mole)	S^o (J/mol K)
$NO_2(g)$	33.9	240.6
$NO(g)$	90.4	210.4
$HNO_3(R)$	−173.2	155.6
$H_2O(R)$	−285.8	69.9

a) (5 pts) ΔH^o calculation.

b) (5 pts) ΔS^o calculation.

c) (5 pts) ΔG^o calculation.

d) (5 pts) Calculate equilibrium constant at 25 °C.

e) (5 pts) Will the reaction be spontaneous at 200 °C? Explain your answer.

VI. (8 pts) Calculate the pH of the solution when 25.0 mL of 0.100 M HNO_2 ($K_a = 4.5 \times 10^{-4}$) and 20.0 mL of 0.100 M NaOH are mixed.

USEFUL INFORMATION

$K_w = 1.00 \times 10^{-14}$

$R = 8.31$ J/mol•K

$$pH = pK_a + \log \frac{[base]}{[acid]}$$

CH_3CO_2H, acetic acid $K_a = 1.8 \times 10^{-5}$

NH_3, ammonia $K_b = 1.8 \times 10^{-5}$

K_{sp} (AgCl, 25 °C) $= 1.8 \times 10^{-10}$

Periodic Table of the Elements

1A 1	2A 2	3B 3	4B 4	5B 5	6B 6	7B 7	8B 8	8B 9	8B 10	1B 11	2B 12	3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
1 H 1.01																	2 He 4.00
3 Li 6.94	4 Be 9.01											5 B 10.8	6 C 12.0	7 N 14.0	8 O 16.0	9 F 19.0	10 Ne 20.2
11 Na 23.0	12 Mg 24.3											13 Al 27.0	14 Si 28.1	15 P 31.0	16 S 32.1	17 Cl 35.4	18 Ar 39.9
19 K 39.1	20 Ca 40.1	21 Sc 45.0	22 Ti 47.9	23 V 50.9	24 Cr 52.0	25 Mn 54.9	26 Fe 55.8	27 Co 58.9	28 Ni 58.7	29 Cu 63.5	30 Zn 65.4	31 Ga 69.7	32 Ge 72.6	33 As 74.9	34 Se 79.0	35 Br 79.9	36 Kr 83.8
37 Rb 85.5	38 Sr 87.6	39 Y 88.9	40 Zr 91.2	41 Nb 92.9	42 Mo 95.9	43 Tc (98)	44 Ru 101	45 Rh 103	46 Pd 106	47 Ag 108	48 Cd 112	49 In 115	50 Sn 119	51 Sb 122	52 Te 128	53 I 127	54 Xe 131
55 Cs 133	56 Ba 137	57 La 139	72 Hf 178	73 Ta 181	74 W 184	75 Re 186	76 Os 190	77 Ir 192	78 Pt 195	79 Au 197	80 Hg 201	81 Tl 204	82 Pb 207	83 Bi 209	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226	89 Ac 227	104 Rf (261)	105 Ha (262)	106 Unh (263)	107 Uns (262)	108 Uno (265)	109 Une (266)									

Lanthanides	58 Ce 140	59 Pr 141	60 Nd 144	61 Pm (145)	62 Sm 150	63 Eu 152	64 Gd 157	65 Tb 159	66 Dy 162	67 Ho 165	68 Er 167	69 Tm 169	70 Yb 173	71 Lu 175
Actinides	90 Th 232	91 Pa 231	92 U 238	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

Please provide some feedback to us about the new laboratory report format so we can learn how to give better advice and direction. Please try to provide as many specific comments as you can. Thank-you.

Time issues

1. Compared to the previous lab report format, how much time did you spend on writing up a lab report under the new format after the lab experiment was finished? If the amount of time was different, by how many hours?

2. Which format do you think was a better use of your time?

3. Do you think the time needed to complete the lab reports is too much with the previous format, the new format or both formats?

Learning issues

3. Compared to the previous format, what do you think is more useful about the new format? And what do you think is less useful about the new format?

4. Compared to the previous lab format, how well do you feel you learned chemistry by using the new report format?

APPENDIX E

SURVEY QUESTIONS USED FOR DATA COLLECTION FOR RESEARCH PRESENTED IN CHAPTER 4

SURVEY QUESTIONS USED IN STANDARD SECTIONS

Chemistry 178L mid-term course evaluation and homework assignment 10 POINTS

Do not put your name on this sheet. Attach this sheet to your next lab report so you can receive credit.
This evaluation is supposed to be anonymous. Your TA will give you credit for completing the evaluation, and then give this sheet to Dr. Greenbowe. He is studying ways to improve the laboratory course, and he would like you to please make a sincere effort to answer the questions. There are no right or wrong answers, and your responses to the "Why" and "Explain" parts of the questions are most valuable. Please try to provide as many specific comments as you can. Thank-you.

Background information.

1. The most recent semester and year that you have completed
Chemistry 177______________________________
Chemistry 177L______________________________
Chemistry 178______________________________(if not currently enrolled in Chemistry178)

2. Your current enrollment classification:
freshman sophomore junior senior

3. Your current major:

Time issues.

1. Estimate the average amount of time you spent on preparing for an experiment (including time spent writing the pre-lab).

15 min or less 15-30 min about 45 min about 1 hr more than 1 hr 2 or more hrs

2. Do you think the time needed to prepare for lab is appropriate? Explain.

3. Estimate the average amount of time you spent outside of class to complete a lab report for an experiment.

15 min or less 15-30 min about 45 min about 1 hr more than 1 hr 2 or more hrs

4. Do you think the time needed to complete the lab report is appropriate? Explain.

5. In comparison to Chemistry 177L, does 178L take more, less, or about the same overall amount of time to prepare for class and complete lab reports?

Learning issues.

1. In comparison to Chemistry 177L, have you found Chemistry 178L to be more, less, or equally helpful to your learning of chemistry? Why?

2. How confident would you feel trying to explain any of the chemistry from the completed labs to a classmate?
1 = very confident 2 = confident 3 = less than confident 4 = not at all confident
Why?

Laboratory reports.

Title, Purpose, Outline of procedure, Data/Observations, Balanced Equations, Calculations, Graphs, Quality of Results, Discussion

1. Identify the part(s) of the lab report that helps you the most to understand a chemistry topic. Explain why.

2. Identify the part(s) of the lab report that helps you the least to understand a chemistry topic. Explain why.

Other issues.

1. Name at least one aspect of the Chemistry 178L course that you find effective. Why?

2. Name at least one aspect of the Chemistry 178L course that you would like to see improved. Why?

SURVEY QUESTIONS USED IN SWH SECTIONS

Chemistry 178L mid-term course evaluation and homework assignment 10 POINTS

Do not put your name on this sheet. Attach this sheet to your next lab report so you can receive credit.
This evaluation is supposed to be anonymous. Your TA will give you credit for completing the evaluation, and then give this sheet to Dr. Greenbowe. He is studying ways to improve the laboratory course, and he would like you to please make a sincere effort to answer the questions. There are no right or wrong answers, and your responses to the "Why" and "Explain" parts of the questions are most valuable. Please try to provide as many specific comments as you can. Thank-you.

Background information.

1. The most recent semester and year that you have completed
Chemistry 177____________________________________
Chemistry 177L___________________________________
Chemistry 178____________________________________ (if not currently enrolled in Chemistry 178)

2. Your current enrollment classification:
freshman sophomore junior senior

3. Your current major:

Time issues.

1. Estimate the average amount of time you spent on preparing for an experiment (including time spent writing the pre-lab).

15 min or less 15-30 min about 45 min about 1 hr more than 1 hr 2 or more hrs

2. Do you think the time needed to prepare for lab is appropriate? Explain.

3. Estimate the average amount of time you spent outside of class to complete a lab report for an experiment.

15 min or less 15-30 min about 45 min about 1 hr more than 1 hr 2 or more hrs

4. Do you think the time needed to complete the lab report is appropriate? Explain.

5. In comparison to Chemistry 177L, does 178L take more, less, or about the same overall amount of time to prepare for class and complete lab reports?

Learning issues.

1. In comparison to Chemistry 177L, have you found Chemistry 178L to be more, less, or equally helpful to your learning of chemistry? Why?

2. How confident would you feel trying to explain any of the chemistry from the completed labs to a classmate?
1 = very confident 2 = confident 3 = less than confident 4 = not at all confident
Why?

Laboratory reports.

Beginning Questions (provided by instructor), Beginning Questions (created by you), Test and Procedures, Observations, Claims, Evidence, Reflection

1. Identify the part(s) of the lab report that helps you the most to understand a chemistry topic. Explain why.

2. Identify the part(s) of the lab report that helps you the least to understand a chemistry topic. Explain why.

3. Do you prefer the laboratory report format used in Chemistry 177L or the format being used in Chemistry 178L? Why?

Other issues.

1. Name at least one aspect of the Chemistry 178L course that you find effective. Why?

2. Name at least one aspect of the Chemistry 178L course that you would like to see improved. Why?

APPENDIX F

LABORATORY PROCEDURES ON GENERAL EQUILIBRIUM USED IN STANDARD SECTIONS FROM CHAPTER 4

178L Experiment #1A: Introduction to Equilibrium

Physical and chemical processes can be considered as either reversible or irreversible processes. A common reversible physical process is the melting of ice to form water and the freezing of water to form ice at 0 °C. However not all physical processes are reversible. Consider the use of a wood chipper to mulch a small tree (or your partner in a kidnapping scheme gone bad). You will physically change the tree, but the mulching process is not reversible because you could not run the mulch "backwards" through the chipper to reproduce the tree (or your partner). This process of "mulch → tree" using a wood chipper is irreversible.

Chemical reactions are often associated with being irreversible, and a common example is the combustion of gasoline in the presence of air. Hydrocarbon fuels react with oxygen to form carbon dioxide and water as products, and the process is considered irreversible. Chemical reactions, however, are often reversible. For example, eyeglasses that can darken when exposed to light are able do so because of a reversible chemical reaction. Tiny crystals of silver chloride are finely dispersed throughout the glass of the lens, and these dispersed crystals appear invisible to the eye (similar to how sugar appears invisible when dispersed in water). When exposed to light, the silver chloride crystals dissociate into silver atoms and chlorine atoms. These metal atoms of silver appear gray and darken the lens. The reverse reaction of silver and chlorine atoms combining to form silver chloride starts to take place immediately, but the lens only becomes clear again in the absence of light which allows the silver chloride crystals to retain their original form and properties.

Equilibrium is the condition in which two opposing processes are occurring simultaneously and at the same rate. In the example of the photosensitive eyeglasses, an equilibrium condition exists when the amount of light that is present is constant. The opposing processes of silver chloride dissociation and silver chloride reformation occur simultaneously and at equal rates, and this is written as $AgCl \rightleftharpoons Ag + Cl$.

In this laboratory experiment you will investigate several reversible processes as an introduction to the equilibrium condition as applied to chemistry. For more discussion on equilibrium, see Chapter 15 in Chemistry: The Central Science by Brown, LeMay, Bursten

1. The physical equilibrium between bromine vapor and bromine liquid (for 20 min)

Your instructor will demonstrate the equilibrium between bromine in the gas phase and bromine in the liquid phase. Record your observations for each step in the demonstration.

If a computer animation of the bromine equilibrium is available, run the animation program and answer any questions.

2. The gas-phase chemical equilibrium between NO_2 and N_2O_4 (for 20 min)

Your instructor will demonstrate the equilibrium between NO_2 and N_2O_4. Record your observations for each step in the demonstration.

If a computer animation of NO_2 and N_2O_4 is available, run the animation program and answer any questions.

3. An investigation of the equilibrium of aqueous cobalt chloride (for 90 min)

An aqueous solution of cobalt chloride appears pink at low concentrations of chloride and blue at high concentrations of chloride. The pink color results from the presence of $Co(H_2O)_6^{2+}$ ions, usually called the hexa-aqua complex of Co^{2+}, and the blue color results from the presence of $CoCl_4^{2-}$ ions, usually called the tetrachloride complex of Co^{2+}. In this study, you will investigate the effect of changing the chloride concentration and the effect of changing the temperature on the equilibrium between $Co(H_2O)_6^{2+}$ ions and $CoCl_4^{2-}$ ions.

Set up a hot water bath at 85 °C using a 250-mL glass beaker. Also set up a hot water bath at 55 °C using a 250-mL glass beaker .

Obtain 4 mL of $Co(H_2O)_6^{2+}$ solution in a 13x100-mm test tube. Place the tube into the 85 °C bath, then place the tube into a cold water bath. Record your observations.

Let the tube reach room temperature. Add drops of the $CaCl_2$ solution until the solution appears blue in color, indicating the presence of high concentrations of $CoCl_4^{2-}$ ion. Add drops of column-purified H_2O until the solution appears pink in color, indicating the presence of high concentrations of $Co(H_2O)_6^{2+}$ ion. Record your observations.

Obtain 4 mL of $CoCl_4^{2-}$ solution in a 13x100-mm test tube. Add drops of column-purified H_2O until the solution contains mostly $Co(H_2O)_6^{2+}$ ions and appears pink in color. Now add 1.5 mL of the $CaCl_2$ solution. Record your observations.

Fill two 13x100-mm test tubes with 4 mL of $Co(H_2O)_6^{2+}$ solution in each tube. Place one tube into the 85 °C bath for a few minutes. Then place both tubes into the 55 °C bath, and record your observations.

Let the solutions reach room temperature, and then combine the two solutions. Set up an ice bath in your 400-mL plastic beaker. To the combined solution, add drops of the $CaCl_2$ solution until the solution appears purple in color. Fill two 13x100-mm test tubes with 4 mL of this purple solution in each tube. Place one tube in the 85 °C bath and the other tube into the ice bath. Record your observations.

Fill a single 13x100-mm test tube about 2/3 full of this purple solution. Place the tube into the 85 °C bath until the solution appears blue in color, then immediately place only the bottom third of the tube into the ice bath for about 60 seconds (so that half of the solution is in the ice, and half the solution is not in the ice). Occasionally remove the tube from the ice very briefly, and record your observations.

If a computer animation of aqueous cobalt chloride is available, view the animation program and record your observations.

- Is there a reversible reaction for an aqueous solution of cobalt chloride?
- Write the equation for the aqueous reaction of cobalt chloride. If the reaction is irreversible, us the single arrow, $\rightarrow$, to show the direction of the reaction. If the reaction is reversible, use the double arrow, $\rightleftharpoons$, to show reversibility.
- Is there a separate purple form of cobalt chloride? Explain.
- Was an equilibrium condition achieved with aqueous cobalt chloride? Explain.
- Did the temperature have an effect on any equilibrium condition or position? Explain.

4. An investigation of the equilibrium of aqueous ferric ion (for 30 min)

Obtain 4 mL of column-purified H_2O in a 13x100-mm test tube. Add 1 drop of 0.5 M $NH_4Fe(SO_4)_2$(aq). Then add 1 drop of 1 M KSCN(aq). Record your observations. Now divide the resulting solution equally among three 13x100-mm test tubes. Add 1 drop of 0.5 M $NH_4Fe(SO_4)_2$(aq) to the first solution, and add 1 drop 1 M KSCN(aq) to the second solution. Use the third solution as a reference solution, and record your observations.

- Is there a reversible reaction for a solution of Fe^{3+}, SCN^-, and $Fe(SCN)^{2+}$?

- Write the equation for the reaction of Fe^{3+} and SCN^-. If the reaction is irreversible, use the single arrow, $\rightarrow$, to show the direction of the reaction. If the reaction is reversible, use the double arrow, $\rightleftharpoons$, to show reversibility.
- Was an equilibrium condition achieved with Fe^{3+} and SCN^-? Explain.

Report for Introduction to Equilibrium:

This experiment requires one laboratory period. The report is due at the beginning of the following laboratory period.

The report should include the following sections:

Title, Purpose, Outline of procedure, Data/Observations, Balanced equations, Calculations, Graphs, and Discussion.

Grading Form for Introduction to Equilibrium:

Cut out this form and staple it to your report.

					Points
Title	No (0)	Yes (1)			______
Purpose	No (0)	Yes (1)			______
Outline of procedure	None (0)	Major omissions (1)	Minor omissions (2)	Complete (3)	______
Data/ Observations	None (0)	Major omissions (1)	Minor omissions (2)	Complete (3)	______
Balanced equations	None (0)	Major omissions (1)	Minor omissions (2)	Complete (3)	______
Quality of results	Poor (0)	Close (1)	Good (2)	Great (3)	______
Discussion	None (0)	Major omissions (1)	Minor omissions (2)	Complete (3)	______

<u>TA Evaluation</u>

The student was adequately prepared to perform the experiment.	No (0)	Yes (1)	______
Overall, the student demonstrates a reasonable understanding of the experiment by doing the work with minimum confusion, by analysis of the data, and by the discussion of the results.	No (0)	Yes (1)	______

Total points (19 maximum) ______

APPENDIX G

LABORATORY PROCEDURES ON GENERAL EQUILIBRIUM USED IN SWH SECTIONS FROM CHAPTER 4

178L Experiment #1A: Introduction to Equilibrium

Most people believe that chemical processes are "irreversible" and that physical processes are "reversible." However, these definitions for chemical and physical processes are extremely limited and not very useful. Consider the use of a wood chipper to mulch a small tree (or your partner in a kidnapping scheme gone bad). You will physically change the tree, but the mulching process is not reversible because you could not run the mulch "backwards" through the chipper to reproduce the tree (or your partner). This pathway of "mulch → tree" using a wood chipper is a one-way pathway. There may be another pathway to regenerate the tree, but this particular path using the wood chipper is one-way only.

In first semester general chemistry, almost all the chemical processes presented are one-way processes so it seems that chemical processes are always one-way pathways. This is completely untrue. Many chemical processes are actually two-way pathways, and you will be investigating two-way pathways in this laboratory activity.

A two-way chemical pathway has been put to practical use in eyeglasses that can darken when exposed to intense light. Tiny crystals of silver chloride are finely dispersed throughout the glass of the lens, and these dispersed crystals appear invisible to the eye (similar to how sugar appears invisible when dispersed in water). When exposed to intense light, the silver chloride crystals dissociate into isolated silver atoms and isolated chlorine atoms. The metal atoms of silver appear gray and cause the lens to darken in color. Yet as soon as silver and chlorine atoms form, the reverse process of the atoms combining to reform the more stable silver chloride starts to take place immediately. The intense light favors the direction of making atoms, but as soon as the light is removed, the reformation of invisible crystals dominates until there are not enough silver atoms to darken the lens. The "invisible crystals → silver and chlorine atoms" process and the "silver and chlorine atoms → invisible crystals" process occur simultaneously so the chemical pathway must be a two-way pathway. Two-way pathways are written as "invisible crystals $\rightleftharpoons$ silver and chlorine atoms" and are given the term "equilibrium processes."

In this lab activity, you will investigate equilibrium processes of cobalt compounds and of iron compounds. For more discussion on equilibrium, see Chapter 15 in Chemistry: The Central Science by Brown, LeMay, Bursten

Investigation of cobalt chloride

A solution of cobalt (II) chloride appears pink sometimes and appears blue sometimes. The pink color results from $Co(H_2O)_6^{2+}$ ions, and the blue color results from $CoCl_4^{2-}$ ions. So at a high concentration of chloride, the solution appears blue, and at a low concentration of chloride, the solution appears pink. In addition to chloride concentration, the temperature can affect the color of the solution.

One group in each class should set up two hot water baths for the entire class to use. Set up an 85 °C water bath and a 55 °C water bath using 250-mL glass beakers. You may set up extra baths if you desire.

Part 1. What's in there? (for 20 min)

Obtain about 4 mL of the pink stock solution in a small test tube. Place the tube into the 85 °C bath, and observe what happens. Now place the tube into a cold water bath, and observe what happens. What do you think is happening? You may repeat these steps as often as you desire.

Save this solution for Part 2.

Part 2. What direction can it go? (for 20 min)

Let the tube reach room temperature, and then add drops of dissolved $CaCl_2$ until the solution is blue. Now add drops of column-purified H_2O until the solution is pink.

Obtain 4 mL of the blue stock solution in a small test tube. Add drops of column-purified H_2O until the solution is pink. Now add 1.5 mL of dissolved $CaCl_2$.

Discard these solutions when you are finished.

How do you explain what happened?

Part 3. What's going on inside? (for 30 min)

Fill two small test tubes with 4 mL of the pink stock solution in each tube. Place one tube into the 85 °C bath until the solution is blue. While the solution is blue, place both tubes into the 55 °C bath, and observe what happens. You may repeat these steps as often as you desire.

Cool the solutions to room temperature, and then combine them. Set up an ice bath in your largest plastic beaker. To the combined solution, add drops of dissolved $CaCl_2$ until the solution is purple. Fill two small test tubes with 4 mL of the purple solution in each tube. Place one tube in the 85 °C bath. Place the other tube into the ice bath. How do you explain what is happening? You may switch the tubes between the 85 °C bath and the ice bath as often as you desire.

Put enough purple solution in a single tube to fill the tube about 2/3 full. Place the tube into the 85 °C bath until the solution is blue, then immediately place only the bottom third of the tube 3 into the ice bath for about 60 seconds (so that half of the solution is in the ice, and half the solution is not in the ice). Occasionally remove the tube from the ice very briefly to observe what is happening. How do you explain what happened?

Investigation of iron thiocyanate

Part 4. Why is this allowed to happen? (for 15 min)

Add 1 drop of 0.5 M $NH_4Fe(SO_4)_2$(aq) to a small test tube that is half-filled with column-purified H_2O. Then add 1 drop of 1 M KSCN(aq). Now divide the resulting solution equally among 3 tubes. Use tube 1 as a reference. Add 1 drop of 0.5 M $NH_4Fe(SO_4)_2$(aq) to tube 2, and observe what happens. Add 1 drop 1 M KSCN(aq) to tube 3, and observe what happens. How do you explain what happened?

Investigation of NO_2 and N_2O_4 (for 10 min)

The sealed tube contains NO_2 vapor which is brown and N_2O_4 vapor which is colorless. With your instructor's help, carefully cool the tube in liquid nitrogen, and observe what happens. Let the tube warm back to room temperature, and observe what happens.

If a computer animation of NO_2 and N_2O_4 is available, observe the animation program and explain how the animation relates to your observations of what happened in the sealed tube.

Investigation of bromine (for 10 min)

The sealed tube contains bromine as a liquid and bromine as a vapor. With your instructor's help, carefully cool the tube in liquid nitrogen, and observe what happens. Let the tube warm back to room temperature, and observe what happens.

If a computer animation of the bromine equilibrium is available, observe the animation program and explain how the animation relates to your observations of what happened in the sealed tube.

Report for Introduction to Equilibrium:

This experiment requires one laboratory period. The report is due at the beginning of the following laboratory period.

The report should include the following sections:

Questions, Tests and Procedures, Observations, Claims, Evidence, and Reflection.

Grading Form for Introduction to Equilibrium:

Cut out this form and staple it to your report.

		Points
Questions	(2)	______
Tests/Procedures	(1)	______
Observations	(2)	______
Claims	(3)	______
Evidence	(4)	______
Reflection	(3)	______
Total points (15 maximum)		______
