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Grading the General Chemistry Laboratory: A Constructivist Approach.

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GRADING THE GENERAL CHEMISTRY LABORATORY:

A CONSTRUCTIVIST APPROACH

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Constructivist theories of learning posit that instructors cannot transfer their knowledge to students; students must actively construct their own understanding. The Inter-Chem-Net project uses technology and instrumentation to provide an individualized experience within the large general laboratory course, effectively establishing a constructivist methodology. A grading rubric was developed to communicate course expectations and provide an easy and reliable method of evaluating student work in the general chemistry laboratory. The grading rubric separates the learning outcomes into a checklist of skills associated with each particular grade. This checklist provides detailed feedback for individualized choices of experiments, a key component of the Inter-Chem-Net model. Questionnaires were used to evaluate the impact of the grading rubric on the students and teaching assistants. The results were compared to student evaluation data from the previous year's pass/fail grading system. Results

suggest the rubric helps students navigate course expectations and provides a consistent grading scheme across multiple sections of the course.

ACKNOWLEDGEMENTS

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INTRODUCTION

Constructivist theories of learning posit that instructors cannot transfer their knowledge to students; students must actively construct their own understanding (Piaget, 1970; Resnick and Klopfer, 1989; Tobin, 1993). According to the theory, "people are not recorders of information, but builders of knowledge structures" (Resnick and Klopfer, 1989, p. 4). This model of learning then structures the dynamic relationship between how teachers teach and how students learn (Lunenburg, F. C., 1998). General chemistry laboratory coursework enables students to construct such understanding by exploring chemical phenomena, applying chemical concepts, and analyzing scientific data (Shiland, 1998). The Inter-Chem-Net project at the University of Maine uses technological innovations in the general chemistry laboratory to establish a constructivist model of learning. This model includes individualized assignments, discovery-based experiments using instrumentation and online evaluation and feedback. A grading rubric was developed and evaluated to determine whether an "A-F" grading structure rather than a "pass/fail" system enhances these learning outcomes of the laboratory course.

Statement of the Problem

The laboratory is a well-established and vital component of science courses, but instructors face the difficult challenge of assigning grades for student work in this discovery part of the course. In large, introductory courses,

graduate students with little or no teaching experience inherit the complex grading task and assign grades based upon their own background and experience rather than on a set of clearly defined goals. Many students then play a cat and mouse game to determine the minimum amount of effort needed to pass the course. To define the expectations of a new laboratory structure featuring choice and individualized assignments, a grading policy was needed to ensure fair and consistent grading for every student.

Background of the Problem

Proper evaluation of student work requires the identification of targeted learning goals followed by the determination of appropriate ways to measure student achievement of these learning goals (Herron & Nurrenbern, 1999). Fueled by "A Nation at Risk: The Imperative for Education Reform" (National Commission on Excellence in Education, 1983), standards, assessment, accountability and grading have emerged as dominant issues in American education in the last ten years. One of the methods used to evaluate performance assessments is a grading "grid" or checklist known as a "rubric." Such rubrics list the desired outcomes for a particular task and then use a grid to reflect varying degrees of accomplishments with traditional grades (A,B,C,D,F) or descriptions such as expert, competent, and novice. Popham (2000) suggests that rubrics have been used successfully for assignments ranging from essay writing to presentations. For example, rubrics are currently being used to grade large numbers of writing samples in statewide testing applications such as the

Maine Educational Assessments, and also have been adopted in numerous school districts throughout the country to provide a reliable system for assessing student work. Rubrics have proven most successful with tasks that are traditionally difficult to grade, and laboratory reports in large, introductory courses offer another application of this type of assessment.

Formal lab reports reflect a student's understanding of an experiment but are time-consuming and difficult to grade. For these reasons, the general chemistry laboratory course at the University of Maine was a "pass/fail" course until the 1999-2000 school year. Within this structure, students would prepare and submit laboratory data in the form of duplicate sheets from a notebook, and graduate students would grant a subjective "passed" or "failed" verdict. This type of feedback is inconsistent with the sort of detailed and specific feedback that encourages learning. However, the course was changed to a "graded" status in the fall of 2000, reflecting a new laboratory initiative called the Inter-Chem-Net Project. The grading rubric was designed to provide a reliable, easy-to-use grading tool for this new laboratory structure.

The Inter-Chem-Net Project

The Inter-Chem-Net project applies innovations in instrumentation and technology to the teaching laboratory. Encompassing a large reform effort in the University of Maine's general chemistry program, three specific applications of technology have defined the Inter-Chem-net model of learning. The first innovation is the cost-effective use of advanced instrumentation in large, general

chemistry laboratories. Instruments such as UV-visible and Fourier Transform Infrared Spectrometers play a pioneering role in chemistry, and they are an essential yet expensive component of any meaningful laboratory curriculum. Hence, these instruments are often avoided in the typical introductory laboratory course because they are expensive and difficult to use. The Inter-Chem-Net system simplifies their use through technological innovations. With this system, students use a simple interface to collect data on an instrument, and the student's data is automatically saved to a networked server. Students then use a web-based program to analyze their data from a separate computer, allowing hundreds of students to use a few instruments easily and efficiently. Students then perform experiments that emphasize fundamental chemical concepts by combining traditional and instrumental techniques.

The second component of the Inter-Chem-Net model is a laboratory browser application called the Lab Navigator. It is a web-based database program that offers an individualized approach to laboratory instruction. Through the Lab Navigator, students can choose an experiment, access background and safety information, and obtain immediate feedback on their results. At the same time, the Lab Navigator records student responses to questions evaluating their opinions of the experiment. For example, a module called "ICN Snapshots" records student responses to questions such as "Overall, how would you rate this lab?". At the instructor's discretion, students may also view other students' responses to these questions. Similarly, instructors can monitor student responses as part of the ongoing evaluation of each experiment. The Lab

Navigator is currently under active development and was used during the spring semester 2000 and again in the spring semester 2001.

The third innovation of the Inter-Chem-Net model is use of the Internet to distribute curriculum and chemical information unavailable in a traditional laboratory manual. The Internet provides electronic access to procedures, techniques, safety data, and sample problems, facilitating the laboratory process. In the Inter-Chem-Net model, this process involves (a) choosing an experiment, (b) preparing for the experiment, (c) performing the experiment, and (d) documenting the results. To choose an experiment, students use the Lab Navigator to view the entire curriculum but only choose those experiments available during a particular week. The experiments are organized according to the lecture text chapters and are made available in modules throughout the semester, offering students a choice of the sequence and selection of experiments (see Table 1.1).

Table 1.1. Sample Schedule of General Chemistry Experiments (Fall 2000)

Experiment	Weeks available
Chapter 01: Matter and Measurement	
• Slime and Superball	Sept 11
Chapter 02: Atoms, Molecules, and Ions	Sept 18
• Identifying Ions Using Paper Chromatography and UV-Visible Spectroscopy	
Chapter 03: Stoichiometry	Sept 25, Oct 2
• Recycling Aluminum	
• Synthesis of Iron Oxide: Determination of an Empirical Formula	
Chapter 04: Aqueous Reactions	Sept 25, Oct 2
• At Home With Chemistry	
• Precipitation	
--experiments deleted--	
Spectroscopy Applications	Nov 27, Dec 4, Dec 11
• Determination of Copper in Brass	
• Caffeine Concentration in Soft Drinks	

Once a student has chosen an experiment, the second part of the Inter-

Chem-Net process is preparing for the laboratory by completing a "prelab"

assignment (see Figure 1.1).

Figure 1.1. Sample "Prelab" Assignment

Pre-Lab Assignment:

In your lab notebook, prepare the following information:

1. View the video clips on <u>Using the UV-visible spectrometer</u>, <u>Using the Balance</u>, and <u>Making Solutions and Dilutions</u>. You will need <u>Quick Time</u> video player to see them.

2. A brief (2-3 sentence) introduction to the lab.

3. A table of <u>safety information</u> including the chemicals used in the lab and any safety handling precautions. This information can be obtained from the MSDS safety sheets.

4. Calculate the weight of 0.00010 moles of your assigned dye.

   **Give the information to your TA at the beginning of the lab.
   You will not be allowed to work in the lab without this
   information.**

This assignment consists of a brief introduction describing the purpose of the

experiment and a table of safety information outlining any safety precautions

associated with each chemical. The Material Safety Data Sheet (MSDS) for each

chemical in the experiment is also linked to a list of chemicals in the lab handout.

Similarly, students are able to view video clips of any lab techniques needed. For

some experiments, stoichiometric calculations are required to determine the

quantity of chemical reagents required for a particular reaction; for others,

students use the prelab to create data tables to organize data both conceptually

and on paper. Since the experiments only provide step-by-step procedures for

hazardous manipulations, this prelab assignment is essential to ensure students work safely and productively in their individualized laboratory activities.

The next step in the Inter-Chem-Net laboratory process is performing the experiment. The Lab Navigator assigns each student an individualized assignment for each experiment. For instance, one student might receive "Unknown A" for a particular experiment while another assignment receives "Unknown B." The discovery experiments also vary in difficulty and content, providing detailed instructions for any hazardous procedures (see Figure 1.2).

Figure 1.2. Sample Discovery Procedure

Diluting the Assigned Dye

--lines deleted--

2. Fill a UV-vis cuvet 3/4 full of the stock solution and scan its spectrum. Based on your spectrum, dilute the stock solution volumetrically until the maximum "useful" concentration of the dye solution is determined. A "useful" spectrum has a smooth peak instead of a jagged "offscale" peak.
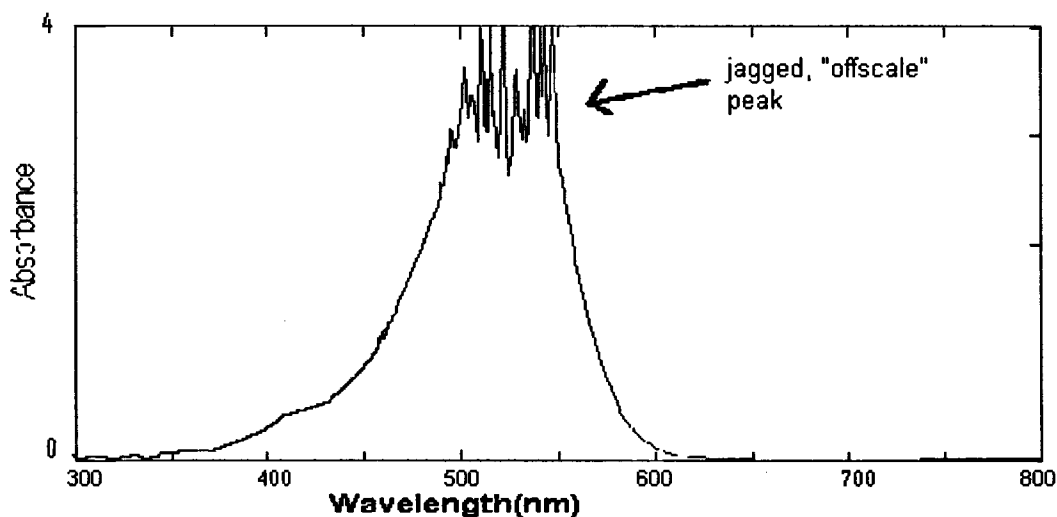
Based on this concentration, make 5 or 6 volumetric dilutions until the minimum detectable amount is reached.

Record the dilution factors and calculate the concentration in molarity of each dilution. See the section on dilution (p 130) in your text.

Students work independently or with a partner on a chosen experiment, but move freely either to an instrument room to collect data or to the computer room to analyze and process the data. The instrument and computer room also have TAs available to answer questions.

The final part to the lab process is a reflection on and documentation of the results of the experiment. A "post lab assignment" is included in each laboratory handout as a guide for completing the lab. This post lab assignment

outlines the requirements for each experiment, including necessary data, graphs, and calculations. It also includes questions to help establish a connection between the experiment and the corresponding lecture material. Students then submit a laboratory report that outlines the important aspects of the experiment (see Appendix B). These laboratory reports then reflect the goals of the course: exploring phenomena, connecting practical applications with abstract concepts, and processing and analyzing scientific data. A grading scheme was needed to provide consistent feedback and expectations within the individualized format of the Inter-Chem-Net model.

Overview of the Method

The investigation was conducted during the 1999-2000 and 2000-2001 school years. During the first year of the study, the course was graded as "pass/fail." In the fall semester, the general chemistry laboratory course was divided into two groups. One group used the Inter-Chem-Net model while the other group used the traditional model of learning with a laboratory manual. All of the students were assigned pass/fail grades by submitting notebook copies of their lab results. The students in both groups completed Pre Test and Post Test evaluations. In the spring semester, all of the students used the Inter-Chem-Net model under the pass/fail grading system. In the summer of 2000, a grading rubric was developed to outline student objectives for the course and assign a grade based on these outcomes. These objectives include preparing a prelab assignment, performing the experiment, and writing a laboratory report. In the fall

of 2000, all students used the Inter-Chem-Net model with the new grading policy. The grading policy was evaluated using student and TA questionnaires. In January of 2001, the grading expectations were modified and evaluated in the spring semester using the newly developed "Snapshot" assessment module of the Lab Navigator program. The web-based program prompted students for feedback after every experiment and displayed the responses instantaneously, providing "snapshots" of student attitudes throughout the semester. Three Snapshot questions were used to monitor student attitudes about the course expectations and grading rubric.

Table 1.2. Overview of the Study

semester	Instructional model	Grading system	Method of evaluation
Fall 1999	Group 1: Inter-Chem-Net Group 2: Traditional with laboratory manual	Pass/fail	Pre Test/Post Test Focus groups Pre Test/Post Test
Spring 2000	All Inter-Chem-Net	Pass/fail	University questionnaire
Fall 2000	All Inter-Chem-Net	A-F	University questionnaire
Spring 2001	All Inter-Chem-Net	A-F	Lab Navigator snapshots

Literature Review

Constructivist learning theory states that knowledge is constructed in the mind of the learner, and instructors cannot simply feed knowledge to willing recipients. Shiland (1999) applies five postulates of this learning theory to the laboratory environment. The first states that learning requires mental activity. This application involves modifying experiments to encourage students to design

parts of the procedures, identify variables and construct subsequent data tables. The second states that naïve theories affect learning, and Shiland suggests moving experiments to the beginning of the chapter, allowing students to make predictions and explain them before the experiment. The third states that learning occurs from dissatisfaction with present knowledge, and experiments should be designed as problems to challenge this knowledge. The fourth suggests that learning has a social component that needs to be addressed through opportunities to discuss results and predictions with other students and instructors. Finally, the fifth postulate states that meaningful learning needs to connect theoretical principles with practical applications. All of these elements are part of the Inter-Chem-Net model, establishing a constructivist model of learning.

In other applications of the constructivist model, Blakely (2000) and Kildahl and Varco-Shea (1996) have developed a laboratory format in which students design procedures to solve chemical problems and minimize "cookbook" procedures. The grading policies in these programs then reflect a balance of time considerations: relying on a mixture of summary sheets for data, practical exams, and formal laboratory reports. Both authors discuss the challenge of assigning grades to discovery procedures, grappling with summary sheets nicknamed the "1040" form (Blakely, 2000) for difficult calculations and cumbersome laboratory reports. Similarly, the Inter-Chem-Net model needed an effective evaluation tool to support a constructivist model of learning.

Scientific writing is a key component of the laboratory experience, and a logical, well-written argument supported by the orderly presentation of data demonstrates both understanding of the content and sophisticated analytical skills. This scientific writing ability is also a highly marketable skill. Hence, one important aspect of evaluating student work in the laboratory is the written report, but these reports are cumbersome and difficult to grade consistently and reliably. According to a national curriculum survey in 1993 (Taft, 1997), student laboratory reports are the most common method of assigning grades in the laboratory course with a large number of schools surveyed using "judgement of the instructor" as part of the grade. In addition, approximately one half of the schools surveyed use written examinations and one-fourth rely on laboratory practicals to assign grades. Given the difficulties of evaluating written reports, many schools use "fill in the blank" or short answer forms in place of formal reports. Very little research supports or refutes the benefits of using formal reports versus summary sheets. In one study, high school chemistry students used a teacher-prepared report sheet, an essay report, or no report (Torop, 1969). Students using the more structured report forms then received the higher marks on a CHEM Study Final achievement test. However, this finding could be due to a variety of factors, including the practice of answering similar questions to those on the test. Similarly, some attempts have been made to develop a system for grading laboratory reports (Gratz, 1990; Brillhart & Debs, 1981), but these grading efforts have focused on just the laboratory report rather than the entire laboratory experience.

In addition, most laboratory programs use one of these traditional methods of grading as part of the expository or "cookbook" method of laboratory instruction. A 1996 survey on the pedagogical methods of general chemistry laboratory programs (Abraham et al., 1997) found that 91 % of responding schools use the expository method with students following step-by-step instructions from a laboratory guide. The survey also found that laboratory reports are the major contributor to the grade, but 71 % of schools responding also use prelab quizzes for up to a quarter of the grade. Similarly, 60 % of schools grade laboratory reports mainly on consistency between data and conclusion. The survey makes no mention of the type or form of these laboratory reports. These findings demonstrate a remarkable consistency over time. A 1952 survey (Currier, 1953) showed very similar results, although the trend reflected an emphasis on quizzes as a major portion of the grade. One teacher in this study commented: "Too many students rely on fraternity files for their formal reports. The laboratory examination tends to 'square things up'" (Currier, 1952, p. 208). Another common comment was "I wish I knew some really good ways to make students think and learn in the laboratory" (Currier, 1952, p. 208). The study also reported that larger institutions tended to use a percentage rating of various items such as quizzes, notebooks, and unknowns to determine the grade while smaller institutions tended to use a subjective and composite rating as the basis for the grade.

Chapter 2

PASS/FAIL COURSE (1999-2000)

The first study was conducted during the 1999-2000 school year with the general chemistry laboratory course at the University of Maine. During the fall semester, approximately 550 students took the one-credit laboratory course along with the three-credit lecture course. 16 teaching assistants (TAs) taught 26 laboratory sections under the direction of a faculty instructor and a laboratory manager. Each laboratory section consisted of 16-24 students; approximately 45 % of these students majored in science, 25 % in engineering, and 30 % in non-science or undecided fields. During the spring semester, 9 TAs taught 14 laboratory sections with approximately 200 students.

Method

Student Pre Test/Post Test (Fall 1999)

26 laboratory sections were divided into two groups: (a) the Inter-Chem-Net group and (b) the traditional group. 10 of the 26 sections (approximately 230 students) were assigned to the Inter-Chem-Net group and 16 sections (approximately 370 students) were assigned to the traditional group. The Inter-Chem-Net group used the new curriculum and instruments in the laboratory, and students chose which experiments they wanted to perform each week. All of the experiments in this group involved instrumentation. The traditional group used the traditional curriculum and experiments without instruments, performing the

prescribed experiments each week. All of the students were asked to complete a pre test and a post test, consisting of background, attitude, and content questions (see Appendix A).

Inter-Chem-Net Focus Groups (Fall 1999)

In addition to the student questionnaire, approximately 175 students using the Inter-Chem-Net curriculum and instruments also participated in focus group discussions during the last class of the semester. Each laboratory section met for twenty to thirty minutes with the author to discuss the strengths and weaknesses of the course. Student responses were recorded under the topics of instruments, instruction, and curriculum. At the end of the session, each student received three orange stickers. The students were instructed to place the stickers by the two most significant responses about the topics discussed. The comments from each section were then consolidated, and the number of orange stickers recorded for each particular comment.

Student Exit Questionnaire (Spring 2000)

During the spring semester, approximately 240 students took the second semester of the general chemistry laboratory course. The one credit lab course accompanied the three credit lecture course and was graded "pass/fail." 8 T As taught 14 lab sections with approximately 220 students. All of the students used the Inter-Chem-Net instruments and chose experiments using the web-based Lab Navigator program. 209 students completed an exit questionnaire at the end of the spring semester 2000. The standardized University of Maine student

evaluation questionnaire consisted of multiple choice evaluation questions as well as a separate sheet for comments and suggestions (see Appendix B). Question numbers 30-33 of the questionnaire were evaluated.

Results

Student Pre Test/Post Test (Fall 1999)

338 students completed a pre test containing background, attitude and content questions (see Appendix A). 134 of these students then used the Inter-Chem-Net curriculum and instruments in the laboratory course. The remaining 204 students used the traditional curriculum without the instruments. All 338 students then answered the same questions in December 1999 as a post test.

According to the background questions on the pre test, 21 % of the students majored in physical or biological sciences, 15 % in chemistry, 10 % in environmental science, 23 % in engineering, and 32 % in non-science or undecided fields. 95 % of the students reported one or more years of high school chemistry; and 76 % reported "high" or "moderate" levels of computer experience.

134 students in the Inter-Chem-Net group responded to three attitude questions (A1-A3) and nine content questions (C1-C9) on both the pre test and the post test. The frequency of each response for each choice was recorded with the correct answer in bold (see Table 2.1).

Table 2.1. Pre Test/Post Test Results for Inter-Chem-Net Group (Fall 1999)

Question	Pre Test				Post Test			
	a	b	c	d	a	b	c	d
A1	14 %	75 %	11 %	--	12 %	75 %	11 %	2 %
A2	32 %	66 %	7 %	7 %	17 %	78 %	3 %	2 %
A3	22 %	45 %	25 %	8 %	11 %	40 %	31 %	19 %
C1	16 %	**57** %	5 %	21 %	8 %	**68** %	3 %	21 %
C2	4%	--	**95** %	1 %	5 %	--	**92** %	2 %
C3	77%	--	**53** %	32 %	4 %	6 %	**62** %	28 %
C4	21 %	8 %	52 %	**18** %	12 %	4 %	54 %	**30** %
C5	16 %	16 %	**55** %	12 %	20 %	5 %	**65** %	10 %
C6	--	13 %	**69** %	18 %	--	8 %	**78** %	14 %
C7	33 %	41 %	**21** %	5 %	23 %	31 %	**45** %	1 %
C8	7 %	**63** %	14 %	16 %	14 %	**65** %	13 %	8 %
C9	**79** %	13 %	5 %	3 %	**64** %	23 %	11 %	2 %

Note: Correct answers for content questions in bold

204 students in the traditional group responded to the same attitude and content questions as the Inter-Chem-Net group. The frequency of each response for each choice was recorded with the correct answer in bold (see Table 2.2).

Table 2.2. Pre Test/Post Test Results for Traditional Group (Fall 1999)

Question	Pre Test				Post Test			
	a	b	c	d	a	b	c	d
A1	18 %	70 %	11 %	--	17 %	71 %	11 %	10 %
A2	22 %	75 %	2 %	1 %	33 %	65 %	1 %	--
A3	30 %	30 %	24 %	16 %	22 %	32 %	25 %	21 %
C1	21 %	**50** %	3 %	27 %	10 %	**61** %	--	29 %
C2	3 %	4 %	**96** %	--	--	1 %	**97** %	2 %
C3	8 %	6 %	**46** %	40 %	4 %	13 %	**52** %	31 %
C4	8 %	6 %	46 %	**40** %	29 %	6 %	42 %	**23** %
C5	27 %	5 %	**54** %	15 %	4 %	2 %	**92** %	2 %
C6	2 %	14 %	**71** %	13 %	--	6 %	**78** %	16 %
C7	32 %	48 %	**15** %	6 %	30 %	42 %	**25** %	3 %
C8	12 %	**68** %	13 %	8 %	18 %	**57** %	17 %	7 %
C9	**82** %	8 %	3 %	7 %	**82** %	13 %	--	5 %

Note: Correct answers for content questions in bold.

The two groups showed similar percentage of responses to both the attitude and content questions, but neither group showed an expected increase in correct responses from the pre test to the post test.

On the post test, students were also asked about feedback on laboratory reports (see Figure 2.1). In the Inter-Chem-Net group 60 % of students felt they received clear and consistent feedback on laboratory reports. In the traditional group, only 36 % of students reported such feedback.

Figure 2.1. Student Evaluation of Pass/Fail Grading (Fall 1999)
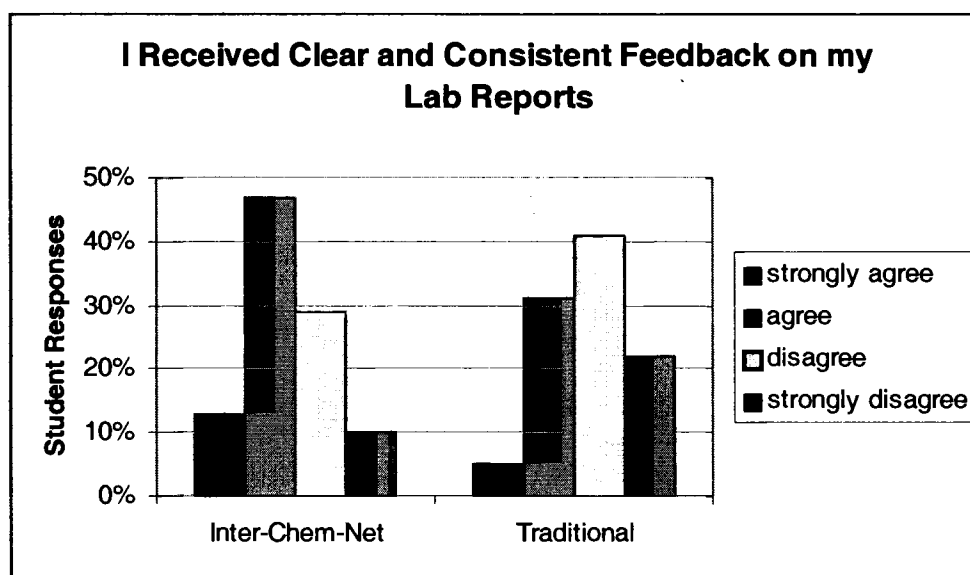
Inter-Chem-Net Focus Groups (Fall 1999)

Approximately 175 students from the Inter-Chem-Net groups offered feedback and suggestions in focus groups conducted with each lab section. Each student received three orange stickers to place by the two most significant responses about the topics discussed. The suggestions from each group were combined and the number of stickers next to each suggestion was recorded (see

Table 2.3). The lack of connection between laboratory and lecture material and students' difficulties in understanding the TA were the most frequent complaints. On the other hand, many students commented on the ease of using the instrumentation, the easy-to-use handouts, and the knowledgeable TA.

Table 2.3. Focus Groups Comments (Fall 1999)

Curriculum	# responses
• Did not correlate with lecture course	54
• Handouts clear, easy to use	24
• Choices help	19
• Labs repetitive	18
• Need better organization, prepwork	17
• Liked no quizzes	13
• Lab navigator doesn't work	11
• Lots of confusion	11
• Labs using instrument more systematic	6
• Real world applications	3
• Need more variety in labs and concepts	3
• IR difficult to read	2
• Need more traditional experiments	2

Instruction	# responses
• TA difficult to understand	46
• TA helpful	31
• Ta knowledgeable	28
• Need someone familiar with ICN in computer lab	31
• Lack of communication	17
• More instruction on analyzing data results	15
• No explanation on how to do lab process	13
• Little feedback on reports	13
• TA stretched too thin need overview	7
• Need more instruction at beginning of lab	5
• Need overview	5
• Received feedback on reports	3

Instruments	# responses
• Instruments easy to use	36
• Computers slow/crash	28
• Data analysis works well	12
• Data analysis hard to use (buttons in wrong places, difficult printing)	12
• Data analysis doesn't mean anything	11
• Printer problems	11
• IR more difficult to use	5
• Long waits	4
• Accounts/names not existing	3
• Need more instruments	2
• Library spectra helpful	2

Student Exit Questionnaire (Spring 2000)

209 students completed an exit questionnaire at the end of the spring semester, responding to questions about the laboratory course (see Figure 2.2). 38 % of students felt the experiments were well integrated with lecture, 48 % agreed that the experiments provided a learning experience, and 43 % offered an overall positive rating of the laboratory. 76 % of students rated the TA "helpful" or "very helpful."

Figure 2.2. Student Exit Questionnaire Results (Spring 2000)
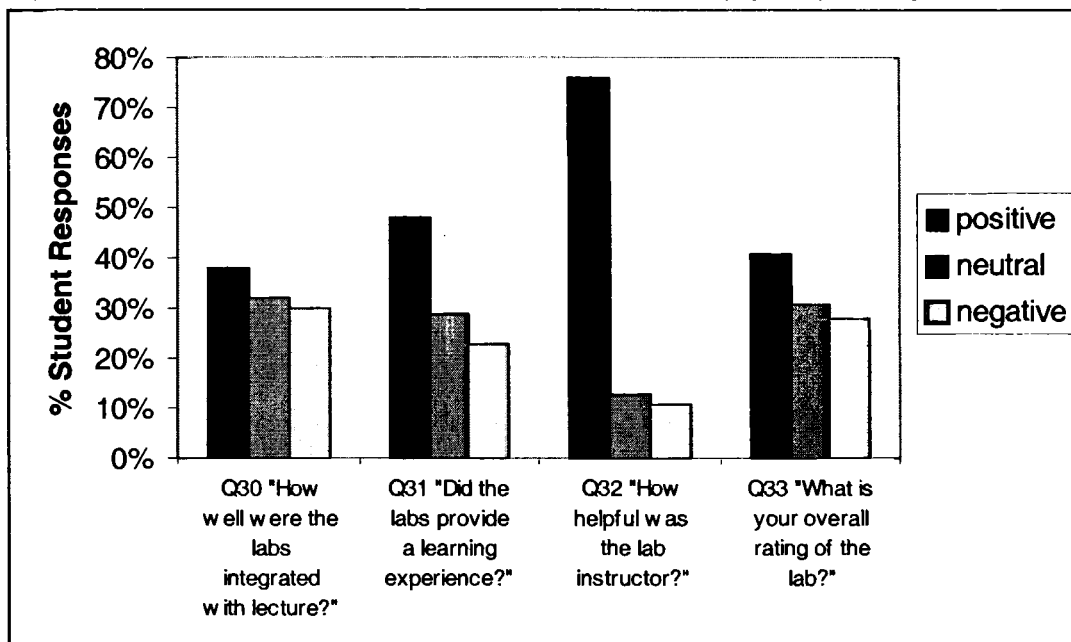
Students also offered comments and suggestions to improve the laboratory course. A significant number of students made comments that expressed an overall approval of the new laboratory program. Some of these comments were as follows:

The way the lab is run is awesome. Working at your own pace allows you to learn and absorb more info.

I found it helpful that students were able to choose which labs they were going to do. It allowed us to integrate the labs with the lectures.

This new system of picking your own labs was a GREAT idea. I think it worked out wonderfully.

The lab/lecture connections were very helpful.

Similarly, students often commented that the laboratory was much improved from the previous semester, reflecting improvements in the Lab Navigator, the curriculum, and the training of the TAs.

Students also provided suggestions to improve the course (see Table 2.4).

Table 2.4. Student Questionnaire Written Comments (Spring 2000)

Comments	Frequency of student responses
Organize the lab supplies and materials	12 %
Provide more sample calculations and analysis instructions on the lab handouts	12 %
Have everyone do the same lab at the same time	7 %
Train the TAs to understand all labs and return lab reports	6 %
Grade the lab course	4%

Discussion

The present study represented three different laboratory experiences with a common Pass/Fail grading scheme. In the fall 1999 semester, one group of students used the Inter-Chem-Net curriculum while the other group used the traditional lab manual. Students using the Inter-Chem-Net curriculum and instruments performed no differently on content and attitude questions at the end of the semester than students using the traditional curriculum. Similarly, neither group showed an increase in the correct number of responses on the post test, despite having completed a semester course in chemistry. The results could reflect the design of the test questions, or they could reflect the difficulty of measuring the long-term effects of the laboratory experience. The two groups did show a difference in response to the question "I received clear and consistent feedback on my lab reports." 60 % of the Inter-Chem-Net group felt they received such feedback compared to 36 % of the students using the traditional curriculum. In the pass/fail system, TAs had little incentive to evaluate student work and often only screened papers for those students not completing the work. The results from the focus groups also supported this conclusion, and many students reported receiving little feedback or communication from the TAs. The practice of minimal feedback negatively impacts student motivation and learning, in effect short circuiting the mental activity and dissatisfaction with present knowledge necessary for learning in the constructivist model. Many students in the Inter-Chem-Net group also commented that the course was too much work for a pass/fail grade and directly requested a change to a graded course. These

requests for the change to a graded course surfaced again in the spring evaluation.

In the spring semester, all students used the Inter-Chem-Net curriculum, representing the third group of laboratory experiences included in the pass/fail study. These students also used the new web-based Lab Navigator assignment module, allowing students to choose experiments and receive individualized assignments. The results from this semester helped elucidate the connection between the lecture and the laboratory courses. One of the most common complaints from focus groups held with the fall laboratory sections in 1999 was the lack of integration between the laboratory and lecture courses. These results are consistent with an exit questionnaire administered in the spring of 1999. In this survey, approximately 90 % of students responded that the laboratory and lecture needed to be more connected. To address this problem, a category called "Lecture Connections" was added to each experiment. The section outlines the keywords and concepts in the experiment and refers students to the corresponding chapter and section in the textbook. Results from the spring exit questionnaire revealed that 38 % of students felt the experiments and lectures were well integrated, marking an improvement from previous surveys. However, 30 % of students felt the experiments were not well integrated with the lecture material, supporting the need for a grading and evaluation scheme to help connect the experiments with chemical concepts.

The results also suggest the need for more opportunities for students to collaborate in the laboratory, supporting the constructivist notion that learning has

a key social component. Individualized experiments lessen the incidence of blind copying but should not promote isolation of students. In one of the focus groups, students suggested that a group discussion at the end of the laboratory would be helpful. Similarly, the Inter-Chem-Net model introduces a new role for the TA. The format allows TAs to act as resources on experiments and provides multiple opportunities to teach and learn the same experiments. However, allowing student choice in the laboratory requires TAs to understand and evaluate a broader range of chemical applications, and teacher training needs to be a continuing and integral part of the laboratory program. Results from both the focus groups and the spring 2000 questionnaire show a high degree of satisfaction with the TAs as facilitators, supporting the constructivist notion of encouraging students to ask questions and construct their own meaning. This satisfaction with the TAs also suggested a more manageable and productive role for graduate students. The missing element in this interaction under the pass/fail grading scheme, however, was the lack of helpful and consistent feedback for students from TAs.

Chapter 3

GRADED COURSE (2000-2001)

The second study was conducted during the 2000-2001 school year with the general chemistry laboratory course. During the fall 2000 semester, approximately 550 students took the one-credit laboratory course along with the three-credit lecture course. 16 TAs taught 26 laboratory sections under the direction of a faculty instructor and a lab manager. Each laboratory section consisted of 16-24 students. During the spring 2001 semester, 9 teaching assistants taught 14 laboratory sections with approximately 200 students.

Method

The Grading Rubric

The grading rubric was designed to evaluate individualized laboratory assignments by organizing three key components of the lab experience: (a) the prelab assignment (b) the experiment, (c) the laboratory report. The first row of the rubric outlines the outcomes of the prelab assignment; a two to three sentence introduction to the experiment, a table of chemical safety information, and any necessary calculations needed to perform the experiment. The grades A-F are then listed across the top of the rubric with the corresponding outcomes associated with each grade. The second row outlines the activity itself. It includes a written record of data, graphs, and calculations as well as the performance in the laboratory. This performance includes proper safety procedures, correct

laboratory techniques, and the ability to work with a partner. The third and final row outlines the objectives of the laboratory report. Important aspects of the report include a clear and concise description of the work, properly labeled tables and graphs, complete calculations and equations, and correct use of significant figures. Once the student has completed the experiment and submitted the laboratory report, the TA uses the checklist to offer feedback on the experiment and to assign a grade (see Figure 3.1).

Figure 3.1. Lab Grading Rubric

Name   **Section**

Lab   **Grade**

	A	B	C	D	F
Pre-Lab	__ 2-3 sentence intro, table of safety info complete, calculations complete and accurate	__ 2-3 sentence intro, table of safety info complete, calculations attempted but incomplete or inaccurate	__ Sketchy intro, table of safety info missing one chemical, major calculations missing	__ No 2-3 sentence intro, table of safety info missing more than one chemical, no calculations	__ No prelab CANNOT DO LAB
Lab	__ All safety measures (goggles, gloves, cleanup, chemical disposal) __ Proper lab techniques (balance, bunsen burner, solution, dilution, titration, UV-vis, other) __ All info recorded in notebook including data, calculations, and graphs __ Contributed equally to lab or worked alone	__ Most info recorded in notebook (missing minor data, calculations, or graphs) __ Contributed some but not equally to lab	__ Improper or sloppy lab techniques (balance, bunsen burner, solution, dilution, titration, UV-vis, other) __ Some info recorded in notebook: missing calculations or graphs __ Contributed minimum effort to lab	__ Very little info recorded in notebook: sketchy data, no calculations or graphs __ Watched lab partner do lab	__ Did not use all safety measures __ Dangerous lab techniques (balance, bunsen burner, solution, dilution, titration, UV-vis, other) __ No info recorded in notebook __ Did not complete lab work or copied lab results
Lab Report	__ Complete intro with background and purpose __ Detailed Procedure __ Complete and accurate data __ Graphs correct and labeled __ All numbers in data tables __ Calculations shown clearly and accurately __ Correct use of significant figures __ All questions answered correctly __ Written conclusion summarizing work	__ Intro missing minor details __ Procedure missing minor details __ Data with minor errors __ Graphs correct but not labeled __ Some numbers not in data tables __ Calculations shown clearly but not accurately __ Mostly correct use of significant figures __ Some questions answered incorrectly __ Brief written conclusion	__ Sketchy intro __ Procedure missing major details __ Incomplete data with errors __ Graphs incorrect __ Most numbers not in data tables __ Calculations not shown clearly or accurately __ Little correct use of significant figures __ Many questions answered incorrectly __ Sketchy written conclusion	__ No Intro __ No procedure or copied handout __ Major sections of data missing __ No graphs __ No data tables for numbers __ No calculations __ No correct use of significant figures __ No questions answered __ No written conclusion	__ No lab report __ Copied lab report

Comments:

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TA Questionnaire (Fall 2000)

At the end of the fall 2000 semester, 13 of the 16 TAs answered the following questions on an exit questionnaire:

- Was the lab grading form easy to use? Did it provide clear feedback for the students? How would you improve it? Explain.

- On average, how long did it take you to grade lab reports each week?

TA Questionnaire (Spring 2001)

During the spring 2001semester, TAs responded to the following emailed question:

- Based on your experience, how would you order your students laboratory work, with 1 being the weakest in general and 10 being the strongest?

  ___ using all safety measures consistently
  ___ using proper lab and instrument techniques
  ___ collecting complete and accurate data
  ___ recording all info and procedures in notebook and lab report
  ___ writing a clear and concise introduction
  ___ presenting data clearly and accurately
  ___ showing all calculations
  ___ using graphs correctly
  ___ drawing reasonable scientific conclusions from the data
  ___ connecting theoretical concepts with what is happening in the lab
  ___ other: ??

Student Exit Questionnaire (Fall 2000)

Students in all of the laboratory sections also completed a standardized University of Maine evaluation questionnaire at the end of the semester. The questionnaire contained 33 affective domain questions covering the instructor, the course, examinations, and the laboratory. It also included a space for written

comments. Seven of these questions were evaluated in the study (see Appendix B).

Lab Navigator Snapshots (Spring 2001)

In the spring 2001 semester, the students used the new Lab Navigator database program to choose experiments and access the experimental handouts. The updated version of the program also contained on online assessment module, and each experiment contained evaluation questions about student attitudes towards the course and the experiments. For the group of experiments offered during the first three weeks of the course, students responded to the question "Are the laboratory report expectations clear?" For the experiments offered during the fourth and fifth weeks of the course, students responded to four questions associated with these experiments:

1. Have the grading procedures for the labs seemed fair so far?

2. Has the instructor feedback on the lab been helpful?

3. Overall, how would you rate this experiment?

4. How long was this experiment, including the prelab, time in the lab and lab report?

Results

TA Questionnaire (Fall 2000)

In December 2000, thirteen of the sixteen TAs provided written comments on the grading form (see Table 3.1).

Table 3.1. TA Comments about the Grading Form (Fall 2000)

- The grading form is excellent
- I just wrote comments on the back, but sometimes checked boxes to focus the attention of students.
- The lab grading form is easy to you and it can provide the students clear feedback. I just write why the question answered is wrong and how to give the right answer. I think it is good for use.
- I didn't really like the grading form. The format wasn't really easy to use or for the students to understand. I think it would be much better to hand back the labs with corrections on them so the students can see exactly what was wrong. If this can't be done then I would increase the size of the comments sections b/c this is what I used most to help them understand what they were doing wrong and needed to fix. I showed them their labs with the grading form so they could see where to make the corrections.
- The grading form was easy to use, but I did not like it at all. It worked well in letting the students know what they should do to improve their lab report grades. The reason I did not like it is if I had a student who received check marks all over the sheet in every different section, the sheet did not really help me in determining a grade for them.
- It was easy to use, although I found making comments directly on the reports and handing these back to the students much more effective. They then returned their lab reports before the end of class.
- I think it would be important to establish a more comprehensive idea of what a lab report should constitute.
- Yes but it did not provide clear feedback for students, maybe put subsections for each entry or add more entries like aside from "graph labeled properly" have also "analysis of data."
- I didn't especially like the lab grading forms. Sometimes there was something I would have liked to explain but none of the boxes seemed applicable. I would make those comments on the back but I didn't like not being able to choose A,B,C,D or E. Overall, the sheet was a good starting point for me but it was not quite what I would like to have been given.
- Yes. The lab grading form is great! Sometimes it cannot provide all situations. For example, some students answered many questions but miss some questions. There is no idea about it.
- No easy job for TA but it is good for the students. If we didn't give a grade they don't care about the reports. So overall grading system is good but too much work load for the TA's.
- My only complaint with the grading form was the emphasis placed on sig figs. It seems redundant since I would take sig figs into account when grading calculations.
- Grading form was good but there needed to be a clearer standard for lab reports on a lab-by-lab basis.

The comments suggested some improvements for the grading policy. The first improvement was to return the laboratory reports to the students. With students completing a particular lab during different weeks in the semester, TAs used the grading rubric to provide feedback while preventing the common "recycling" or copying of reports. Many of the TAs and students felt that it was much more helpful to see the corrections on the report itself. In fact, some of the TAs would return the reports for students to view during the laboratory period and then return at the end of class. For these reasons, this policy was changed for the spring semester. Similarly, several TAs commented on the need for sample laboratory reports and more examples of student work. These suggestions were incorporated into the next semester's course with expanded laboratory report expectations and sample laboratory reports (see Appendix D). Similarly, modifications to the form reflected small changes in areas such as graphing and analysis of data, as well as renaming the "post lab" section to "lab report." Finally, the comments on the "excessive" workload were examined separately.

In addition to comments about the grading form, the TAs estimated the amount of time required to grade reports each week (see Table 3.2).

Table 3.2. TA Estimation of Grading Time Each Week (Fall 2000)

# students in each section	Time
23	15 min/student –6 hours
15	3 hours
22 and 21	5-6 hours (2 sections)
26 and 26	8-12 hrs
20	3 hrs
20 and 20	1 ½ hours/section
20	---
16	2-2.5 hrs
20	2-3 hrs
22 and 22	6-8 hrs
20 and 20	6 hrs (3 hrs/lab)
19 and 19	1 ½ hrs/section

One of the arguments against requiring laboratory reports is the amount of time required to grade them. In the introductory laboratory course, this time consideration weighs heavily into the acceptable workload for a paid TA stipend. In general, 20 hours per week is required for most of such stipends. For the laboratory course, TAs spend about 10 hours in the lab and help sessions. According to the TAs' estimates, the maximum amount of time required to grade reports each week still fell within the acceptable workload of 20 hours. It also reflected a large variation in the amount of time spent grading reports, with a minimum of one and a half hours per section to a maximum of six hours per section.

TA Questionnaire (Spring 2001)

Six TAs rated the strengths and weaknesses of student work (see Table 3.3). The TAs identified "drawing scientific conclusions" from the data and "connecting theoretical concepts" as the weakest issues. According to one TA,

"this of course is a mere matter of careful thinking and an understanding of the inductive process of going from facts to theories, and conversely of deductively moving from the ideas to their relevance to the experimental results." Another TA commented, "Lab is more like play-time, and lecture is learning time. There isn't any real connection between the two, so when I ask someone why something is happening, most have to switch to lecture mode to answer. Conclusions that completely defy what their textbook says fortify my suspicion of this." At the other end of the scale, "using safety measures," "recording procedures in the notebook," and "using proper techniques" were identified as the strongest areas for students. The areas with the largest variation in response were in the "use of graphs correctly" and "showing all calculations." According to one TA, "those who put in the time to do [graphs] correctly use them very well." Other TAs expressed the sentiment that graphing problems usually reflected minor errors, while another TA identified this issue as the weakest area for students, reflecting a genuine misunderstanding of the data itself. Similarly, some suggested that the issue of "showing all calculations" reflected minor misrepresentations based on laziness, while others identified a more fundamental problem: "They can present it but they don't know how to tie it all together at the end."

Table 3.3. TA Rating of Student Labwork (Spring 2001)

10=strongest
1=weakest

Mean	Standard Deviation	Grading Expectation
9.2	0.75	using all safety measures consistently
8.4	1.67	using proper lab and instrument techniques
6.7	1.92	collecting complete and accurate data
7.2	0.84	recording all info and procedures in notebook and lab report
4.6	2.64	writing a clear and concise introduction
6.0	1.87	presenting data clearly and accurately
4.4	3.00	showing all calculations
5.33	3.67	using graphs correctly
2.6	1.21	drawing reasonable scientific conclusions from the data
2.4	1.67	connecting theoretical concepts with what is happening in the lab

Student Exit Questionnaire (Fall 2000)

At the end of the fall semester, students completed a University exit questionnaire. 199 students offered written comments on the questionnaire. These comments were categorized according to frequency of response (see Table 3.4). Through these comments, many students expressed approval of the TA (129 responses) and with the overall lab course (60 responses). In addition to these comments, some students commented directly on the grading policy. Four students commented that the grading was very fair, while three expressed concern over inconsistent grading. Similarly, a small number felt that the workload was inconsistent between sections. Others commented that the workload was excessive, with one student specifically requesting that the laboratory grade count toward the lecture.

Table 3.4. Student Comments on Exit Questionnaire (Fall 2000)

Student Comments	# responses
• Great T.A.	129
• Lab course good overall.	49
• Need English speaking TA.	23
• Lab supplies unorganized/messy.	20
• Lab procedures difficult to follow.	14
• Excellent learning experience/helped lecture course.	11
• T.A. did not understand the labs.	10
• Did not correspond with lecture.	9
• Did not like lecture.	5
• Overall bad experience	7
• Very fair grading.	4
• Error/mistakes in the handouts.	4
• Some lab sections did less work than others.	3
• ICN good system.	3
• Lab better than lecture.	3
• Grading not consistent.	3
• Too much work.	3
• Confusing having people doing different labs.	2
• Enjoyed variety of labs.	2
• Want to get lab reports back to see mistakes.	2
• Frustrated with variation in time for different labs.	1
• Count lab toward lecture grade.	1
• Lab reports hard.	1

In addition to the individual comments, students responded to three questions about the grading policy (see Figure 3.2).

Figure 3.2. Student Evaluation of the Grading Policy (Fall 2000)
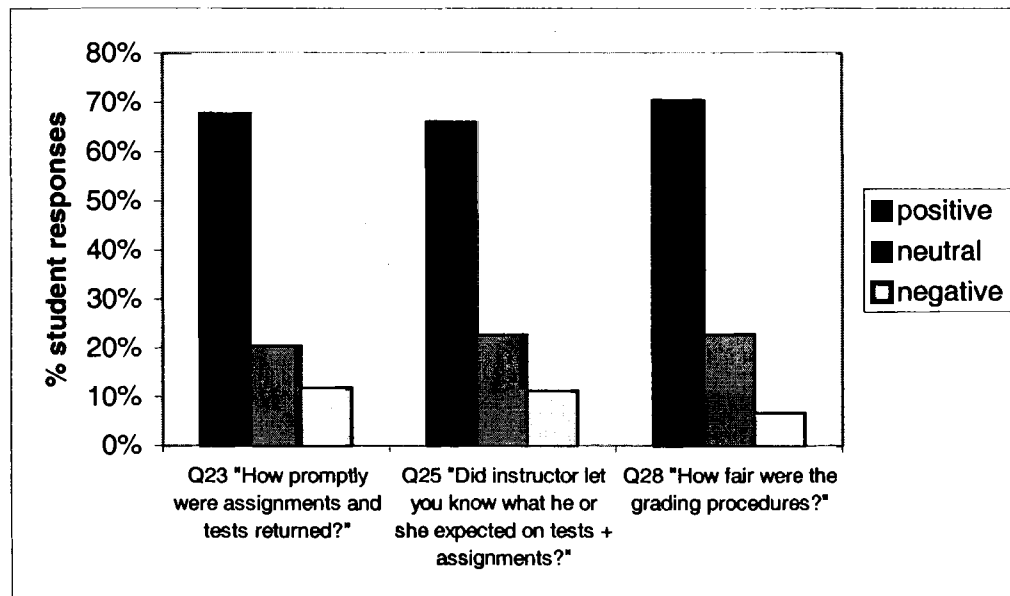
Of the 280 students responding to the question "How promptly were assignments and tests returned," 88 % responded that the assignments were returned within a reasonable time. In contrast, one of the most common complaints from the 1999-2000 evaluation data was the lack of feedback and failure of the TAs to return student work. Similarly, 89 % of the 260 students responded either with a positive or neutral response to the question "Did the instructor let you know what he or she expected on tests and assignments?" Finally, 92 % of students gave a positive or neutral response to the question "how fair were the grading procedures?"

In addition to the grading questions, students responded to four questions about the overall laboratory course (see Figure 3.3).

Figure 3.3. Student Exit Questionnaire Results (Fall 2000)
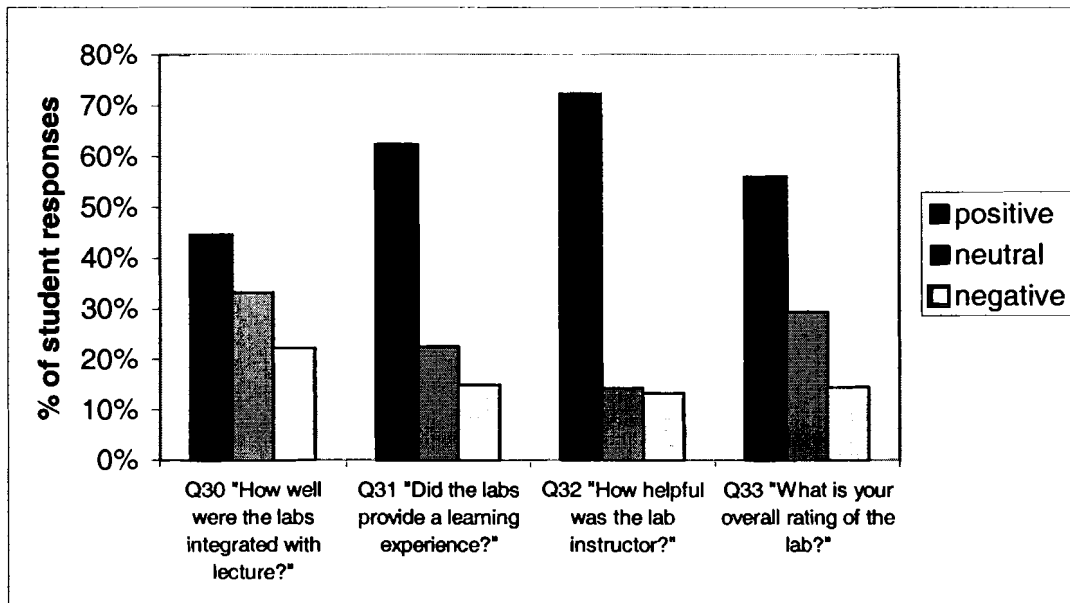
45 % felt the experiments were well integrated with the lecture material, 64 % felt the experiments provided a learning experience, and 59 % offered an overall positive rating of the laboratory. These results compared to 38 %, 48 % and 43 %, respectively, for the spring 2000 questionnaire. 73 % of students rated the TA "helpful" or "very helpful," compared to 76 % in the spring.

Lab Navigator Snapshots (Spring 2001)

Evaluation questions about the grading rubric were used to test the new ICN Snapshots module that was piloted during the spring semester 2001. For the first four labs of the semester, one of these questions was "Are the lab report expectations clear?" Students answered the questions online after completing each experiment, and the results were automatically recorded and displayed as a histogram (see Figure 3.4). For this first laboratory report of the semester, 88 % of the students reported a "very clear" or "mostly clear" understanding of the

39

report expectations. Results from the other three experiments offered were similar.

Figure 3.4. Snapshot Evaluation of the Course Expectations (Spring 2000)

"Phases of Water" Experiment

207 students have been asked:
Are the lab report expectations clear?

```
      10.00    30.00    50.00

1  ████        27.05

2  ████                61.35

3  ████  9.66

4  1.98
```
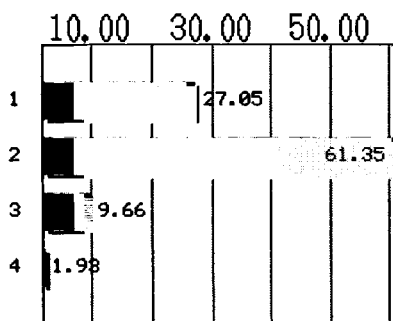
```
1 = Very clear.
2 = Mostly clear.
3 = Unclear.
4 = Very unclear.
```

During the fourth and fifth weeks of the semester, students were queried about the feedback they received on laboratory reports as well as whether the grading policy was "fair" (see Figure 3.5). 83 % of the students responded that the grading procedures were "fair" or "very fair" and 75 % of the students found the instructor's feedback "very helpful" or "helpful". Results from the other two experiments offered during the fourth and fifth weeks showed similar results, offering glimpses or "Snapshots" of student attitudes about the grading policy early in the semester.

Figure 3.5. Snapshot Evaluation of Grading Procedures

Anthocyanins in Fruit Juices

208 students have been asked: Have the grading procedures for the labs seemed fair so far?

209 students have been asked: Has the instructor feedback on the lab reports been helpful?

1 = very fair.
2 = fair.
3 = somewhat fair.
4 = unfair.

1 = very helpful.
2 = helpful.
3 = somewhat helpful.
4 = not helpful.
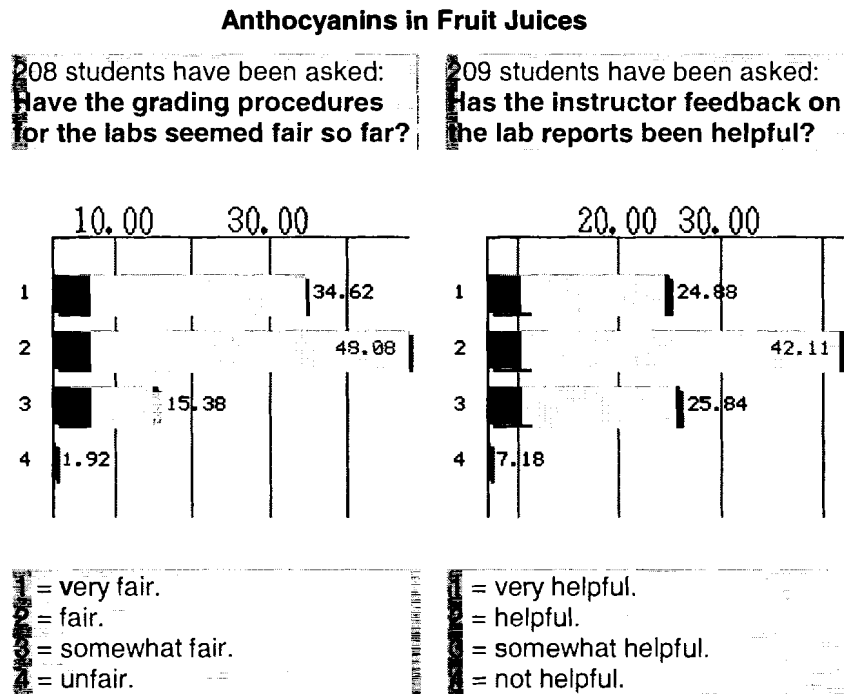
In addition to the two questions about the grading procedures, students also responded to questions about the overall quality of the experiment and the amount of time required to complete the experiment (see Figure 3.6).

Figure 3.6. Snapshot Evaluation of "Anthocyanins in Fruit Juices"

199 students have been asked: How long was this experiment, including the prelab, time in the lab and lab report?

198 students have been asked: Overall, how would you rate this experiment?

1 = 1-3 hours
2 = 3-5 hours
3 = 5-7 hours
4 = more than 7 hours

1 = Excellent.
2 = Good.
3 = Fair.
4 = Poor.
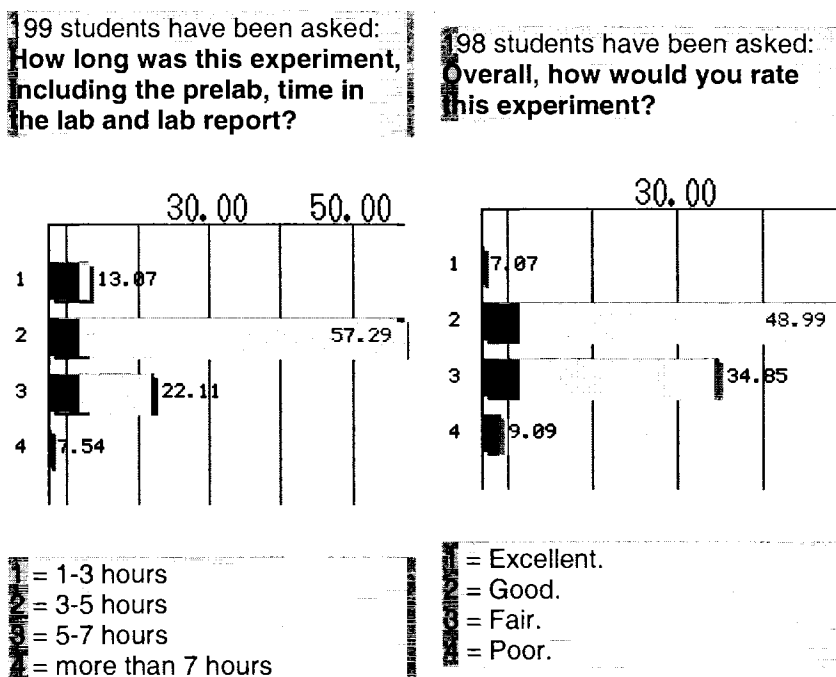
According to the 199 students responding to the Snapshot questions, 57 % reported spending three to five hours on the "Anthocyanins in Fruit Juices" experiment and other 22 % spent five to seven hours. Results from the other experiments showed similar results. The "Anthocyanins in Fruit Juices" experiment also received a favorable rating overall from 56 % of students. In contrast, an experiment entitled "Electrochemistry" received a very different overall rating with 35 % of the students assigning a "fair" rating and 31 % rating it "poor" (see Figure 3.7). These differences in overall ratings contrast with the consistent ratings of the grading procedures and the workload for each experiment.

Figure 3.7. Snapshot Evaluation of "Electrochemistry"

141 students have been asked:
Overall, how would you rate this experiment?

	10.00	20.00	30.00
1	1.42		
2			32.62
3			34.75
4			31.21
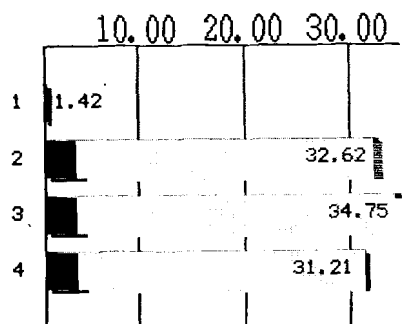
▮ = Excellent.
▮ = Good.
▮ = Fair.
▮ = Poor.

Discussion

The grading rubric was piloted in fall 2000 as a constructivist approach to assigning grades in the general chemistry course. It was created to provide consistent feedback for students within the Inter-Chem-Net model. This model involves choosing experiments, using instrumentation, solving problems, and discovering chemical principles. The lecture course builds a foundation of chemical principles, but this construction of knowledge through experimentation defines the term "chemist." The grading rubric was used to examine whether the traditional A-F grading structure helped students construct such knowledge. First, results suggest that students are receiving consistent and timely feedback from the TAs, a marked improvement from the earlier pass/fail grading system. In the fall of 1999, 60 % of the students in the Inter-Chem-Net group felt they received such feedback while only 36 % of the students using the traditional curriculum reported such feedback. The results from the focus groups also supported this conclusion. In contrast, 88 % of students from the graded course in the fall of 2000 reported that the assignments were returned within a reasonable time. Similarly, 89 % of these students also responded with either a positive or neutral response to the question "Did the instructor let you know what he or she expected on tests and assignments?" Finally, 92 % of these students gave a positive or neutral response to the question "How fair were the grading procedures?" Similarly, results from the Lab Navigator snapshots in the spring semester 2001 revealed that 83 % of the students found the grading procedures "fair" or "very fair;" and 75 % of the students found the instructor's feedback "very

helpful" or "helpful." This feedback then enhances student motivation and learning, encouraging the mental activity and dissatisfaction with present knowledge necessary for learning in the constructivist model.

The results also help to elucidate how students construct meaning from the lab, suggesting that students do not understand the chemical principles. First, the study examined the amount of time students spent completing and TAs spent grading each experiment. In the fall semester 2000, graduate TAs reported spending an average of six hours a week grading reports, which is within the acceptable workload for a graduate stipend. In the spring semester 2001, over half of the students reported spending three to five hours on each experiment, but one third of the students reported spending five to seven hours each week. If a student's time is closely tied to learning in the lecture portion of the course and significantly enhances this content knowledge, this time and effort is well spent. However, the results suggest that many students are not connecting concepts in the lecture portion of the course with the experimental results in the laboratory. Secondly, the TA's consistently rated this understanding of the underlying chemical principles as one of the weakest areas of student work, and analysis of a random sample of laboratory reports across multiple laboratory sections confirmed this result. Third, student evaluations revealed that 25 % of students did not feel that the laboratory was well connected with the lecture portion of the course and another 35 % gave a "neutral" response to this connection. These percentages were similar to the spring 2000 results under the pass/fail grading system. Finally, the Snapshot data from the spring semester of the graded

course revealed markedly differing results in overall ratings of individual experiments, suggesting a difference in the quality of particular experiments. These differences could be due to a variety of factors. An easy experiment may receive a favorable rating because it is easy, not because it is particularly instructional. On the other hand, experiments receiving a poor rating may be poorly written or may represent a complex topic that needs more instruction to be fully understood. Further studies are needed to determine whether these student choices produce different learning outcomes, but the Lab Navigator Snapshot results suggest that the grading rubric provided consistent feedback for the students for these choices.

The study also helped understand the social component of learning in the laboratory, and the results suggest that the grading rubric improved the students' satisfaction with the TAs. Results from both the spring 2000 semester of the pass/fail study and the fall 2000 semester of the graded study revealed a high degree of satisfaction with the TAs. These results differ from the complaints in earlier semesters about heterogeneous teaching abilities of TAs. For instance, one of the most frequent comments from the focus groups in the pass/fail study was "my TA was difficult to understand." In contrast, the most common written comment from the fall 2000 semester of the graded course was praise for the TA with129 written responses. These responses came from across a large number of laboratory sections, rather than representing simply a plethora of comments from a few sections. This overwhelmingly positive student response to the TAs was one of the most striking findings in the study, and it could reflect the new role

of the TA in the Inter-Chem-Net model. It could also represent satisfaction with the consistency of feedback demanded by the graded laboratory course. On the other hand, other changes in the laboratory could have impacted this result. These changes include hiring a number of advanced undergraduate students hired to teach the course in the fall of 2000, a new system of staffing the computer and instrumentation rooms, and the new emphasis on training. These factors could have also influenced student satisfaction with the laboratory. As for the social component of collaborating with other students, the organization of experiments into chapters prevented more than five different experiments from occurring simultaneously. Students were encouraged to work in pairs but were individually responsible for their assigned variable values and a separate report. In the fall 2000 semester, TAs handed only the grading rubric to student without returning the laboratory reports, but numerous comments from both students and TAs dictated a change in this policy for the spring 2001 semester. Similarly, the lab report requirements were modified to include examples of each section (see Appendix D).

Finally, the grading rubric facilitated the choice of experiments with real world applications. Since the experiments are listed by chapter in the lecture text, the choices in each chapter apply specific concepts and techniques to a variety of scientific fields. For instance, the experiment "Analysis of Vitamin C in Fruit Juice" contains apparent biological applications, while the "Acid Base Titration" experiment provides a traditional chemical focus. These laboratory connections in the Inter-Chem-Net course involve applications in terms of content but also

with the techniques and instrumentation. The grading rubric delineates these features, specifically listing techniques common throughout the laboratory course. Many of these techniques are completely new and foreign to the students because they are largely absent from the lecture course and common experience. Similarly, the long-term effects of using these instruments in a general chemistry course may not appear until much later. The grading rubric serves as another instructional tool to emphasize the central nature of instrumentation in laboratory science. Furthermore, the pedagogy and curriculum related to the instrumentation remain active areas of development in the Inter-Chem-Net model.

Chapter 4

CONCLUSIONS

In most undergraduate science laboratory programs, large numbers of students are taught by graduate students and with limited equipment and supplies (Abraham, 1997). The Inter-Chem-Net project addresses these issues through a variety of innovations in the general chemistry course. The new laboratory program is a student-centered model offering students choices and discovery-based activities that use modern instrumentation. With this system, all students can access these activities with the TAs acting as facilitators rather than as gatekeepers to knowledge. This model allows students to construct knowledge by experimentation in the chemical laboratory, a process that defines the field of chemistry. Constructivist by nature, the Inter-Chem-Net model then helps define the interaction between how teachers teach and how students learn. A key part of this interaction is the evaluation of student work, and the grading rubric is the first step towards providing detailed feedback to students on individualized laboratory assignments.

Built upon the assumption that students must participate in the scientific process in order to understand the underlying chemical principles, the grading rubric synthesizes the practice, application, and communication needed to explore chemistry. The grading rubric does not provide right or wrong answers or delineate point values for individual sections in an experiment. Instead, it offers a framework for instructors to evaluate the entire laboratory experience. The results suggest that students received fair and consistent feedback from the grading rubric. This feedback contrasted with the earlier pass/fail system that

discouraged this type of feedback. Similarly, students reported a high level of satisfaction with the TAs and the overall experience of the graded course. Results also suggest that students expend a considerable amount of time and effort participating in the lab and recording their findings in a report. However, this effort still does not connect the laboratory and lecture material for many students, suggesting the need for development in two areas.

The first area of development involves an interactive evaluation scheme to complete the student's learning cycle. The Lab Navigator is a key evaluation tool, providing the ability to analyze student feedback and reactions to individual experiments. Identifying the learning outcomes of particular experiments may help elucidate how students learn the underlying chemical principles. Secondly, the role of the TA remains a crucial part of the evolution of a successful program. Evaluation of this role includes developing a comprehensive TA training program and developing creative solutions to enhance the positive interactions between students and instructors. Though feedback from TAs to students is a crucial component of this interaction, it is not clear whether the laboratory report is the most effective construct to facilitate learning. The evolution of the Lab Navigator may provide online evaluation of students' laboratory learning, allowing automated quizzes as part of the laboratory grade. This technology may also help identify the effects of grading on student learning, particularly on the effects of the social interactions of learning. The Inter-Chem-Net model provides a constructivist approach to facilitate both student learning and instructor research on this learning in the laboratory environment.

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Appendix A. Pre Test/Post Test Student Questionnaire (Fall 1999)

A1. How do you think scientists are regarded in our society today?
- a. admired and emulated
- b. well regarded
- c. mostly ignored
- d. disliked

A2. Which of the following best characterizes a scientist?
- a. an innovator
- b. an investigator
- c. a routine plodder
- d. a complete nerd

A3. Do you think a career in chemistry would be:
- a. exciting and rewarding
- b. a good way to earn a living
- c. OC, if you couldn't think of anything else to do
- d. Utterly boring

C1. Moles are to molecules as:
- a. centimeters are to boards
- b. dozens are to apples
- c. cows are to horses
- d. books are to libraries

C2. Which of the following best describes the scientific objective of a lab experiment:
- a. to generate the correct experimental answer
- b. to perform an experiment without making many mistakes
- c. to draw conclusions based on observations and data
- d. to complete the lab in the allotted time

C3. In visible spectroscopy, absorbance is related to the concentration in which way:

- a. reciprocal square root
- b. negative log
- c. directly proportional
- d. inversely proportional

C4. In order to prepare a 0.1 M aqueous solution of NaCl (molecular weight = 58.4) in a 250 mL volumetric flask, you will need to:
    a. weigh 58.4 grams of NaCl and add 1 liter of water
    b. weigh 2.92 grams of NaCl, add 50 mL of water, boil for 5 minutes, and fill to mark
    c. weigh 5.84 grams of NaCl, dissolve in water, transfer to flask, and fill to mark
    d. weigh 1.46 grams of NaCl, dissolve in water, transfer to flask, and fill to mark

C5. The end point of a titration is reached when:
    a. the indicator is exhausted
    b. the pH drops below 7.0
    c. the indicator's color changes
    d. the pH changes color

C6. If you wanted to measure 25.00 mL of water, which piece of glassware would be your best choice:
    a. 25 mm diameter test tube
    b. 50 mL beaker with volume markings
    c. 50 mL graduated cylinder
    d. 50 mL volumetric pipette

C7. Infrared spectroscopy records:
    a. electrons moving from higher to lower energy levels
    b. electrons moving from lower to higher energy levels
    c. molecular vibrations
    d. bonds breaking

C8. You record the time a reaction takes to generate 20 mL of gas, using a clock with a second hand. The results are as follows: 129 seconds, 132 seconds, 133 seconds, 129 seconds. You conclude:
    a. the results show great accuracy
    b. the results show great precision
    c. the results show great accuracy and precision
    d. the results are not meaningful since a control reaction was not run

C9. Compounds A and B, both white solids, are weighed and added to a flask with water and heated. The solution is then removed and a white solid remains. No other observations are made. Which of the following procedures might tell you if a reaction has taken place?
    a. weigh the final solid to determine if the weight is different from the weights of A + B
    b. add phenolphthalein and obtain a UV-visible spectrum
    c. add nujol, grind until like toothpaste, and obtain an infrared spectrum
    d. add water and measure the specific gravity

Appendix B. Student Evaluation Questionnaire (Spring 2000 and Fall 2000)

23. How promptly were assignments and tests returned?

VERY PROMPT　　　　　　　　　TOO SLOW

O　　　O　　　O　　　O　　　O

25. Did the instructor let you know what he or she expected on tests and

assignments?

VERY CLEARLY　　　　　　　　NOT CLEAR

O　　　O　　　O　　　O　　　O

28. How fair were the grading procedures?

COMPLETELY　　　　　　　　　UNFAIR

O　　　O　　　O　　　O　　　O

30. How well were the labs integrated with lecture?

VERY WELL　　　　　　　　　　NOT AT ALL

O　　　O　　　O　　　O　　　O

31. Did the labs provide a learning experience?

VERY MUCH　　　　　　　　　　VERY LITTLE

O　　　O　　　O　　　O　　　O

32. How helpful was the lab instructor?

VERY MUCH　　　　　　　　　　VERY LITTLE

O　　　O　　　O　　　O　　　O

33. What is your overall rating of the lab?

EXCELLENT　　　　　　　　　　POOR

O　　　O　　　O　　　O　　　O

Appendix C: Lab Report Requirements (Fall 2000)

Your lab report should be typed and neat. You may include photocopies of your data or calculations from your lab notebook if they are neat. Lab reports are required for every lab. A lab report should contain the following:

- **Name, TA name, Data, and Title of Experiment**

- **Introduction (Prelab Assignment)**

  This section should include a brief summary of the background information needed to complete the lab as well as the purpose of the lab. Since this section is part of the Prelab Assignment for each lab, you may simply reference the page number in your lab report ("see p. 15 of lab notebook," for example).

- **Procedures (Prelab Assignment)**

  This section describes your individual procedure. Since this section is also part of your Prelab Assignment, you may reference your lab notebook and include any modifications to the procedure.

- **Data Analysis (Post Lab Assignment)**

  This section includes all of your data in table or graph form. Any tables or graphs that you completed in your notebook during the lab can be photocopied and inserted into the lab report. You should also reference your lab notebook ("see p. 21 of lab notebook," for example) for any data collected in your notebook.

- **Discussion (Post Lab Assignment Questions)**

  Answer any Lecture Connections Questions in this section.

- **Conclusions**

  This section includes a few paragraphs including pertinent observations, equations or reactions, sources of error and a summary of your results. Pertinent observations are any observations that affect the outcome of your experiment, or mark a crucial step in your experiment. They could include color changes at the end of a titration experiment, formation of a precipitate, change of stat, as in crystallization, or any major procedural changes, ie. You spilled an unknown amount of acid into your solution, back titrated to discover the amount added, and then calculated you new concentration. You should also include major concepts or equations used in the lab. If you used the ideal gas lab to determine the volume of your unknown gas, for example, you should state what the ideal gas law is and how the appropriate equation is used. Finally, include a discussion of any deviations from the results that you expected to get.

Lab Report Requirements

Your lab report should be typed, neat, and easy to understand. See <u>Turning Lead Into Gold</u> for a sample report. It should contain the following:

- Name
- Lab partner
- TA
- Date

Title of Experiment

Introduction

This section should contain a brief summary of the background information needed to complete the lab as well as the purpose of the lab.

Example

Titration is a common procedure to determine the concentration of a solution. It is performed by adding a standard solution of known concentration to a solution of unknown concentration. The solutions undergo a chemical reaction. When there is an equal molar amount of both solutions, an indicator dye is used to signal the equal molar amounts of the solutions. From the chemical reaction and its stoichiometry, the concentration of the unknown solution can be calculated. An acid-base titration was used to find the concentration of a basic solution and then to determine the molecular weight of an unknown acid.

Procedures

This section describes what you actually did in the lab. It should include any variations from the lab procedure given in the lab handout as well as your individual assignment from the Lab Navigator.

Example

Four FTIR spectra sample cards and four pieces of plastic material samples, an overhead projector slide, a plastic bag, saran wrap, and unknown sample "A" were obtained. Each piece of the sample materials was cut to a size just larger than that of the hole in the spectra sample card. The cut pieces of samples were stretched smooth and placed over the hole on their own respectively labeled FTIR sample card. The material samples were held onto their sample card with a clear tape adhesive. An FTIR

card with no material sample attached to it was used to blank the spectrometer. The blank card was then removed and replaced with the first sample card. The first sample was then scanned the amount of light that was absorbed was charted by the instrument. This procedure was repeated for the remaining two known materials and for the unknown material.

Data Analysis

This section includes all of your data and calculations in table or graph form. The Post Lab Assignment at the end of each lab handout gives a description this data for each particular lab. Calculations can be hand written if necessary. Graphs or tables on separate pages should be included in this section.

Example 1

Part 1 - concentration of standardized base:

#1 - ? m NaOH = $\frac{1 \text{ mol NaOH}}{1 \text{ mol KHP}}$ x $\frac{.500 \text{ g KHP}}{204.2 \text{ g/mol KHP}}$ x $\frac{1}{.0205 \text{ L NaOH}}$ = .119 m NaOH

#2 - ? m NaOH = $\frac{1 \text{ mol NaOH}}{1 \text{ mol KHP}}$ x $\frac{.500 \text{ g KHP}}{204.2 \text{ g/mol KHP}}$ x $\frac{1}{.0209 \text{ L NaOH}}$ = .117 m NaOH

Example 2

Unknown observations

Unknown	Water Soluble	Iodine	Vinegar	Alkaline
1	Yes	---	No bubbles	Non-alkaline
2	No	None	Bubbles	---
3	Yes	---	No Bubbles	Non-alkaline
4	No	Yes	No Bubbles	Non-alkaline
5	Yes	---	---	Non-alkaline

Discussion

Answer any **Post Lab Questions** in this section.

Example

1. The maximum concentration that allows for a smooth, readable spectrum is 0.0000200M. In this experiment, this concentration was obtained from a dilution of 1/50 of the stock solution. This dilution was dilution C.

2. The minimum detectable concentration of my dye was obtained from dilution F. The concentration was 0.00000120 M and was obtained from a dilution that was 6/5000 of the stock solution.

3. The relationship between the concentrations of my solutions and their respective absorbance values is that the absorbance values get smaller as the concentrations get smaller. Likewise, the larger the concentration, the greater the absorbance value will be. If the concentration gets too large or too small, the value is unreadable. The only exception was dilution F. In this case, the absorbance value was actually larger as the concentration got smaller. Concentration and absorbance are thus directly proportional.

4. By graphing absorbance versus concentration, I could find the concentration of any value that fell within the range of the plotted points. The value can be estimated from the plot or calculated using the equation for a straight line: $y = mx + b$.

Conclusions

This section includes a few paragraphs including pertinent observations, equations or reactions, sources of error and a summary of your results. Pertinent observations are any observations that affect the outcome of your experiment, or mark a crucial step in your experiment. They could include color changes at the end of a titration experiment, formation of a precipitate, change of state, as in crystallization, or any major procedural changes, ie. you spilled an unknown amount of acid into your solution, back titrated to discover the amount added, and then calculated your new concentration. You should also include major concepts or equations used in the lab. If you used the ideal gas law to determine the volume of your unknown gas, for example, you should state what the ideal gas law is and how the appropriate equation is used. Finally, include a discussion of any deviations from the results that you expected to get.

Example

Ascorbic acid is present in varying amounts in both IGA brand Pink Grapefruit Juice Cocktail and Ocean Spray White Grapefruit Juice. By titrating a standard iodine solution into samples of these juices, the average amount of vitamin C in the juices was found to be 1.17 g per 8 oz. serving and 0.648 g per 8 oz. serving respectively. The results show that each of the two juices contain more than enough vitamin C per serving to met the RDA of 60 mg per day set by the Food and Nutrition Board. The amount, in grams, of ascorbic acid calculated from the titration data in each juice sample is a reasonable number and the discrepancy between the

results found for each respective sample is small enough to be attributed to experimental error.

BIOGRAPHY OF THE AUTHOR

Barbara Stewart was born in Princeton, New Jersey on November 7, 1969. She was raised in Houlton, Maine and graduated from Houlton High School in 1988. She attended Wesleyan University and graduated in 1992 with a Bachelor's degree in Chemistry. She taught high school for four years before entering the graduate program in Education at the University of Maine in 1999.

After receiving her degree, Barbara will pursue a Doctor of Philosophy in Chemical Education at Maine. Barbara is a candidate for the Master of Science degree in Science Education from the The University of Maine in May, 2001.