DOCUMENT RESUME

ED 238 725 SE 043 746

AUTHOR	Wotring, Anne Miller; Tierney, Robert
TITLE	Two Studies of Writing in High School Science. Classroom Research Study No. 5.
INSTITUTION	California Univ., Berkeley. School of Education.
SPONS AGENCY	Carnegie Corp. of New York, N.Y.; National Endowment for the Humanities (NFAH), Washington, D.C.
PUB DATE	81
NOTE	73p.; Developed by the Bay Area Writing Project.
PUB TYPE	Reports - Research/Technical (143)
EDRS PRICE	MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS	*Academic Achievement; *Biology; *Chemistry; Classroom Research; Comprehension; High Schools; Learning; Science Education; *Science Instruction; *Secondary School Science; *Writing (Composition)
IDENTIFIERS	Science Education Research

ABSTRACT

Presented are two studies examining effects of using expressive writing in the science classroom. The first study, "Writing to Think About High School Chemistry," was conducted by a high school English teacher who enrolled in a high school chemistry course. The course was typical with the exception that students were encouraged to keep a journal in which they were to write whatever they wished, or whenever they were confused or the teacher thought they had gone over difficult material. Analysis of three student journals (including the author's) indicates that writing provoked these students to reflect on their own thoughts, take responsibility for their own learning, and begin to raise and answer their own questions. The second study, "Using Expressive Writing to Teach Biology," examined use of writing assignments (reading logs, notes, practice essays, summaries) in two high school biology classes. It was predicted that writing encourages students to think about subject matter and to discover and clarify points of confusion. Although posttests showed generally similar levels of achievement for experimental (N=69) and control (N=67) groups, the experimental group appeared to do better on the delayed posttests. Statistical analyses were not reported. (JN)

TWO STUDIES OF WRITING IN HIGH SCHOOL SCIENCE

Anne Miller Wotring   Robert Tierney

TWO STUDIES OF WRITING IN HIGH SCHOOL SCIENCE

Writing to Think About High School Chemistry

By
Anne Miller Wotring
Teacher of Writing
Fairfax County, Virginia, Public Schools
and at
George Mason University
Fairfax, Virginia

Using Expressive Writing to Teach Biology

By
Robert Tierney
Biology Teacher
Irvington High School
Fremont, California

University of California, Berkeley
Bay Area Writing Project

Classroom Research Study No.5

The Bay Area Writing Project is an effort by school teachers, college faculty, and curriculum specialists to improve the teaching of writing at all levels of education. The Project is funded by the CARNEGIE CORPORATION OF NEW YORK, the NATIONAL ENDOWMENT FOR THE HUMANITIES, and the UNIVERSITY OF CALIFORNIA, BERKELEY. The findings of this study do not necessarily represent the views of the National Endowment for the Humanities or the Carnegie Corporation of New York. Individuals desiring information concerning The Bay Area Writing Project or the National Writing Project should write to Bay Area Writing Project, Tolman Hall, University of California, Berkeley California 94720.

Series Editor: Gerald Camp

Cover Design: [illegible]

Preface

There has been much talk in recent years about "writing across the curriculum." The studies in this volume offer evidence to support the belief that writing can indeed aid student learning. In them, two teachers explore the question of the value of using personal, expressive writing in teaching high school science. Each went about studying the question in a very different way.

Ann Kotring, an English teacher, enrolled in high school chemistry, a course she had never previously taken. She used what she calls [illegible] to assist her own learning in the course, and she worked with other students to show them how to use the technique and reports their successes and failures with it.

Robert Tierney, a biology teacher, enlisted the cooperation of a colleague in setting up a more traditional method study using experimental and control groups. In experimental groups, taught for one unit by each teacher, students wrote daily about their learning in a variety of forms for a variety of audiences.

The conclusions reached in both these studies have implications, not merely for science teachers, but for all teachers interested in finding ways to help students learn potentially difficult subject matter in any subject.

James Gray, *Director*
Bay Area Writing Project
School of Education
University of California, Berkeley

Contents

Writing to Think About High School Chemistry

Anne Miller Wotring

INTRODUCTION

"Writing to Learn" Across the Curriculum

The term "writing to learn" includes any kind of writing which is done by a student in the learning process. It includes the notetaking at the presentation of the material, the written work on a homework assignment, and the written answers on test questions. Educators have used writing in these ways for years although it hasn't been until recently that they realized the importance which writing has for their students beyond expediting the evaluating of students through their written efforts. Most teachers know that the activities of reading, listening, talking, *and* writing are all crucial to their students' ability to understand.

Recently, writing researchers have given the phrase "writing to learn" a more particular meaning. They have seen how students learn by writing freely and personally about the subject in their own words, and using their own experience. They suggest that teachers need to offer their students many opportunities to write in their own terms in a nongraded atmosphere about a school subject.[1] In *Writing and Learning Across the Curriculum (11-16)*,[2] the authors suggest "a personal log book" or "diary" as a means for offering students "expressive" writing ex-

periences in school. Other researchers[3] suggest "journals" for the same purpose.

Last summer when I met Pat D'Arcy, co-author of *WAC*, I was about to embark on a writing research project. She suggested that if she had the opportunity, she would join a class of high school students studying a subject she'd never taken and in which she didn't have an "aptitude." As a student she would keep "a personal log book" while she learned. In addition she would observe other students in the class who also wrote to learn. I was fascinated with the idea and knew just what subject I wanted to study. With D'Arcy's blessing and a promise that I would let her know what happened, I became the only 29-year-old student in a high school chemistry class and set out to discover what happens when students write in personal terms about high school chemistry.

I had been led to believe early in my school career that science and math were not for me. I had no "aptitude" in these areas. I did not take chemistry in high school because I had been convinced that it would be too hard and that I would do poorly if I tried. My mother got a "D" in it. I took biology and "Earth Science" to complete my science graduation requirements in both high school and college. I secretly liked them both, and secretly I wished I could know what chemistry was all about. When I realized that by doing research about writing I might get a second chance to go back to high school and take a subject I had always been curious about but hadn't dared take, that the grade would not matter, and that I would have plenty of excuses for doing poorly, I was secretly excited.

My Research Constructs

Carolyn Lavallee, a colleague at South Lakes High School, Fairfax County, Virginia where I had taught English, enthusiastically agreed to let me become a student in her fourth period chemistry class. I attended daily, had a lab partner, did the homework, took the tests, received grades, was known by my first name, and called the teacher by her last.

I was a high school student again. My husband received my report cards in the mail and a stern call from the associate principal, my long time friend and colleague, when I cut class one day.

Carolyn also agreed to ask and encourage each student to keep what we called interchangeably a diary or a journal in which each would keep his thinking about chemistry. Each would include anything he had read, heard, or done in class as well as any related thoughts from his experience. The students would write whenever they wished, or whenever the teacher thought we had gone over difficult or confusing material, or whenever I, as a student of chemistry, was confused or felt the need to write. I knew that because of my background in writing, I would more naturally gravitate to pen and paper than the other students, even though they might be just as confused about chemistry. I asked Carolyn to direct the writings, whether they were initiated by me or her. I wanted her to make the assignments because I assumed the students might be more inclined to do them at her instruction than at the instruction of a person who was just another student in the class.

Although Carolyn "directed" the journal writing, she agreed she would not evaluate nor penalize students who did or did not write. In fact, she didn't read the journals unless a student requested her to. The student decided if he wrote and what he wrote, and knew that I would want to read his journal for my research.

I quickly discovered that I didn't have time to be both a researcher and a chemistry student at the same time. I tried very hard to do both, to keep up with my own journal and the homework and labs, as well as to read the students' diaries each week or two and to talk to them about their writing. I simply didn't have enough time or energy, so I decided to relax and enjoy learning and writing about chemistry without worrying about what was happening to anyone else. I knew there would be time later to observe what happened to the other students.

This paper focuses on the experience of two students, Laura and Tim. A description of my experience follows in the conclusion. The similar experiences of two others, Jim and Pieta, are omitted from this

paper. Jim's thinkbook was misplaced, and Piera's personal discovery of think-writing two years ago in addition to her chemistry writing deserves to be the topic of another paper.

Formulation of My Question

I used the descriptive research model of Donald H. Graves, Director of the Writing Process Laboratory at the University of New Hampshire, to ask and answer my research question: "What happens when students write to think about high school chemistry?" My original question had been, "What happens when students *write to learn* about high school chemistry?" However, in the course of doing the research, I came to see that the phenomenon which I observed in four students and experienced myself was, in fact, very different from what my original question was asking.

When we discussed the chemistry writing, the students and I never called it "writing to learn." I most naturally referred to it as "figuring out writing." Tim told me about the "get into it writing" he was doing. Laura said she did "write it out writing." At times, we also called it "getting it straight writing," "rough writing" (what Teddy Roosevelt did), and "practice writing." As Suzanne Langer notes in her work *Philosophy in a New Key*,[4] the correct word is by nature symbolic and powerful in meaning. I realized I had to revise the term I had adopted from *WTL*. In the process of writing about my research, I came to see that no matter what we had called it, no material got "figured out," "straightened out," or "gotten into" by the writer, unless he was *thinking* about his material.

People have written to learn for years. They find they can acquire and retain information if they write it down in their own hand. Some people take notes for this reason, and others write out everything they know so they will remember it better. But thinking is not necessarily part of this acquisition process. In addition, we commonly misuse the word "learn." At the dinner table children ritualistically tell their parents what they "learned" in school, what they mean is "were presented

with." But presentation is only the first step in the learning process. Simplistically, after the student is presented with the material, he must do something with it before he can learn it. He may memorize it, or he may physically work with it, but no matter what activity he pursues, his participation precedes the acquisition of knowledge. By the same token, the activity of thinking comes before learning is acquired. Writing for us was the visible physical activity of chemistry thinking which was going on invisibly in our heads. As we wrote, we could see what we knew about it. What we saw in our writing were questions we had; that is, we knew what we still needed to know. Or what we saw in our writing were answers; that is, we knew what we knew.

I use "thinkbook" in this chapter to denote the book in which we wrote about chemistry for the same reason I revised my question. In the case study sections, Tim and Laura refer to it as "journal" or "diary" because at that time we didn't know the new term. Students associate journals with English teachers; we were writing for chemistry. Diaries are for personal thoughts; chemical concepts are not personal. Notebooks are for recording th. teacher's words; we were using our own. Logbooks are for keeping records of information; we weren't recording. Writing Book is vague. Practice Bcok and Workbook imply drudgery; what we were doing was often invigorating and refreshing.

I believe that the redefinition of "writing to learn" to "writing to think" will be of great interest and help to writing researchers, educators, and students alike. It forms the basis for my future research in the field.

LAURA

> "It's usually better for me to [write] at night, after...all that...has time to rest.... I can think a lot better."
>
> "I just started writing the things I didn't understand.... I started writing questions...[which were] all specific.... Then I brought them up to [the teacher] and she could answer them for me.... That way all my questions were cleared up."
>
> "Some of the questions I would have never thought of [if I hadn't written]."
>
> "I found that when it was time to study [for a test], there really wasn't much I had to study because I knew everything."
>
> "If I did take the time to write it out, the confusion would be [resolved] or I would have questions to ask [the teacher] tomorrow."

Laura worked hard in all her subjects. In most classes she received superior marks. Chemistry was her most difficult course, and she worked especially hard and received anywhere from below average to excellent daily grades. Her favorite subject was World Civilization.

From her first entries it was evident Laura trusted me and was comfortable writing to me: "There have been many things I have learned so far in this course. As I was watching the candle burn in lab 1-3, I remember thinking how dumb it was. To tell the truth, I thought that

Mrs. Lavallee was a little strange for making us do it." In addition to her truthfulness, Laura carefully maintained perfect punctuation, handwriting, and sentence structure. Anything she crossed out, she crossed out neatly with a perfectly straight line through it. Her only cross-outs were made at the completion of her effort, to edit out grammatical errors she made in the course of writing. For example, in the first writing she crossed through "was" and changed it to "is," making the entire writing in the present tense, and she crossed through an improper nominative pronoun "I" and changed it to the objective "me."

Laura explained later how she felt about doing the writing:

> In the beginning, I thought it was the dumbest idea in the world. I was really mad, and I didn't want to do it. [But]...you and Mrs. Lavallee were really insistent, so I figured 'oh well, I'd better start writing.' I was really hesitant to write because I knew you were an English teacher.... I felt like it was an added thing, where the writing would have to be perfect.

But Laura wrote because she thought that she should participate in the research project which her teacher and I were encouraging her to do.

By the end of the first quarter, Laura was very frustrated with chemistry and writing. "Everything I was writing wasn't helping me at all." She was writing to me and for me, as the researcher, about what she was learning in chemistry and how she felt about the class and the tests. Laura missed an "A" that quarter by one point. "I was kind of, real upset about that...." With a fresh grading period beginning, Laura vowed to work for an "A" the next time. She still felt that I, as an English teacher, could not help but silently evaluate her as I read what she wrote. She liked me and wanted me to like her and respect her intelligence. Laura felt encouraged by something I said. "You kept telling us to start writing what we learned and what [we] didn't understand."

With her overriding desire to learn the material so she could get better grades and a notion that it might be acceptable for her to

actually write down things she didn't understand, Laura used her think-book to work through some metric conversion problems the class was given. She did her scratch work in the book she had previously reserved for writing only the things she was sure of. She had no idea of whether she would be able to do the problems. Her caution in writing was evident. Her earlier entries were in pen. The metric conversion problems were in pencil. She wrote with the security of knowing that she could erase anything which was too wrong or too messy before I ever read it.

This writing (reproduced on pp. 16-17) showed the first evidence that she was writing to herself for herself. It looked quite similar to the writing a math student does to "show his teacher his work;" however, the difference was that Laura wrote all the thoughts going on in her head, not just those which related directly to the product of the problem. She wrote words which were extraneous to the product of the problem, the words of thought she was thinking to herself and for herself as she worked through and solved the problems. They were the clue that *she was writing to and for herself.*

Laura began the metric conversion problems by writing words of encouragement to herself. Her encouraging voice got her started by saying "okay ---." She wrote the conversion formulas as she had memorized them. She congratulated herself by writing "So far so good -- Now ---." She proceeded to figure out the first problem by writing out the steps of her thoughts. When the problem was solved, she exclaimed on the paper, "I did it!" Laura turned the page and started another problem. When it, too, was solved, she did another. With two more completed, she began to feel more confident and wrote, "I think I'm catching on." She copied another, more complicated than the others. Again she couldn't help but exclaim to herself about her ability to solve equations she had thought were impossible. After working through one more, she felt confident enough to stop. She felt she could do any of them now. She realized, though, that she still wasn't confident about "rounding off" numbers, and so she wrote a few reminders to herself. With these recorded on the paper and in her mind, she confidently chided herself, "I better pass this dumb quiz. Don't forget!" She completed the writing

by outlining to herself rules for determining the significant figures in an equation.

Laura's caution in her first think-writing entry carried over into her next, but in a different way. When she was confused and frustrated with her inability to understand, she often asked the teacher for help. But she wasn't always able to tell the teacher exactly what it was that she didn't understand. The teacher was frustrated, too, with general statements of non-understanding.

> Whenever I went up to Ms. Lavallee... and said, 'I don't understand,' she couldn't help me...because...I didn't tell her *what* I didn't understand.... So, I started writing questions down.... I just started writing the things that I didn't understand and then I brought them up to her, and she could answer them for me and I could just...write them out.... That way...it was all specific and all my questions were cleared up."

Laura was delighted to find that she could write questions she thought of on her own about her own confusion. "Some of the questions I would have never thought of.... When I went home and thought about it, new questions came up, and so I would just write those down." Before this, she hadn't realized that she had the ability to ask the questions which could help her understand the material. She didn't yet have the confidence in her own ability to attempt to answer the questions for herself. She was st·ll convinced she needed the teacher's help. She wrote the questions ..hich she had discovered on her own and for herself so that the teacher could answer them for her.

In a few weeks Laura was taking complete responsibility for her learning. Not only was she still discovering and asking her own questions, but she now had discovered that she herself could often answer the questions she posed. She realized that writing helped her understand the material.

Laura wrote the entry on Thomson (reproduced on pp. 1‾-20) and electrically charged particles with the confidence that she would be able to figure out the material on her own. She knew that if some of

the material failed to make sense to her, she could always ask the teacher for help.

She began the entry with a reminder to herself which had great significance for her. She underlined "particle" four times and ended the sentence with three exclamation points. Then she got into the material which she needed to think about. The key word for her was "Thomson." The reader can actually see and hear her thinking here. She wrote the name and paused and thought to herself, "Okay, what do I know about Thomson?" Writing "okay" gave her time to think. She wrote the first thing which came to mind: "He did an experiment with a ball." That triggered her thinking about the experiment: "If the ball is charged," and so on. She told herself what happened in the experiment. This caused her to wonder why that should happen. She asked herself "why?" and answered herself.

In this entry Laura was no longer concerned with perfect prose. Laura knew the rules of grammar well enough to know that "Because electricity interacts with a magnetic field" is a sentence fragment. But she was writing fast, concentrating on chemistry, and was not thinking about the rules of grammar at this time. She was only concerned about getting her thinking out on paper, not with demonstrating her knowledge of "proper writing."

At the end of line 12 she exhausted her train of thought and paused again to write the "okay" on line 13 and begin some new thinking. She wondered about the variables involved in the experiment. She answered her question (lines 13-17) only to realize that she couldn't follow "so" with a conclusion from the information she had. She realized that she had forgotten about a key occurrence in the experiment and couldn't yet draw the conclusion which she had been told was the correct one. Because she was writing while she was thinking, she ... where she was jumping to the conclusion too quickly. On lines 17-19 she parenthetically reminded herself that she "forgot about deflection." She began a section on deflection. She divided her thinking into sections like paragraphs except her indentations were reversed. Each section dealt with a new

idea.

She defined her understanding of deflection on lines 19-20 and explained how it related to Thomson's experiment. She was evidently delighted with the information she had about Thomson and deflection because she felt the need to exclaim about what a "smart guy!" he was for discovering that deflection was "the arc of a perfect circle." With the exception of the "O.K.'s" and the reminder at the top, Laura often used parentheses to enclose the comments she made to herself about what she was thinking. She marveled at the scientist's work and stopped herself when she realized she had forgotten something important which she needed to write about so all the data made sense together.

"Now" gave her another chance to pause and recap in her thinking before she plunged into the next ideas. Lines 25-27 were her first attempt at putting together the information she had laid out in the three previous sections. She took a stab at making the connections. The minute she began to write, she realized the material couldn't make sense yet. She wrote, "Wait, that doesn't make sense," the thoughts a person sometimes says out loud when she realizes that the idea which seemed to make sense in her head doesn't make sense when she says it. Just as that person might try to rethink out loud, Laura attempted to get it straight on paper.

Laura knew it was okay for her to let lines 25-27 stand and didn't take the time to put scratch marks through them. She trusted the writing to know that the important thing was for her to go on and write some more, not to take the time to cross out what she had. She realized her purpose for writing was not to read and understand later on what she had written, that once she had written and gotten it all straight, she wouldn't need to go back and read it later because she would already understand the information.

With her new attempt at puzzling it out, she felt closer to understanding and thought faster, using shorthand arrow signals to represent "increases" and "decreases." What she said on lines 30-31 seemed to make sense to her, but she wanted to try the idea again, this time in

other words, which were signaled by "or" in line 32. She wondered why deflection decreased.

Between lines 30 38 she got the idea straight and even drew a diagram to see even better how deflection works. In the next two sections she tried out her idea of deflection by setting up two hypothetical problems which she proceeded to work through so that they corroborated the idea she had set forth and agreed with each other. Again, she left the sentence fragment in lines 41-43 and the "than" on line 40 and 45. Laura knew the difference between "than" and "then" but couldn't be concerned with pursuing letter-perfect prose when she was more concerned with pursuing her understanding to its end.

At line 49 she needed to recap what she had just learned from writing out the hypotheticals. She listed the four variables involved. Then it occurred to her (lines 56-57) that there was one more variable which was known, and so she noted this.

Then she wrote from her notes the exact words about deflection the teacher had given in class lecture: "Deflection is proportional to the charge of the particle and the strength of the magnetic field." As she wrote each word, she thought to herself "do I understand?" and, as she understood, she continued to write. With the writing of these words, Laura checked to see that, indeed, her own train of thought and language had led her to the same conclusion. She *saw* that the teacher's words fit into her understanding of the experiment. The teacher's words, succinct and to the point, now made sense to Laura because she had played with the ideas in her own order and way.

On line 63 she wrote the equation which represented the idea expressed in 59-62. In lines 64-66 she copied another passage from her notes as if to say "yes, I understand this idea now too. These words make sense to me." So she wrote the equation which represented the idea. Then she combined the two equations, as she had seen done in class. But this time, *she* did the combining, not the teacher. She could do it not because she had seen the teacher do it in class or because she had committed it to memory, but because she had worked it through herself.

She knew how the two equations corresponded.

With the equations in place, both on the page and in Laura's head and in complete harmony with all her other information, she prepared a little quiz for herself. She knew each question was an important one to ask. She posed these questions, not because she knew the answers, but to see if she did. If she didn't, she knew she would have to get help. But by the time she had completed writing each question, she knew she knew the answer. As she saw that she could answer each, she did.

After the questions on lines 76-78, she replaced the conventional question mark with an arrow which pointed the way to the answer, as if to say, "I can ask the questions and I can also answer them!" These arrows reveal her delight at her ability to understand chemistry.

When a teacher delivers a lecture, he presents his own experience and knowledge of the subject. When a student hears the lecture, he applies his own experience and knowledge to the material presented. The teacher's ideas and order of presentation may be completely different from the student's own ideas and train of thought. It is difficult for him to listen to the new ideas and at the same time to relate them to his own ideas. Until Laura let the old and new ideas in her mind flow out, be seen, and mix together, she couldn't assimilate the ideas so that all the information was in accord.

During the first quarter, she had followed her usual study habits, which meant she kept up with the material required on the day-to-day worksheets, labs, quizzes, exercises, and homework. Then, as Laura told it, "[on] the night before a test, I [had] to cram for everything and memorize everything." But in chemistry, Laura found that

> when I [wrote] down every single day what I learned, and I understood everything every day, I found that when it was time to study [for a test] there really wasn't much I had to study because I knew everything.... It's a lot easier doing it this way.... This quarter in this class I haven't had to [cram or memorize] once.... But you have to do it day-by-day.... Every single day you do have to understand what's going on.

Laura had come to realize she didn't have to spend her energy cramming everything and memorizing everything if she spent her energy thinking about everything as it was presented. Previously, she had never actually thought about the material presented in chemistry because she never realized *she could* think about it or really understand it. In other words, not only did the writing enable her to think about a subject which was difficult for her, but it also enabled her to understand it. But even as Laura told me how she no longer had to cram to study on the night before a test, she didn't yet realize or understand that by discovering and asking questions about the material day-to-day, she was studying.

As the class progressed and Laura continued to write, she began to read over her writing before a test and found that even though she didn't cross out things which she knew were wrong at the time she wrote them, she could still tell which things were right and which were not.

Eventually she changed her review habits. On the night before a test she would write

> in my diary just everything I knew,
> I didn't even look in my notes. I
> wrote everything I knew, and then,
> I checked my notes to see if I'd
> left out anything or if everything
> I'd written was correct and it was."

She realized that the writing she did in her thinkbook was important for thinking about and figuring out chemistry. But for the purpose of reviewing for a test, she found it more helpful to read over her notes from the lecture. The notes organized the material in the most succinct and understandable way and were easier for her to read than to take the time to read her writing. The [illegible] for her in being able to use the teacher's notes.

Laura found that the class time she was given to write was unsatisfactory for her purposes.

> [Ten minutes in class] usually
> doesn't give me enough time be-
> cause it takes me a long time to
> think.... In class, I seem really

confused and I don't have everything straight in my mind.... It's usually better for me to do it at night after [class] because all that, that [the teacher] said, has time to rest. And I can think a lot better.

Her reasons revealed what happened to the information she had taken into her brain while she was in class. She could tell that her brain needed a chance "to rest," to mull the information about subconsciously until a little while later when it would be able to process it. To borrow an analogy from Pat D'Arcy,[5] this phenomenon is much like the process of photography. An image is made on the film when a picture is "taken" and is then "developed" over a period of time and under special conditions before it can become clear and forever-captured. For Laura, it took time and special conditions for the information she had been presented with in class to develop in her brain before it became clearly formed and not easily forgotten.

Laura discovered that she didn't have to write every day. She only needed to write over the period of time new material was presented. She collected the material in her head until she felt she had enough ideas which needed to be thought about and connected together. Laura explained,

> Last night I didn't do [the writing] and I still...haven't thought about what she said yesterday at all, so I'm still really confused about it. But I know that tonight, if I did take the time to write it out, the confusion would probably be [resolved], or I would have questions to ask her tomorrow.

Laura's confidence in her ability to "write it out" and either be able to understand the information or to ask questions about it is remarkable for a student who had little confidence about learning chemistry in the beginning. She knew that if she wrote she would be able to understand the information.

Laura's metric conversion writing (typed from her thinkbook)

Okay ---

$1\ km = 1000\ m$
$1\ hm = 100\ m$
$1\ dkm = 10\ m$

$10\ dm = 1m$
$100\ cm = 1m$
$1000\ mm = 1m$

So far so good ---

Now ---

$10m = \_\_\_\_\_ km$

$?km = 10\ m \ \frac{.001\ km}{1\ m}$

$$\begin{array}{r} .001 \\ \times\ 10 \\ \hline 000 \\ 001\ \\ \hline 0.010 \end{array}$$

3 sig. figs
2 sig. figs

$.01\ km = 10m$

I did it!

$?l = 250\ ml \ \frac{1l}{1000 ml}$

$?l = \frac{250}{1000}$

$l = .250$

$.25\ l = 250\ ml$

$?\ kg = 2000g \ \frac{.001\ kg}{1g}$

$2\ kg = 2000\ g$

I think I'm catching on

$?cl = 10\ ml \quad \frac{1l}{1000\ ml} \quad \frac{100cl}{1l}$

$= \frac{10 \times 100}{1000}$

$= 1$ cl

1 cl = 10 ml

All right!

7.7l = 7.7l $\frac{10}{10}$ $\frac{10}{1l}$

77 dl = 7.7l

Just remember to place the
units in the right order so you
can cancel out. Remember
to go up to major unit if
necessary & then proceed.

I better pass this dumb quiz
Don't forget!

All digits are sig. figs
All zeros between 2#'s are
sig figs
All zeros after a # & after a
decimal are sig figs
All zeros after a # & before
a decimal are sig figs

u = micro
um = micrometer

Laura's writing on Thomson (typed from her thinkbook)

Don't forget to pretend
that the ball is really
a particle!!! 1

Thomson
O.K. He did an experiment 5
w/ a ball & a magnetic field

If => the ball is charged, there is a greater attraction between the ball & magnetic field. Why? Because electricity interacts w/ a magnetic field.

O.K. What if the mass of the ball was changed? The magnetic field would have a harder time attracting the ball. So --- (I forgot about deflection)

Deflection is a change in direction. Thomson found in his experiments that deflection was the arc of a perfect circle. (Smart guy!)

Now => As the ball w/ the larger mass goes through, the deflection goes down.

Wait, that doesn't make sense.

As mass of ball ↑ ,
deflection ↓
or
It takes longer for the magnetic force to attract the ball (Why? because of the added weight) &..the deflection or arc is not as curved.

If the balls speed is increased than deflection is less again. Because it takes longer for the magnetic field to attract it.

If the magnetic field is increased than the ball will have a greater deflection because the attraction is greater.

So far -- 4 variables involved.
1) charge of moving particle
2) speed of moving particle
3) mass of particle
4) strength of magnetic field.

The amount of deflection can be measured.

So 5 variables now.

deflection is proportional to the charge of the particle & the strength of the magnetic field

$d = eB$

deflection is inversely proportional to the mass and volacity of the particle

$d = \frac{1}{mv}$

Combine Equations

$$d = \frac{EB}{mv}$$

Can deflection be calculated? yes
Can the charge of the particle be calculated? no
Can the magnetic field be calculated? yes

Can mass of particle be
calculated => no
Can speed of particle be
calculated => yes

TIM

> "Since I [got] it confused even writing it, obviously, if I was just trying to hold it all in my mind, it would have confused me, probably even more."

> "If you just try to sit there in your mind,...the ideas are all mixed up and hard to figure out."

> "If I [hadn't written] it, I never would have thought about it until the day before the test."

> "If I hadn't written it out, then I probably still would have been confused."

> "I guess I was confused, and I kept writing to try to figure it out in my mind."

> "It was more like just writing out what I [was] trying to do, even though I didn't know."

Tim's aptitude lies in the sciences including chemistry. He always sat in the front row, paid rapt attention to the teacher's lectures, and fearlessly asked any question which occurred to him in spite of occasional groans from the other students. He wanted to learn. Tim thought writing to think sounded interesting and was curious about my research.

At first he wrote everything to me and for me, as if he were writing me a letter recording the day's events in chemistry. His handwriting was very neat and his grammar flawless. Later Tim said, "It's usually

hard for me to write for me because I'm used to writing for what...the reader is going to think about it."

In no time at all, he began writing for himself; however, he continued to write to me. He still wrote to tell me the material being presented, but he included, for himself, more detailed and specific information. With more complete information recorded daily in his own words, he realized he would be able to review easily and quickly for a test by reading through his thinkbook. At this point he used his thinkbook as a log book.

He was still concerned about his reader:

> ...if Anne saw this, I [would] want her to think that I know what I'm talking about.... To me...when [I'm] writing something..., even if it's nothing important, I think about correct grammar and correct punctuation, and does this sentence make sense? and is it clear? and all that stuff. And so if you're writing 'the electrons are negative,' you have to make sure that you say it right and it sounds good.

Shortly after he began writing for himself, Tim decided to "take" his lecture notes in his thinkbook along with his writing. He decided it would be convenient to keep all his information recorded on the pages of one book. Hereafter, his journal shows pages of dated notes taken in class interspersed between dated entries of writing. He wrote the entries from his memory of the material presented in class. Although it often seemed to him redundant and inefficient to write the material over again from memory which he had already recorded in his notes on the previous page, he continued this practice, finding the rewriting helped him remember the material. He was "writing to remember." He was also "writing to check," for, after he made an entry, he always checked it against his notes to be sure the information he wrote from memory was correct and complete.

At this time, he recorded the material from rote memory and recall. He listed in sentences the facts he could remember and referred to his

notes to continue the list for facts he could not recall. He didn't make connections between facts or put them in any particular order. He didn't draw any conclusions or look for any relationships. *He didn't actually think about the material.* Tim explained, "I just sort of write down what I think I learned." In other words, he wrote down the facts which were presented, not those which he had thought about. He made most of these entries in the ten minutes of class time allotted for think-writing or during his lunch period which preceded the chemistry class.

With the end of the quarter approaching and his grades falling short of his goals, he decided to get more serious about studying. The teacher lectured daily about electrically charged particles. She introduced three very important experiments which were historically based on one another. That is, it was necessary to understand the first, Thomson's, to understand the second, Millikan's, to understand the third, Goldstein's.

One day the teacher was cut off in the middle of something important when the bell rang. Tim didn't have his usual time to write in class. The next day there was no time left again. On the third day without time to write, Tim knew he had to get all the material straight. He was really confused. That evening, he took home his thinkbook with his notes in it. This was the first time he had ever written about chemistry at home. Tim explained what happened:

> I was really having problems with something. I didn't know what was going on.... I think it was like the day or a couple of days after we had actually done the lesson, and I went back to [my notes] and I said, "what is this?".... Instead of saying [to myself], "now if Anne saw this, I want her to think that I know what I'm talking about...," I started just writing in my journal what I remembered....

He began writing about Goldstein's experiment (reproduced on pp. 28-30). He recorded the facts he remembered until he got to line 9.

There he found himself writing something which didn't fit with information presented by the teacher. He couldn't continue to introduce any more facts onto the paper until he had the facts on the paper correct and in order. He realized he truly wasn't sure how Goldstein had set up the experiment and consequently wasn't sure about *any* of the facts he had written to that point.

> I was writing about that drum that that guy made where he caught the oil drop. .. I was writing along and I was putting...'and then he had two negative plates...and the atom or the electron got attracted towards one.' And, all of a sudden, I say, 'Wait a minute! It wouldn't get attracted if it was negative!' And so I wrote that: 'it wouldn't get attracted if it was negative. This is wrong!' I wrote 'this is wrong.... Wait a minute. Let me...go back.' I wrote that down.

Seeing the confused material on the paper forced Tim to see his confusion. For the first time, he recognized that the words on the paper were the symbolic representation of the ideas which had come from his head.

Tim was incredulous that he had actually allowed himself to confess on a piece of paper that he hadn't understood something. By writing those words, he felt as though he had admitted to the world, or at least to me, that he didn't always understand everything. Tim took the chance and wrote these words to himself with no concern for the opinions of anyone else who read them. For the first time, he realized that *he* was the only audience he needed to worry about when he wrote to think about chemistry. If he needed to write down "I am totally confused," then it was important that he write it. If he was thinking those words, then he wanted to write them along with the other words he was thinking. He realized that his need to get things straight was far more important than his need for the reader to see that he is smart because he understands everything.

He had written first that protons were sent through the chamber, and, at this point he wondered if that was wrong. He decided that .

perhaps this was the errot causing everything else not to make sense and come together. So on line 13 he drew a diagonal line after the sentence which had led him to a dead end. He began again with an idea he thought of while writing. At line 15 he told himself that what he was writing presently must be right. Yet, by line 17, he obviously had run into another snag. From line 17 to line 21 he made his first cross-throughs.

It is important to know that he did not make the cross-throughs until he had almost finished with the writing. In other words, he did not know until later in the writing that what he had written on those lines wasn't going to continue to make sense with later things he wrote. As he added to the idea, he had to change and/or reword earlier ideas to make them all agree. What is crossed out now remained uncrossed out until Tim did further writing and came to a point where again the information didn't continue to relate. When he realized the problem, he went back and made these cross-throughs and wrote in the correct information which made this section accord with the rest.

When he first wrote them, Tim wasn't totally sure lines 17-21 made sense, but he left them anyway. He was frustrated. He knew he couldn't go any further in thinking about lines 17-21 as they stood. If he wanted to go on with this same train of thought, he would have to figure them out. He almost knew how it all went, but not quite, and it didn't seem important to work out what seemed at that point to be a small kink in the process. He was still in the habit of writing for other people; consequently, he didn't care about correcting fine thinking errors he sensed he was making in a writing few would see. He thought fine thinking errors were corrected in writing to help the reader read. He didn't know that the correction of a fine thinking error enabled the writer to think through and understand the material. If he had felt his own writing were important to him and not just to other people, he might have pursued that hazy line of thought. If he had known the relationship between writing and thinking, he would have realized the importance of puzzling out the information for himself, so that he could understand it.

Instead of taking the time to write the thought through again so that it made total sense, he shifted gears. He jumped to a new train of thought. He was sure he could pursue another thought successfully without ever having to work through the problem with the previous one. He began the new thought with "anyhow," a clue that he was jumping from his old train of thought to another, a clue which could foreshadow a bigger problem ahead. The "anyway" signified that "even though this previous statement doesn't make complete sense to me, I'm going to go on." He continued on with new facts of the experiment. In lines 25-28 he clarified the previous words for himself in the parenthetical statement. He simply reworded the idea into words that made better sense. He went on with little trouble until line 39 when he realized that what he had just written was *very* wrong.

He drew an arrow and gave himself the bad news, "But." He realized that the information in his head no longer coincided with what he had just written. To prove to himself that it wouldn't work, he next wrote this data from his head so he could *see* that it couldn't. Then he told himself to wait and think the problem through. He continued to write these thoughts on paper. He chose a plural subject "we" (in line 42) as if he were two people working on this problem together, as if these two people were talking about the experiment, and one of them was going to try to set the other one straight about his misunderstanding. Tim started drawing diagrams which illustrated to his other self what was happening. Then he "okayed" himself as if to say to his other self, "I understand so far, go on."

At this point he went back and rethought some of the information about Millikan's experiment, even though when he had begun the writing, he had thought he understood it fully. He needed to understand it now, not in isolation, but as it related to Goldstein's experiment. After having done the writing about Millikan's work, he went back and crossed through most of those earlier troublesome lines (17-21) to make them agree materially and grammatically with his completely revised thought. What he had believed was a small kink in the process turned out to be

an important kink in understanding the big picture.

At the time he talked to me about this writing, he scratched the two light diagonal crossout lines over lines 40-42. He did this because he said that he still couldn't believe that he had actually written those embarrassing words, and he considered this aside to intrude upon my reading and understanding of this section. He still hung on to the idea that I was reading his journal to appreciate his knowledge of chemistry.

The correction he made on lines 17-21 was his last word in that entry. That correction was the key to his understanding all the experiments. He didn't need to continue to write about Goldstein's research because, with the correction, he had it straight. He had accomplished his purpose for writing; his thinking process was complete, and it didn't matter if his product wasn't. Had his purpose been to record everything about the experiments, he then would have written a complete, accurate and neat explanation of his understanding on another page.

Tim now knew that he didn't need help understanding the three experiments. He had had all the knowledge; he just needed to know what he had and get it in the right order. He had used his hand to write it down, his eyes to see it, and his brain to think about the connections it made.

In an interview, Tim told me about his usual learning experiences:

> When the teacher is writing the thing on the board, you understand how she's doing it. But when you get home and look at the book, you have *no* idea. And then when she explains it the next day, you understand what she's saying, but you still would never be able to figure that out yourself.... She's almost telling you too much. She's telling...you...a + b is going to equal c, but she's not telling you how to get there.... It's like Mrs. Lavallee is telling us something about the electrons. She says, 'okay, the electrons do that and they do this.' Then I get home and I say 'yeah, but, how did they do that or what happens if they don't do it?' That's when

> you get confused because you...sort of understand what they're doing but not why they're doing it. And it's hard to understand what something does when you can't understand why they're doing it,...or what's going to happen when they do it, or why the other things don't do it.

He also commented on his experience writing in chemistry class:

> Sometimes you get into it [the writing]..., meaning that you really want to do it, you really want to find out why it didn't work or what's wrong. Other times you'll just say, 'oh, well. I don't understand.' And you won't write down why you don't or what you don't [understand]. You just write you don't understand. [But when I'm serious about trying to understand,]...it's easier to get into it and just write.... And so if you tried not to worry about whether it sounds good and whether it's correctly punctuated and you just write it, it's a little bit easier. But it's hard to [not worry]. It's like untraining the way you've been trained.... [When] I didn't have to stop and think about writing, I just thought about chemistry and...I just wrote what I was thinking.

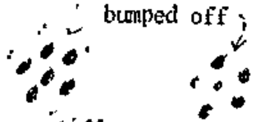
Tim's January 22 writing (typed from his thinkbook)

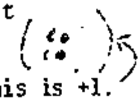
January 22 entry

We learned about the mass spectrograph. Goldstien devised this apparatus to measure the mass of protons. A current of protons is sent into a chamber with a negatively charged plate. The plate has a hole in the middle, so the pro-

tons will speed forth in a straight line. Then neon atoms then bump off the electron--from a proton? I'm totally confused. I don't know what is sent into the apparatus to start--electrons, atoms? / The plate is positively charged, which means that negatively charged ions must be sent into the apparatus, to shoot through the hole, be bumped with neon, and ~~become protons~~ neon becomes → positively * charged ions ~~But how does one turn a negative~~ Neon's electron is bumped off and it becomes a ~~ion into a proton by introducing neon?~~ Anyhow, the ~~protons~~ Neon ions are then deflected by a magnetic field outside the apparatus. The variables of mass and charge are the most significant. Those with higher charge have a higher deflection, (farther to the right, closer to the negative magnetic field) The heavier ones deflect less, and a ratio can be set up to balance between mass and charge to see how they can land in different places. Using known elements, a scale was set up so unknowns could be calibrated. Each proton has the same mass, but different atoms have different numbers of protons, thus different masses and different readings on the spectrograph. → BUT

this is ~~wrong~~, because individual protons have the same mass. wait--we're talking about an atom, with the electrons bumped off, so



each atom has a different mass, thus the different readings. O. K. The charge is simply how many *more* positive protons *than* electrons *or* vice versa. It is simply a representation.  despite the real charge, this is +1. Millikan's drum had *one neg.* and *one pos.* plate and a negative charge on the oil drop. The drop was attracted up toward the plate, but pulled down by gravity and the other charge, so it became stationary.

CONCLUSION

Conclusions Drawn from Case Studies

Students who wrote to think about chemistry:

- -- wrote when they felt confused and needed to get material straight.
- -- were interested in understanding, not just in memorizing the material.
- -- wrote for themselves.
- -- wrote to themselves.
- -- needed to see the material in their own words and in their own order of thought, not only in the words and order in which the material was presented.
- -- didn't need to write about all the material.
- -- wrote when they were rested.
- -- wrote when there were few internal or external distractions.
- -- drew diagrams and wrote evaluative comments to themselves about the material.
- -- needed encouragement because writing to think is hard.
- -- sometimes used their writing later to check or refresh their memories.
- -- thought others would be critical of their writing and not be able to read or understand the information.
- -- didn't need the teacher to explain things over and over.
- -- didn't always find it necessary or convenient to keep all the writings.
- -- asked well thought-out questions.

-- figured out material without the teacher's help.

-- delighted in their ability to learn and understand chemistry.

-- took responsibility for their learning.

What Happened to the Researcher When She Wrote to Think about Chemistry

I wrote when I had been presented with a lot of material or difficult material. Usually introductory material was uncomplicated, and I could do the thinking in my head. But when we got into new vocabulary, new concepts, new details, new processes, I found myself needing to write.

It was never quiet enough in the classroom for me to write successfully. If it weren't the other students' talking, it was the talking going on in my own head which disturbed me. I needed peace both externally and internally to think about chemistry. I couldn't do it when other things were pressing on my mind. When the teacher gave us ten minutes at the end of class to write, I was still too overwhelmed by all the new material to know where to begin. I needed distance and time from it before I could think about it again. Sometimes I was too preoccupied thinking about something else, such as what I was going to do after class, and couldn't focus on chemistry. But if I had enough time, I could usually write the things out of my head which preoccupied me so that I could get to the ideas in there about chemistry. When I was able to write about chemistry, I invariably ran out of time and left class frustrated. And when the teacher gave us ten minutes at the beginning of class to write, I usually sat through the remainder of the class struggling to concentrate on the lesson because I was still thinking about the chemistry I had been writing about.

I often felt that had I not been writing while I learned chemistry, I would not have worked with difficult ideas as long as I did without getting help. I often rely on others for help when I think something is too difficult for me to do on my own or when I need to hear myself talk so I can know what I know. My urge to talk about anything I learn is very strong. I believed that chemistry was difficult, so it would

have been natural for me to seek out a willing helper. But when I did the writing, I no longer felt I needed another person. The writing enabled me to know what I knew and to figure out the difficult ideas on my own. I realized I could listen to myself think while I wrote my ideas on the paper.

I wrote down whatever I thought, as if I were trying to capture the flow of ideas in my brain on the paper. Sometimes I captured tangential thoughts which always proved to be useful and interesting. Frequently, I "captured" ideas which didn't make sense or sounded silly or were wrong. When this happened, my internal critic or common sense, for lack of a better word, interrupted the idea with an evaluative comment. I would write the evaluative comments on the paper as well. If the internal critic remarked "that doesn't seem right," I'd write "that doesn't seem right." I learned quickly to trust my internal critic's intuition. And my internal critic didn't only tell me when I was wrong; she often made comments of encouragement, such as "I think I'm getting it," which kept me going when I was on the right track.

I didn't cross out the nonsensical, silly, or wrong things I wrote. I also didn't cross out the internal critic's comments. I just went on writing. Crossing out wasn't necessary. I wrote not because I wanted to get all the ideas clear and correct *on the paper* but because I wanted to get all the ideas clear and correct *in my head*. It wasn't important that no one else would be able to read my writing and understand what I was saying about chemistry. What was important was that *I* understood what I was saying by the time I had completed the writing. The writing was for *now*, at the time I was doing it, not for later, and the writing was for me, not someone else.

When I wanted to think, I didn't always write in my thinkbook. I wrote on my homework sheet or on the back of my test, on whatever paper was immediately available. I also liked keeping the writing with other information which had started me thinking.

If a concept wasn't clear and perfect in my brain, I formulated questions I needed answered by the teacher to get it that way. Most of

the questions required yes or no answers, such as "is this right so far?" All I wanted or needed was the teacher's simple response. I didn't want her to explain why it was wrong or what happens next. I didn't want her to take my knowledge out of my hands at that point. I wanted to figure out why it was wrong or what happens next. I needed her simple direction, and then I wanted to get back to work with my ideas, my words and my train of thought. I wanted to get back to my desk and write. Once she gave me my lead, I couldn't hear what else she explained because I was listening very hard to what was going on in my own head. I couldn't use any additional ideas until I had thought through the implications of the answer she had given me to my question. To use an annlogy, she was giving me more than I chould chew at that time. I had no room for more. I had to swallow what I already had before I could take in any more. I knew that when I was hungry for more, I would get it.

When I wrote, I also felt as though I let the ideas at the forefront of my brain out onto the paper so that the ideas in the back of my brain could move up into the front. Once those first ideas, the conscious ones, were out of my head, the ideas in the back of my brain, the subconscious ones, had room to move to the forefront to become the conscious ideas. And when I wrote these out, more ideas moved into the forefront. The new ideas had been too far in the back of my brain, and I couldn't get to them until I made room.

With all those new ideas now available to me, I felt as if I were discovering new things about chemistry which I didn't know I knew. At the same time, I was making connections between one bit of information and another, sorting and reshuffling and discovering even more. When I transferred the idea to paper, I could actually *see* what I knew about the idea. Seeing that I knew something about the idea, and seeing precisely what I knew, whetted my appetite to see what else there might be rattling around in my brain about the idea. As an experiment I tried using a tape recorder to see if it would give me the same benefit. Although I could hear what I knew as I talked into it, I missed not being able to see what I knew, even though I could hear it again. In addition,

when I wrote my ideas, I could much more easily look up the page to see an idea than I could rewind the recorder to find the exact place where I could hear the idea. I ended up transcribing onto paper the tape recordings I made so I could work with them more easily.

The beauty of having it on paper was that I felt as if my brain was freed of a lot of the information it had been storing so that it could work more spontaneously with the ideas on paper. I could arrange and rearrange the sentences and ideas and fill in the gaps with additional ideas as it worked towards making everything make sense together. Because it was on paper, I was able to work back and forth between paper and head until I had everything out on paper and it all clicked.

I found that writing eliminated all my need to study the night before a test. I knew and understood everything already. I didn't need to memorize anything or cram anything into my head; and, because I didn't have any information precariously and hurriedly jammed into my head, I knew that I couldn't forget it in the middle of the test. I knew I had it all in there in order so that it made sense, and I could call upon it and find it when I needed it. It was all neatly filed, not just thrown in. I was confident in this knowledge and in my knowledge. All the pressure I'd always associated with tests vanished.

For me, writing was like putting together a jigsaw puzzle. The teacher showed me the picture on the box (the text) and showed me *her own* completed puzzle (her lecture). With these general impressions of what *my own* puzzle should look like, I laid out *my own* pieces. As I did, I arranged the pieces into groupings. Some linked together. Then I concentrated on the border and worked from there. If I got stuck, I consulted the picture or the teacher's completed puzzle. She looked at my puzzle, but I didn't want her to put it together for me. As more and more pieces fit, I worked more rapidly and contentedly. When I was finished, I kept my completed puzzle and the knowledge that I had done it myself.

The very best part for me was that I realized I could actually think well enough on my own to figure something out without someone else

showing me the direction or giving me clues. I could think well enough to ask questions which were right on point. The writing had eliminated my anxieties about chemistry, a subject I wasn't supposed to be able to do. It gave me confidence in my ability. I felt independent. I felt free. I could understand chemistry on my own. And if I could do chemistry, what else could I do on my own? I suddenly wanted to try more and difficult things. I was delighted about my ability and amazed at my knowledge. I knew I had done it all by myself.

What Happened to the Other Students and Why

About one-third of the twenty-six students in the class were so unsure about what writing to think meant they didn't write anything. Others wrote to me and for me, pretending I was not a member of the class and informing me about what was happening. In school, students write for this purpose almost exclusively, pretending that someone else, usually the teacher, is uninformed and writing to him about a subject he already understands.

Students who were concerned about their grades wrote to memorize and/or wrote to check their recall of the material. In a sense, they were actually "writing to learn," i.e., memorize. They knew there is a relationship between the act of writing and the ability to remember. Before a test, these students wrote everything they could remember to see if the information in their brains was factually accurate and complete. They didn't write information they were uncertain about until they consulted their notes for the teacher's explanation. They didn't want to write anything wrong. They crammed the teacher's words into their writings and their heads. They wrote as if the teacher would read and correct their written products. Some teachers encourage their students to write for themselves for these purposes.

Only four of the twenty-six high-school-age students were able to write to think. I was very curious to know why the majority could not. My first guess was that I had erred in my description of the purpose for the writing. I did not know the term "write to think" until after I

completed my work with the students. However, three students had done it without knowing the most succinct words to describe what they did. These students shared a desire to want to understand chemistry. But, there were others who wanted this as well. With Piera as the exception, none of them had ever written to think before. But even Piera wasn't convinced that the writing she had been doing for over two years was a *legitimate* use for writing. Until she came into the chemistry class, she had never discussed her writing with anyone nor heard writing discussed in this way. In fact, she had not thought of the writing she was doing as thinking. So my second thought as to why the majority didn't write to think was that none of them *knew* that *writing is thinking*.

The students viewed writing as the act of putting on paper ideas which already make sense and which the writer wants to record for others to read. Our society holds the same belief. We see writing as a final offering of ideas which a writer makes to his readers. We assume the writer has conceived of and organized the ideas in his head *before* he ever commits them to paper. We teach this to our students. They remain unaware that writing can have another legitimate purpose. They don't know they can write ideas which don't already make sense in their heads before they put them down on paper. They need to know that it is worthwhile for them to write down these mixed up ideas, in the circles they come in, in the repetition they come in, in the words they come in, in the order they come in. They need to know these written mixed-up ideas don't have to be seen by anyone else or make sense to anyone else. Their ideas are meant only for themselves. They can write at any time, anywhere, in any way, to figure anything out. Their ability to write is theirs to own and to control. They need to know that they can write without someone else dictating that they write, or how, what, when, where, and why they write. There is no question in my mind that when they know these things, they will be able to think and write.

Suggestions to Teachers

I suggest that writing is a means which teachers have long ignored as a way for students to approach the learning of a subject. It should

not be ignored any longer.

I strongly suggest teachers themselves experiment with writing while encouraging their students to do the same. Because the teacher already understands the subject he teaches, he will want to write about other material he has or is being presented which he wants to understand better. He might write about a personal dilemma, his graduate school work, or a student he wants to understand better. I believe that many teachers will find "writing to think" an exciting means of understanding information for themselves and won't need to be convinced by my research to encourage their students to write. They will want to offer it to their students. As the students write for themselves, the teacher will come to find, much to his relief, that he no longer must take so much responsibility for his students' learning. As it is now, teachers feel that they must pose questions to their students to which they themselves know the answers for the purpose of discussing information. The teacher asks, and the student is supposed to respond with the answer. Now, if students write to think, they will begin, as Laura and Tim did, to ask authentic questions which they have discovered in the process of puzzling out, straightening out, and getting to the bottom of the material while writing. The teacher will no longer pose the questions; the student will. In other words, the person who genuinely doesn't know the answers will be asking for them. And the student won't always have to ask the teacher for the answer. Like Laura and Tim, the student will begin to pose the question first to himself and then to try to figure it out by writing. He will take pride in finding the answer himself or in finding the key questions about which he needs further information to go on and find the answer. He will want to take responsibility for his learning.

For teachers who want their students to try writing to think, I have a few words of advice. I think it's too much to say that students should write every day. Writing to think needs to be done while the material is being presented, not in a rush before a deadline or a test. The mind doesn't seem to be able to sort out a lot of information efficiently in a short period of time. The mind needs time to play with information

before it can make sense of it. Students need to do the writing when the material becomes confusing to them -- that is, when they start to have questions. Only the student can know when she has a question so it is her responsibility to write when she feels the questions arise. However, I believe it is possible for the teacher to anticipate the problems and confusions a student might have. From the teacher's experience, he can anticipate where students tend to become confused about particular material. He also may know a student's ability and self-confidence with certain types of material to guess when he will have problems. As a writer and as an objective observer, the teacher, who is in tune with the material and his students, may know when a student needs to write, just as he has developed an ability to know what material he needs to present and when the student is ready for more.

Obviously the maturity of the student will have a direct bearing on how much direction and encouragement in writing the teacher needs to give. The inexperienced thinkwriter will need more help. But he will become more responsible for his writing and learning as he feels good about his ability to write and to learn. He'll want to take more responsibility for his mind and its learning because he gets more in return when he does.

There is no reason to write in a bound volume. I quickly went to a loose leaf binder so that I could write on any available paper and put it all together later. I also didn't have to carry my thinkbook with me. I found advantages keeping it in one place. I occasionally reread sections as review, but I particularly enjoyed looking back out of curiosity to see how I had come up with some of my ideas. I felt proud to be able to hold in my hands pages and pages of chemical thinking that I had done on my own without help.

Many students might never need nor want to show their writing to their teacher. When they come to a specific question, it may be easier and more efficient to ask it out loud. But when the confusion is bigger, it may be easier and more efficient to literally show the confusion to the teacher by letting him read the writing.

The teacher whose student asks him to read his writing must keep in mind at all times the purpose of writing. He must also keep in mind his purpose for reading it. Only the asking student can know this purpose and needs to explain it to the teacher. If the student doesn't explain why, then the teacher needs to ask, "Why do you want me to read this? What is your question or problem with it?" The student might respond, "I want you to see if what I have makes sense," or "I can't figure out what I'm doing wrong." The teacher then knows his purpose for reading.

In any case, the teacher needs to read the writing with his attention focused on the *process* the student went through in thinking through the material. The teacher will be of no help to the student if he reads with his attention focused on the *product* itself. The teacher *will not help* the student by reading the writing and suggesting line by line revisions and corrections in the ideas and logic. The teacher *will help* the student by reading the writing slowly and thoughtfully in its entirety a couple of times, keeping in mind the purpose the student has given him for reading. He must also remember that the sentences and logic the student writes on the paper correspond directly to the ideas the student is thinking. The student is think-writing because he is weak and unclear in his understanding of the material. Thus his writing is weak and unclear. As he continues to write, he begins to get stronger and clearer in his understanding. Correspondingly, the words, sentences, and logic on the paper begin to get stronger and clearer.

The teacher will be able to see this progression of thinking and understanding on the page. By carefully reading the writing, the teacher will know what the student is thinking. By carefully reading the writing, *the teacher will know what the student knows and what the student doesn't know*. He will know why the student has asked him to read the writing or why the student has asked him a question and how he can best assist each student in further understanding the material. He can pinpoint the information the student doesn't yet have straight or now needs. He will discover clues the student leaves behind which may indicate what help he

needs. Questions or question marks are overt clues to the student's confusion. Vague words, incorrect information, illogic, critical asides, or tangential thinking are less obvious clues as to what may be confusing the student. Even crossed out words or sentences may provide hints as to what the student doesn't understand.

The teacher must remember that all think-writing is by nature difficult to read, from the handwriting to the spelling to the organization. The most difficult reading is at the beginning where the most difficult thinking is happening. But for the teacher who takes the time to read and sticks with it, the rewards will be enormous. The teacher will be able to give to each student his very own special, individual *key* to understanding the material. With his own key, each student will be able to unlock his own doors and go on learning and understanding more material without needing or wanting the teacher's help.

Notes

[1] See the following articles and books: Barry Beyer, "Using Writing to Learn in History," *The History Teacher*, 13 (February, 1980), 167; Janet Emig, "Writing As A Mode of Learning," *College Composition and Communication*, 28 (May, 1977), 122; William F. Irmscher, "Writing As A Way of Learning and Developing," *College Composition and Communication*, 47 (October, 1979), 240; Robert Parker, ed., "Understanding, Teaching, and Assessing Writing: A Report," Rutgers University Graduate School of Education, May, 1979 (includes excellent bibliography); Andrew Stibbs, *Assessing Children's Language* (London: Ward Lock, 1979).

[2] Nancy Martin, Pat D'Arcy, Bryan Newton, and Robert Parker, *Writing and Learning Across the Curriculum* (London: Ward Lock Educational, 1976), p. 32.

[3] Toby Fulweiler, "Journal Writing Across the Curriculum," ERIC ED 161073, 1978. (Includes excellent bibliography of works about journal writing.)

[4] Suzanne Langer, *Philosophy in a New Key*, 3rd ed. (Cambridge: Harvard University Press, 1963).

[5] Letter received from Pat D'Arcy, 6 April 1980.

Bibliography

Beyer, Barry. "Using Writing to Learn in History." *The History Teacher*, 13 (February, 1980), pp. 167-178.

D'Arcy, Pat. Letter to author. 6 April 1980.

Emig, Janet. "Writing As A Mode of Learning." *College Composition and Communication*, 28 (May, 1977), pp. 122-133.

Fulweiler, Toby. "Journal Writing Across the Curriculum." ERIC. ED 161073. 1978.

Irmscher, William F. "Writing As A Way of Learning and Developing." *College Composition and Communication*, 47 (October, 1979), pp. 240-244.

Langer, Suzanne. *Philosophy in a New Key.* 3rd ed. Cambridge: Harvard University Press, 1963.

Martin, Nancy, *et al. Writing and Learning Across the Curriculum.* London: Ward Lock, 1976.

Parker, Robert, ed. "Understanding, Teaching, and Assessing Writing: A Report." Rutgers University Graduate School of Education, May, 1978.

Stibbs, Andrew. *Assessing Children's Language*. London: Ward Lock, 1979.

Acknowledgments

I wish to thank my esteemed colleagues, Pat D'Arcy, for her enthusiastic correspondence and Don Graves, for his direction and insightful words of encouragement.

Further, I am extremely grateful for the support of my thesis committee, Chris Thaiss, Bob Gilstrap and Don Gallehr, who encouraged me to write a readable work.

In addition, I want to thank the administrators of South Lakes High School, Reston, Virginia, a Fairfax County Public School, for permitting me to conduct my study there.

Finally, I want to thank Carolyn Lavallee, who taught me chemistry, and Laura Fanning, Tim Stanard, Jim Jeans, and Piera Pelligrino, my fellow chemistry students, without whose efforts my research question could not have been answered.

Using Expressive Writing to Teach Biology

Robert Tierney

INTRODUCTION

Though most high school biology teach- agree, to some extent, that all teachers should be teachers of writ..g, they are often reluctant to include student writing exercises, beyon. normal transactional reporting,[1] in their programs. Biology teachers point, with some pride, to the numerous lab write-ups, student reports, and tests they have corrected for grammar, spelling, and neatness as their contribution to the improvement of writing. Expressive writing, the language used in friendly talk, or the writing which takes place during the initial phase of thinking through a problem, is best left to the English teacher down the hall. After all, they reason, English teachers are trained for that sort of thing.

Probably the primary reason for not including expressive writing in the biology class is lack of time. Time devoted to the teaching of writing is time lost for biology; there isn't enough time to present all of the biological subject matter that should be presented. Biology teachers, like most teachers, find themselves forced to make value judgments about which topics to delete, and they sometimes feel guilty about their decisions afterward. How can one justify a skimming over of the Echinoderms, or short-changing the Kreb's Cycle?

Another reason for not emphasizing writing in the biology class is the paperwork load. As it is, most biology programs include labs every week, and labs mean lab reports or workbooks to be corrected. Add to the

lab write-ups a few student reports, a notebook, and other assignments, and it means confronting a stack of uncorrected papers that would intimidate even the most dedicated tutor.

Probably the saddest reason for not including expressive writing is many biology teachers fail to realize its potential as a learning tool because they are not familiar with writing as a process. Few biology teachers are themselves writers. Yet modern biology instruction requires a hands-on, inquiry, think-through-the problem approach. Expressive writing is a means of thinking through a problem. The student is free to do his thinking on paper without fear of the teacher as an examiner. Expressive writing can provide the biology student with the essential experience of free inquiry -- the essence of the scientific method.

The biology student who is allowed time, and encouraged, to write expressively about what he has been presented in biology will be a better student. He will have a more thorough understanding of the biological concepts and will experience both the pain and the thrill of problem solving. Certainly his reports will be more interesting for the teacher to read, and that, in itself, might make the effort worthwhile.

This experiment is an attempt to suggest some techniques for including expressive writing in the biology class and to objectively evaluate their potential. Perhaps it will encourage other biology teachers to try some of the ideas, refine them, or develop new ones.

BACKGROUND

The School

Irvington High School, built in 1961, is situated in the suburban community of Fremont on the southeastern shore of San Francisco Bay. It is one of four high schools in a rapidly growing community. The student body is a heterogeneous mixture of Anglo-Saxon, Chicano, Asian, and Black students. The approximately 2000 students are taught by a faculty of 80 teachers; most with ten or more years of experience.

The Teachers

This experiment was made easier by the uniqueness of the situation at Irvington High School. All of the biology, four sections with a total of 136 students, is taught by me and my long time friend, Harry Stookey. We have similar academic backgrounds and interests. We both possess California General Secondary Teaching Credentials. We have both taught for twenty-six years. We were both evaluated by the same administrator this year, Mr. Richard Guidici, Vice Principal, and given the same rating -- excellent. We are both the same age. The probability of finding a situation where the teachers involved are so closely matched seems unlikely. It provides a unique opportunity for a controlled educational experiment.

The essential difference between me and Harry Stookey is that I have published some freelance writing and attended a five week Invitational Workshop sponsored by the Bay Area Writing Project at the University of California, Berkeley.

The Students

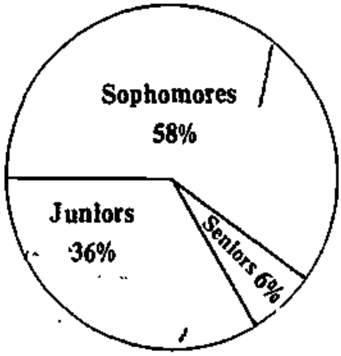
A profile of the biology classes was made to determine what differences existed between the composition of my classes and Harry Stookey's. We were able to obtain the student scores for the Fremont Unified School District Competency Tests and used the written language skill and the reading comprehension scores, along with other data, t[illegible]truct the profile. (see Figure 1)

Apparently my students had slightly lower ability in both written language skills and reading comprehension. They also tended to miss class more often and were younger, as indicated by year in school, than Harry Stookey's classes. They did, however, turn in a higher percentage of their assignments.

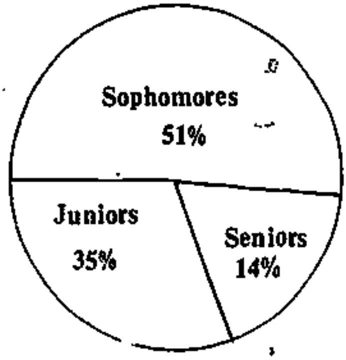
Group	Average Score—Written Language Skill	Average Score—Reading Comprehension	Percentage of Assignments Turned in	Average Days Absent Per Pupil	Number of Students Enrolled
Tierney I	85.5	88.5	92	7.6	69
Stookey II	89.5	90.3	87	4.2	67

Figure 1

Comparison of Basic Skills, Assignments Turned In, and Attendance of Groups.



Group I



Group II

Figure 2

Composition of Groups by Year in School

DESIGN OF THE STUDY

The Problem

Do secondary biology students learn and retain fundamental principles of biology better in a biology program which stresses expressive writing than in a class that uses only traditional expository writing?

The Hypothesis

The act of writing encourages a personal response by the student. He must assume a chosen position, he must involve himself in the subject -- he must think. Expressive writing allows him to think in his own language, to sort out what he does know from what he is still confused about, and to do so without intimidation from a teacher-examiner. It seems reasonable that students who have been encouraged to use expressive writing as a vehicle to transport themselves through the "think" part of scientific methodology will not only learn more, but will retain what they have learned to a greater degree than those students who have not used expressive writing to sort out their thoughts.

The Procedure

My two biology classes (69 students) were designated as Group I. Harry Stookey's two classes (57 students) were designated as Group II. The students remained with the same teacher for the entire year. Group I served as the experimental group during the first semester while Group II served as control. The roles of the groups were reversed for the second semester. Thus each teacher served as director of an experimental group and a control group. We hoped this procedure would negate the teacher as a variable in the experiment.

Both experimental and control groups covered the same biology topics at the same time, did the same labs, watched the same educational films,

and had homework assignments corrected with a stress upon proper word usage and spelling.

The differences between the experimental group and the control group are shown in the following chart:

PROCEDURAL DIFFERENCES BETWEEN THE EXPERIMENTAL AND CONTROL GROUPS

EXPERIMENTAL GROUP	CONTROL GROUP
1. reading logs	1. no reading logs
2. neuron notes	2. no neuron notes
3. practice essays	3. no practice essays
4. writing to a specific audience other than the teacher	4. writing to the teacher as an examiner
5. end of class summaries	5. no end of class summary
6. group writing	6. limited group writing
7. essay tests	7. multiple-choice tests.

Two units were selected as "test units," i.e., subject matter to be tested and the results compared. The test unit for the first semester was genetics. Genetics was selected because it was scheduled far enough into the semester to allow time to acquaint the students with the writing techniques to be used. The unit was three weeks long. A pretest (multiple-choice) was given just before the Thanksgiving holiday on November 24th, prior to starting instruction about genetics. A posttest (the same multiple-choice test) was given after the unit, on December 19th, just before the Christmas holiday. On April 10th, 16 weeks after the completion of the genetics unit, a recall test (the same multiple-choice test) was given to determine how much of the genetics unit had been retained by the students.

Although we used essay tests as an additional way of utilizing writing to learn in the instruction of the experimental group (see pp. 57-58) multiple-choice tests were used instead of essay for pre- and posttesting of both groups for the following reasons: (1) most standardized tests

are multiple-choice and most of our questions came from textbook exams; (2) essay tests may not have been fair to the control group; (3) most biology classes use multiple-choice tests.

The test unit for the second semester, when Harry Stookey's class served as the experimental group, was seed plants. The pretest was given on April 17th. The students took the posttest on May 8th. The recall test was given to the students on May 29th, three weeks after the unit had been completed. Since the school year was about to end we were unable to extend the period between post and recall examinations any longer than three weeks.

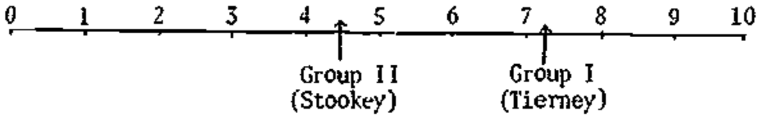
The expressive writing exercises used by the experimental groups, and the results of those exercises, are described below.

The Reading Logs

Reading Logs were assigned in an effort to improve reading comprehension and provide opportunity for expressive writing. The students were instructed to record their thoughts, on notebook paper, as they read, as some people do in the margins of books. The notes were to be thoughts or impressions, they were not to be an outline of the reading. The students knew the teacher would not read their Reading Logs. When due, the students held up their Reading Logs to show that they had been completed and then filed them in personal folders which were kept in the classroom but were available to the students at any time.

An anonymous poll of student reaction to the Reading Logs was taken in mid-March. The students were told to rate the value of Reading Logs on a scale of zero to ten on which zero represented "of no value at all" and ten represented "extremely valuable." The reactions of the students, after some initial groans and mumblings about more homework, was mixed. The following scale represents the average value given to the Reading

Log by each of the groups:



Some of the anonymous student comments appear below:

> *I think the reading log is very useful if you have to write about the chapter then your going to read it. If you write a paragraph or two of something you just read, then it stays on your head a lot longer then just reading it and forgetting it.*
>
> -- A student in Group I

> *The RL was a pain mainly because I ended up doing them one hour or so before they were due. For the most part I would say they weren't helpful to me because of unwillingness to do them before class and consequently I merely rushed to get them done and not fully understanding what I read or wrote. Admittedly they are a good idea, but they shouldn't be used as an assignment because students will BS their way through them. I believe they should be used as an extra-credit, or very carefully read. In this way they would be fully effective.*
>
> -- A student in Group I

> *I think they are great. They are sort of a reward for studying. Not because they are worth five points, but because they help you where you need it most, on the test.*
>
> -- A student in Group II

> *The reading logs don't help at all for me. I think they make reading the chapter harder because you have to stop and right down stuff.*
>
> -- A student in Group II

The Neuron Notes

Many professional writers keep daily journals. The British seem to have success with "Learning Logs."[2] It sounded like an excellent idea. We called our version of writing-to-think *Neuron Notes*. The Neuron Notes provided another opportunity for expressive writing and forced the student to organize his thought, to sort out what he learned from what he was

confused about.

The students were instructed to take at least ten minutes each day to sit down and attempt to explain, to themselves, what they had learned in biology that day. They were encouraged to write down any thoughts that occurred to them even if they regarded the thought as trivial or nonsense. They were also encouraged to pose questions for the teacher about things that confused them. Though Neuron Notes would not be read by the teacher without student permission, we hoped that many students would use them as a vehicle for individualized instruction.

Although 90% of the students wrote Neuron Notes, only a few granted permission to have them read, most of those were regurgitations of what had been presented -- not what was actually learned. They were expressed in a style designed to please the teacher. Most students were unable to overcome the idea of writing for a grade.

A few excerpts from Neuron Notes follow:

Today, we watched a movie on genetics. Considering it was an old movie, it was pretty interesting. It explained how the genes are passed on from generation to generation through heredity. It talked about Mendel's work and how he came to be the father of genetics.

The most interesting part was when it showed the different stages of mitosis. I have a clearer view of how mitosis works by being able to see the changes from interphase to metaphase, etc.

It's also possible for scientists to actually see the genes lined up on a chromosome of a fruit fly. They know this because when a certain gene wasn't present, that trait didn't show up.

-- A student in Group II

I guess I didn't understand the punnett square as well as I thought I did. The thing I don't understand is if it's stated that something is homozygous does that mean that it's dominant or recessive? I'll ask Mr. T. what that means.

-- A student in Group I

We watched a movie about genetics. It showed the idea of our book in different ways. If somebody did not already know what was going on it would be hard to follow. I followed it pretty well.

-- A student in Group II

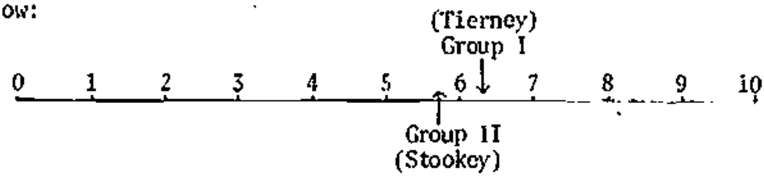
They explained about Mendel's experiment and I would explain it again on paper but I've written about it so many times I know it by heart.

-- A student in Group I

In biology today we first took a quiz. It was based on what we learned yesterday: monohybrid and dihybrid crosses. I missed problem one all together. I didn't miss it because I didn't know the way to work it. I missed it because I got nervous and confused a little because it was in word problem form. It was asking about the cross of a black heterozygous pacing horse with a black heterozygous trotting horse. I misread heterozygous as homozygous. The result was that my missing the whole problem, wow was I ever mad at myself.

-- A student in Group I

An anonymous response to Neuron Notes was solicited from the students in mid-March, the same day they evaluated the Reading Logs. A rating of zero indicated the students thought Neuron Notes had no value. A rating of ten indicated that Neuron Notes were invaluable as a learning device. The average rating of Neuron Notes by each group is shown on the scale below:



Some written response to the evaluation of Neuron Notes follows:

To say quite honestly I never gave the Neuron Notes a fair chance. A lot of times I wouldn't get them done so I couldn't really say if they would have helped me or not but I did feel they were a good idea.

-- A student in Group II

I thought the Neuron Notes were beneficial to me during the genetics part of the course. They made me sit down and determine what I learned and if I was confused to go back and review or ask Mr. Tierney. I think they should be required through other phases of biology. Why can't we do them all year?

-- A student in Group I

Neuron notes had a great effect on my learning habits. If I remember what I did each day and can explain it, I

usually remember more, and more clearly.

-- A student in Group II

The neuron notes helped me some but not as much as the Reading Logs did. Somedays you wouldn't learn anything so you would just put a lot of bull down. I was never that enthused about the neuron notes so I just did it half assed all of the time.

-- A student in Group I

The Practice Essays

Science teachers often ask students to write essay-type responses or reports, but seldom take any time to explain to the student how to write one. We mistakenly assume that teaching essay writing is solely the task of the English teacher. We expect the student not only to know how to respond in essay style, but we ask him to write his response without any prior "warmup" or "think-it-through" time. We then correct the student's paper as if it were a final draft, forgetting that few professional writers write a finished piece on the first try.

The teacher assigning an essay should write an essay response to his own question before assigning it to the students. He should allow sufficient time for the student to think through the problem. Since examinations for the experimental group were essay type (except for the objective tests used for research purposes), we tried to provide instruction and practice in essay writing. We called this instruction *Practice Essays*.

The students were told to read the topic carefully and to make any notes they wished, i.e., make a short Reading Log. The students then shared their notes with each other and deleted or added items. Some students volunteered to read their notes aloud; other students were allowed to add items to their own lists. They were then given twenty minutes to write about the topic. They were told it was a first draft and not to be concerned about spelling, grammar, or mechanics. A few of the papers were read aloud for class reaction and comment. The Practice Essay sessions usually took place about a week before the actual exam.

When polled later 75% of the students thought that Practice Essays were very helpful, especially in learning how to take an essay exam. Negative reactions came from about 15% of the class while 10% had no opinion. A few anonymous comments follow (all from Group I):

I think the practice essay helped me alot. I think it is a very wise study habit. If I were to not write a practice essay I would probably do worse. After I write the practice essay I read it to myself and write things down or rewrite things that I forgot or just needed to make more sense. The practice essay helps alot!

I feel it is much better to do such a practice SA is a very good idea. Now this doesn't mean I enjoyed, no way. It was, as I suspected, hard work, but considering it is the first time I have received an A in any kind of science test (at least for as long as I can remember) I feel any amount of hard work is worth it (up to a point).

I would like to admit something that I never would admit to classmates. Instead of feeling nervous only about the test, for a strange reason I felt it a challenge. I feel it to be a good idea.

The practice essay was very great! I learned the material much better and it still stays with me. I've learned more by practice essay than by just failing the test. I don't fail the tests since we have Practice essays. The class is not boring like most classes are.

I think the SA test was a waste. I would rather read a chapter out of the book because you can get more information. While writing up the SA you just don't absorb all information.

Writing for a Specific Audience

British studies indicate that 87% of all student writing in science is written to the teacher as an examiner[3] -- informing the already informed. It was no great surprise to see that our students were writing to the same audience despite frequent suggestions not to do so. Grade conscious students feel compelled to tautologize what the teacher has told them, or to write reports that sound like, and often are, copies from

the textbook or encyclopedia.

Our alternatives to writing to the teacher as an examiner included: (1) letting the student write to himself as much as possible (Reading Logs and Neuron Notes); (2) having the student write for his peers (group labs); (3) having the student write to the teacher as a partner (Neuron Notes that students asked the teacher to read); (4) having the student pretend to write to a particular person other than the teacher.

The fourth method was accomplished by placing a large photo, or poster, on the wall and asking the student to write for the person depicted on the poster. Sometimes the students wrote for Miss Piggy, Wonder Woman, Evel Knievel, a clown, a boy on a skateboard, a bum in a doorway, an old lady on a porch, Superman, and so on. There were frequent discussions regarding how much the person in the poster might be expected to know about a particular subject. Wonder Woman, it was agreed, probably knew everything, but Miss Piggy would not be expected to know, or care, about the respiration cycle of a cell. These discussions turned out to be excellent review sessions.

The following are excerpts from papers written to a boy on a skateboard. The subject is mitosis and meiosis. Teacher comments follow each excerpt.

> *I'm going to explain meiosis to you buddy. It starts out with one cell, with a nuclear membrane. The first stage is that the membrane disintergrates and chromosomes are visible, two more chromosomes are duplicated, and line up right next to each other, then they start twisting up to mix up the genes. All of them line up on the equater and then split into two cells, each carrying two chromosomes, then those two split up again forming four more cells, each have four cells which have one chromosome. This is called haploid.*

TEACHER COMMENT: This student starts by addressing the postor, but quickly slips into writing to the teacher as an examiner. His view of what takes place in cell division is a bit distorted.

> *Mitosis is a term that applies to the splitting of all cells higher than bacteria and not including sex cells. In mitosis the nuclear membrane (a thin wall that covers the nucleus, the control center of the cell) is broken down and distributed throughout the cell. Next the chromosomes*

of the cells (chromosomes are the bodies in the nucleus that control what you will look like, do, etc.).

TEACHER COMMENT: This student makes an attempt to explain some of the terminology to the boy on the skateboard.

Dear Young man on the skateboard:

I am going to try to explain about mitosis and meiosis. Mitosis is a process that happens when all cells duplicate themselves except sex cells. It starts when the cell nucleus starts dissolving and the chromosomes are present. They duplicate themselves and turn so that they are horizontal with the poles. Then they begin to split and half go to one pole and half to the other pole. The cell then makes a duplicate of itself.

TEACHER COMMENT: This is the voice of a high school biology student attempting to clarify the idea in his own terms. It's reasonably accurate, but probably confusing to his reader.

There are three methods of cell division. One of them is fission and the others are mitosis and meiosis. Mitosis occurs in more advanced cells, and meiosis occurs only in sex cells. In mitosis there are several stages the cell goes through before it divides to form two cells exactly like it. In meiosis, the cell goes through various steps to form four cells. Mitosis and meiosis both involve chromosomes.

TEACHER COMMENT: This sounds like expressive writing that takes place as the student tries to clarify the idea to himself. He's learning.

Mitosis is the splitting up of a cell with a full set of chromosomes. Mitosis can split up all higher level of cells except sex cells. Sex cells are split up by a process called meiosis.

TEACHER COMMENT: The student has grasped one idea, but has ignored his reader and is writing to the teacher.

I'm sorry to tell you that I was sleeping during the lecture and did not have a thing to write. However you should get enough information from the other perple that are writing to you, if they know anything. Please do not read this letter while skateboarding or when your doing anything else. Please disregard this letter, burn it up, or throw it away just get rid of it.

TEACHER COMMENT: Refreshingly honest. The student is writing to the skateboarder, but is also apologizing to me for not paying attention. It tells me something about the student and/or my ability to lecture.

> *I can't explain mitosis very well for I don't understand it yet, myself. But I will try to attempt to explain meiosis. Meiosis is a process in which sex cells are produced. If you have one cell which has 46 chromosomes inside of it the chromosoms split up in half.*

TEACHER COMMENT: A confused voice, but being able to admit you don't know is the first step toward learning something. It also informs me that I had better review the subject with the entire class.

End of Class Summaries

Sometimes, after a teacher presentation, the students were asked to take the last fifteen minutes of class to summarize what they had learned about the topic presented. This activity was similar to Neuron Notes except that the student turned it in for credit. The student received full credit if he did it, regardless of content or how well written, and zero credit if he did not turn it in.

Besides an additional opportunity for expressive writing, it provided a real insight into how much of the teacher presentation is being absorbed. It also keeps the class alert and can provide a break in routine.

The following are examples of student summaries after a discussion of cell respiration, a difficult and not very exciting topic:

> *I don't understand this stuff.*

> *I understand most of what happens in respiration. One thing I don't understand though, is where the carbons go when you lose one or two. Also, where does the CO_2 + H_2O come from when you lose carbons?*

> *What I know about respiration is that all organisms need it. The carbon from glucose is taken and split in two. You take one of the two and it is split into two carbons, the one carbon is used to make CO_2 and H_2O comes out, also. Those were the first steps or the anaerobic stage, it needs no*

oxygen and happens outside the mitochondria. The aerobic stage needs oxygen and happens in the mitochondria. The mitochondria forms 4C which combines with the 2C. They form 6C. It's split into 5C, carbon forms CO_2 and H_2O.

Sometimes the end of class summary provided an insight different from what was perceived by observing the class. They may all have looked as though they understood, but the summaries often revealed they did not. We knew when we had to cover the material again.

Group Writing

Group writing took place when students worked as a team while doing a lab. Sometimes the team consisted of two students, sometimes three. Only one paper was required from the group so the writing effort was a team product. We kept everyone honest by occasionally giving an unannounced quiz immediately after the lab was turned in. Students who worked at understanding the lab were rewarded; those who didn't do their share generally lost points.

Another type of group writing occurred when we organized the class into teams in order to solve a problem. Harry Stookey and I, over the years, have developed several group problem-solving assignments. One that was used during this experiment involved trying to determine why the oxygen curve on a lake in San Francisco did not drop very much during the hours of darkness.

We organized the students into teams, taking care to distribute the talent, and presented them with the problem and the data available. As a team they had to formulate a hypothesis, interpret the data, and make some conclusions. They were given parts of several days in class. They also met frequently outside of class. They were told, at first, that each of them must write a first draft and attempt to solve the problem. Later they would get together and review and discuss each other's papers. Then, as a team, they wrote a report that was turned in for grading.

The sharper students seem to enjoy these assignments. There is generally good discussion and cooperation between students in a team,

but sometimes one student may dominate the others, resulting in the paper being written by the most grade-conscious student in the team.

There are many biological principles that enter into the problem posed, and the exercises are generally excellent for reviewing material, stimulating ideas, giving students some problem-solving experience, and teaching the nature of science. On occasion the students might argue with our interpretation of a correct answer, and that makes it an interesting challenge for both teachers and students.

Designing one of these assignments is a stimulating experience. It's a chance to be creative. Unfortunately it takes lots of time and time is scarce.

Essay Examinations

All examinations for the experimental group were essay type except the tests given to evaluate the experimental test units (genetics for Group I; seed plants for Group II).

Several days prior to the examination the students were given practice essay instruction and had a good idea about what might be asked.

The following questions are typical of the essay questions asked:

A. Describe Francisco Redi's experiments. Remember to: state his problem; his hypothesis; his procedure; including the control used; his results; his conclusions.

B. Briefly summarize the various hypotheses concerning the development of life on earth. Select one hypothesis and defend, or refute, it.

C. Explain, in as much detail as you can, how the leaf of a plant is adapted for photosynthesis. Remember what is required for photosynthesis and be sure to explain how the structure of the leaf is suited for these requirements.

In order to evaluate the examination, we first wrote the essays ourselves in order to make certain we looked for particular things and did not reward the glib student who wrote well, but didn't really know

the material. Our essay also served as a model for student appeal when the tests were returned. We read our essay to the class, and if some student thought we'd made a mistake on his grade he challenged us by reading his essay aloud. After a discussion, his grade might be altered, either up or down. The discussions were often lively and generally involved the entire class. I thought they became one of our best learning situations. For fun, I kept score on the blackboard, labelling the scoreboard as "NEAT TEACH" and "PUNKS." If the student lost a point I placed a score under "NEAT TEACH." If the student won a point it was credited to the "PUNKS." Although keeping score was designed for fun, it served to eliminate some student reluctance in challenging the authority of the teacher. The students invariable scored more points than the teacher, and they looked forward to the test reviews. Their eagerness motivated me to return their tests as promptly as possible.

Generally speaking the students complained bitterly about essay examinations at first. They often reminded me that biology was not supposed to be an English class. It was interesting, and very satisfying, to hear them ask for essay examinations when my group became the control for the experiment and started using multiple-choice tests.

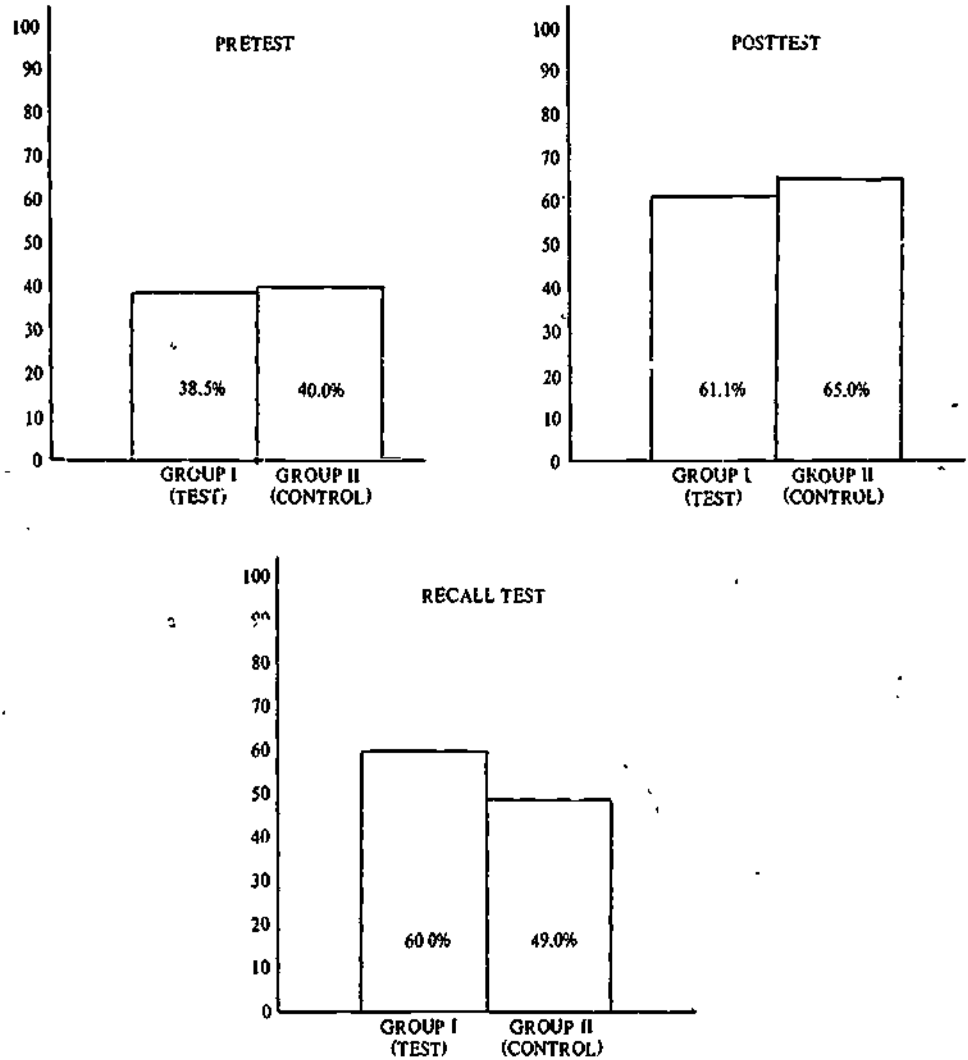
The essay examination requires a lot of work on the part of the teacher, but we felt it more truly reflected what the students knew about the subject. It rewarded those who prepared. It's also another way to teach writing in the biology class.

RESULTS

The results of the test units (see graphs, pages 65-66) were, for the most part, expected. The pretest for both units, genetics and seed plants, indicated that the previous subject matter knowledge of both control and experimental groups was about the same. The results of the posttests were disappointing, though not unexpected. Since Group II seemed to have more maturity and scored higher on basic skills tests, we expected them to do slightly better than Group I. It was hoped,

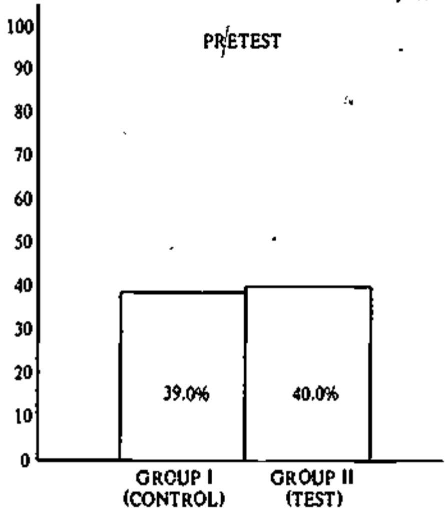
RESULTS, MULTIPLE-CHOICE PRE, POST, AND RECALL TEST--GENETICS

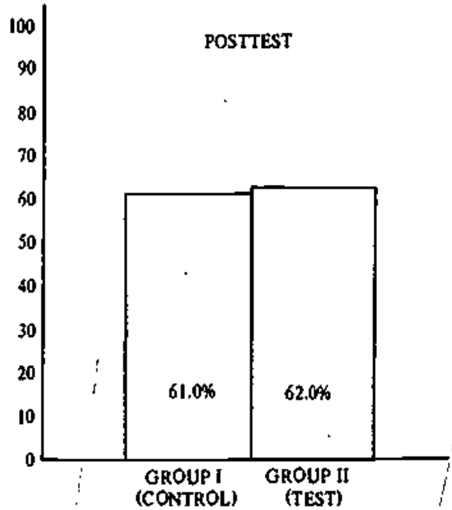
(Based upon mean average test scores expressed in percent correct)

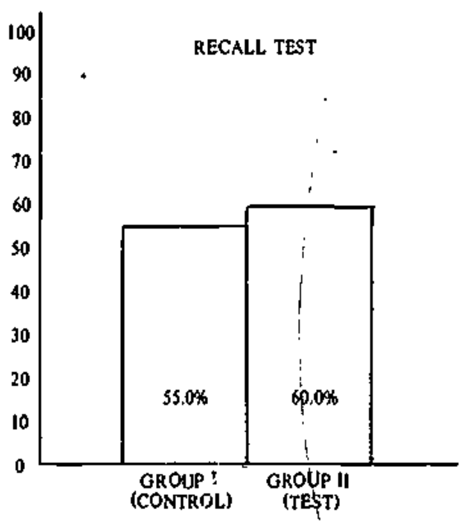


RESULTS, MULTIPLE-CHOICE PRE, POST, AND RECALL TEST--SEED PLANTS

(Based upon mean average test scores expressed in percent correct)







however, that the writing efforts of Group I might compensate for the difference in basic ability between the two groups. Apparently it didn't. Post exam results for both experimental test units were very close.

The recall tests, given sixteen weeks after the first unit and three weeks after the second, did, however, indicate a clear difference between experimental and control groups. The experimental groups scored noticeably higher on recall than the control groups.

CONCLUSIONS

Apparently students in classes where expressive writing is stressed will score about the same on a particular unit multiple-choice examination as students who are not in a class that emphasizes expressive writing. "School-wise" students learn to memorize what they need to know for a particular test. It would be interesting to see how the groups would have scored if essay tests had been used to evaluate the two units used for comparison in this experiment.

The results of this experiment clearly indicate that students who have been g[illegible]n opportunity to use expressive writing as a learning tool will retain more of what they have learned.

Although the experiment was [illegible] designed to evaluate improvement in student writing, we feel that student writing did improve. If nothing else, students became aware that what they learn in their composition classes does apply in other segments of the curriculum. Another experiment, to assess writing improvement, should be developed and carried out.

It seems clear to us that biology teachers who stress expressive writing will work harder, have a heavier paperwork load, and will have to delete some biology topics from their program to allow time for writing. They will probably derive more satisfaction from their teaching experience, however. Their students will learn the subject matter presented more thoroughly, and their papers, reflecting what the student actually understands, will be more interesting to read. The teacher will be able better to assess his own performance and enjoy the satisfaction of seeing

his students learn the principles of biology, improve their basic writing skills, and enjoy the class.

Harry Stookey and I, impressed by the results of this experiment, will continue to use the expressive writing techniques cited in this paper with the following modifications:

1. Neuron Notes will not be assigned every day and they will be read by the teacher. We will not correct the papers, but will attempt to carry on a written dialogue with the student to increase his understanding of the subject.
2. The Neuron Notes activity, used in combination with End of Class Summaries, has a lot of potential for individualized instruction. We will continue to refine and develop this technique by increasing the number of End of Class Summaries and decreasing the number of Neuron Notes.

Perhaps what Harry Stookey and I have accomplished with this experiment is a pilot study that may stimulate others to experiment. We certainly gained some valuable insights into our own teaching methods; it was worth our time and effort.

Notes

[1] To differentiate the "writing for learning" utilized for the purpose of this study from the usual forms of expository writing required in biology classes, I have adopted the functional categories described in Nancy Martin, *et al.*, *Writing and Learning Across the Curriculum 11-16* (London: Ward Lock Educational, 1976), pp. 22-23. Briefly, they define *transactional writing* as writing "in which it is taken for granted that the writer means what he says and can be challenged for its truthfulness to public knowledge; . . . the language most used in school writing." *Expressive writing*, by contrast, is more like written down speech, writing in which the writer "feels free to jump from facts to speculation to personal anecdote to emotional outburst and none of it will be taken down and used against him." It is this latter sort of writing we encouraged students to use as a learning tool in our classes.

[2] *Writing in Science, Papers from a Seminar With Science Teachers*, London: Schools Council Publications, 1976.

[3] *Ibid.*