Penny J. Gilmer

Transforming University Biochemistry Teaching Using Collaborative Learning and Technology

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Ready, Set, Action Research!

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I dedicate this book to my late parents,
Peter Ellsworth Gilmer and Barbara Gilmer,
who taught me both ethics and a love
for learning.

Preface

Before delving into my research, I would like to preface this book with a story entitled, *Why We Struggle* that one of my biochemistry students posted on the electronic bulletin board during the middle of the semester of this action research study.

> A beautiful thought for you all to enjoy! A man found a cocoon of a butterfly. One day a small opening appeared; he sat and watched the butterfly for several hours as it struggled to force its body through that little hole. Then it seemed to stop making any progress. It appeared as if it had gotten as far as it could and it could go no farther. Then the man decided to help the butterfly, so he took a pair of scissors and snipped off the remaining bit of the cocoon. The butterfly then emerged easily. But it had a swollen body and small, shriveled wings. The man continued to watch the butterfly because he expected that, at any moment, the wings would enlarge and expand to be able to support the body, which would contract in time. Neither happened! In fact, the butterfly spent the rest of its life crawling around with a swollen body and shriveled wings. It never was able to fly. What the man in his kindness and haste did not understand was that the restricting cocoon and the struggle required for the butterfly to get through the tiny opening were God's way of forcing fluid from the body of the butterfly into its wings so that it would be ready for flight once it achieved its freedom from the cocoon. Sometimes struggles are exactly what we need in our life. If God allowed us to go through our life without any obstacles, it would cripple us. We would not be as strong as what we could have been. And we could never fly.

This quote from one of my students gives the reader an idea of the struggles that my students experienced as they tried to learn not only biochemistry but also to use technology (before we had as many tools as we now have) and the language of science as the students learned to work in collaborative groups. I really pushed them and myself to learn.

Tallahassee, FL Penny J. Gilmer

Acknowledgments

To begin, I want to thank my students for enrolling in the Web-enhanced biochemistry class and for being a part of my study. I additionally owe a great deal of gratitude to the students for communicating with me after the course ended and contributing to my study by (1) allowing me to interview them, (2) corresponding with me on their reactions to the fictionalized story that I wrote about our classroom, (3) proofing their electronic portfolio, and/or (4) making me a quilt, a symbol of one student's ability to weave together the strands of biochemistry.

I learned so much from my two co-major professors, Peter C. Taylor and Kenneth Tobin, during my doctoral work in Science Education. Peter gave me the courage to try some innovative writing (e.g., the fictionalized story) for the reporting of my results. From Ken, I learned to think analytically with qualitative data and to utilize the power of theory in educational research. My action research has been quite a personal challenge and educational journey for me.

I also want to acknowledge and thank Professor Emeritus Robley J. Light for having critically read my doctoral thesis and participated with me in writing the metalogue (found in Chapter 7). I also appreciate the comments from my biochemistry colleagues not only during the semester that I taught the class and but also afterwards. Additionally, I want to thank Professor Timothy Logan for allowing his parallel section of the class, *General Biochemistry I*, to be the larger section so that my experimental section of the same class could be smaller during my action research study.

I wish to acknowledge my secretary, Lisa Upham, with editing an earlier version of this book, which became my doctoral thesis at Curtin University of Technology. FSU's College of Business generously allowed me to use their technology-rich classrooms twice a week so that I could offer the course, as I did.

When my daughter, Helena M. Safron, was 15, she left the comforts of her high school in Tallahassee, Florida and came halfway around the world with me to Australia in 1997. While I enrolled in my first semester at Curtin University of Technology, she went to high school for one semester. Twelve years later, she was instrumental in teaching me to improve my writing and in editing my book for this final version. I thank Helena for making me more aware of my speaking and writing.

I am thankful for the patience and love of my husband, Sanford Alan Safron, and our son, Nathaniel Steven Safron, during the course of this study.

Contents

Abbreviations

AAHE	American Association for Higher Education
ASTE	Association for Science Teacher Education
ATP	Adenosine-5'-triphosphate
BCH	Biochemistry
CAPA	Computer-Assisted Personal Approach
CCL	Connecting Communities of Learners
CHAT	Cultural Historical Activity Theory
CLS	Collaborative Learning Survey
DNA	Deoxyribonucleic acid
FSU	Florida State University
GLP	Group Learning Project
HEES	Higher Education Environment Survey
LEQ	Learning Environment Questionnaire
LON	Learning Online Network
NAEP	National Assessment of Educational Progress
NARST	National Association for Research in Science Teaching
NASA	National Aeronautics and Space Administration
NCLB	No Child Left Behind
NRC	National Research Council
NSF	National Science Foundation
NSTA	National Science Teachers Association
PISA	Program for International Student Assessment
POV	Point of view
QSR	Qualitative Software Research
RNA	Ribonucleic acid
STEM	Science, Technology, Engineering and Mathematics
SM&E	Science, Mathematics and Engineering
SM&T	Science, Mathematics and Technology
STS	Science, Technology and Society
TIMSS	Third International Mathematics and Science Study in 1995; Trends in International Mathematics and Science Study in 1999, 2003 and 2007
Web-MC	Web-Mediated Course Assistant
WWW	World Wide Web

Chapter 1
Introducing the Study

1.1 Why Study a University-Level Classroom?

The purpose of this book is threefold. Firstly, I examine the methodologies that other researchers use to study college-level classes for enhanced learning using technology and collaborative strategies. Secondly, I share my learning from an action research study I conducted in my undergraduate-level *General Biochemistry I* class. The impetus for this study was my goal of becoming a better teacher. Thirdly, I put forth ideas for other college faculty, who are grappling with improving the learning environment in their science classrooms, and who may identify with my experiences and learn from my action research study.

1.2 What Are My Objectives?

By engaging in science education research, my foremost objective is to improve my own teaching in order to enhance my university students' conceptual understanding and interest in biochemistry. I want my students to see the connections between the various topics in biochemistry and understand that all the sciences interconnect. In my teaching, I hope to encourage students to tap into their prior learning through their coursework (both in my course and in other courses), as well as their real world experiences. Most importantly, though, I want my students to engage in a scientific discourse with other students about biochemistry. Having my students use the language of science in writing, oral presentations, and discussions with peers in collaborative groups is critical for their learning. Students become lifelong learners as they start to recognize the connections between prior knowledge and current studies.

My secondary objective is to develop a model to help other college science faculty members improve teaching and learning in their own classrooms. I want to facilitate faculty (including myself) from universities, colleges, and community colleges to become aware of the critical issues in the reform movement in the teaching and learning of science. I hope faculty will become motivated to try new ideas in teaching

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within the classroom, to become cognizant of the power of educational theory, and to conduct action research in their own classrooms.

Here, too, I demonstrate methods other faculty could use to learn to teach more successfully, both for the quick learning students and those having more trouble learning. From my students, I request feedback on methods to improve the learning environment so that students become more engaged in learning. As other college faculty members learn the theoretical perspectives and methodologies underpinning current educational research, collectively we could transform the teaching and learning of science in higher education classrooms.

The teaching of college science courses needs improvement, especially in introductory courses. The report of the Boyer Commission on *Educating Undergraduates in the Research University* (1998) criticizes colleges and universities in the undergraduate teaching of science and closes with the statement:

> This report hopes… to affirm that the most important obligation now confronting research universities is to define in more creative ways what it means to be a research university committed to teaching undergraduates. The nation demands and deserves no less. (p. 38)

Druger (2002) highlights that both science majors and other majors would profit from a college science course, which "improves science knowledge and skills; demonstrates the relevance of science to society and the intellectual life of a student; illustrates the changing and uncertain nature of science; develop[s] students' critical thinking skills; improves speaking and writing skills; and motivates students to like science and to want to learn more" (p. 148). Druger's goals nearly mirror my own a few years prior, as I designed and conducted action research in my biochemistry classroom.

College faculty members often teach biochemistry using teacher-centered lectures, thus making their students, for the most part, passive learners (Leonard 2000; Wright et al. 2004). I, however, want to bring the teaching of biochemistry alive. Biochemistry is the chemistry of living things. We change our ideas about biochemistry as we learn more through research. The very composition of the word, research, implies we are searching for answers to our research questions again. Biochemistry (or any science) does not consist solely of mere facts to be learned; rather, biochemistry is a way of thinking about the world and a way of asking and answering questions about living things. So instead of simply lecturing, making my students passive learners, I engage them actively in the pursuit of understanding the living world around them.

Like Druger, I want to make my students critical thinkers. I want to get my students beyond memorized knowledge of biochemistry to knowledge that they can apply to solve real world problems. Paul and Elder (2007) define critical thinking as, "the art of analyzing and evaluating thinking with a view to improving it" (p. 4). My biochemistry students, once they become scientists, will solve problems and answer research questions, as yet unsolved, or resolve conundrums that we think we understand now. However, through critical thinking, these students will come to better understand the biochemical systems in the future. I am teaching them critical thinking skills, so that they are prepared for their future endeavors, whatever they may be.

1.3 How Did I Structure This Book?

1.3.1 Ongoing Growth

I organized this book with a design that demonstrates the ongoing growth (and detours) during my journey. Through several key chronological stages I demonstrate the progressive development in my professional evolution, from a practicing physical biochemist to a science educator. In my writing I utilize an interpretive structure, which allows my research questions to evolve as I progress through stages of intellectual development. This study was part of my quest to obtain a second doctorate, this time in science education, which started in 1997 and concluded with my degree from Curtin University of Technology (in Western Australia) in 2004. My first doctorate was in Biochemistry from the University of California, Berkeley in 1972.

Eleven years have passed since I taught the biochemistry class that was the site of this action research study. Since that class took place, increasingly I have incorporated innovations in qualitative research into my own writing. As I read and critically examined the research by other qualitative researchers, I became drawn into the postmodern movement, particularly with the tendency towards doubt, rather than the certainty that I internalized from engaging in my previous biochemistry research and teaching science.

As Richardson (1994) states so elegantly,

> The core of postmodernism is the *doubt* that any method or theory, discourse or genre, tradition or novelty, has a universal and general claim as the "right" or the privileged form of authoritative knowledge. Postmodernism *suspects* all truth claims of masking and serving particular interests in local, cultural, and political struggles. But postmodernism does not automatically reject conventional methods of knowing and tellings as false or archaic. Rather, it opens those standard methods to inquiry and introduces new methods, which are also, then, subject to critique. (pp. 517–518)

You, the reader, might ask why a research scientist with her Ph.D. in Biochemistry, already a professor of chemistry and biochemistry, would want to spend her time and effort to completely reinvent her teaching, earn a second doctorate in science education, and question her own beliefs in science. I came to this point because my interests both in teaching and in science compelled me to push further in the teaching of science to the new generations. Traditional teaching of undergraduate science typically presents science as a set of absolute truths (i.e., a set of objectified facts to be learned) rather than as a progressing area of inquiry, in which the "facts" may change with more scientific research.

Moreover, our current understanding of science is nowhere close to static. In fact, one reason science fascinates many people is precisely because we understand science as a continual process of learning. While students have sets of facts to be learned, giving epistemic status to such truths can be problematic. Though as scientists we know our understandings may change with time, while teaching often we present scientific ideas as static facts. Herein lies the paradox; we know science in one way, but most scientists teach science in another. To begin, I believe scientists perpetuate this paradox because our best learning style was auditory, which reflects our initial learning of science. Since most of us in science first learned science via didactic teaching, we tend to teach science in the same way, believing naïvely that most people learn similarly to ourselves. Secondly, I also believe scientists perpetuate this positivist view of science because we fear that through a different approach, we might lose the authority that science commands. Humanists in the postmodern movement fault science and scientists for the presumed authority of science. However, I believe that if scientists were to present science as our best understanding of knowledge at the current time instead of as absolute truths, the public would view science as a learning process, and not with disillusionment when scientific facts are overturned, as happens now. Instead the public would see science as a stimulating area of inquiry, and understanding that our conceptions of the world inevitably change with time.

I have been in the sciences long enough to witness shifts in our scientific views. One example that really struck me as a freshman undergraduate chemistry major was that my chemistry textbook said that all noble gases were "unreactive" (Sienko and Plane 1961, p. 494). A mere semester later, a discovery that the element, xenon, one of the noble gases, could react under certain circumstances, completely undermining this fact in my textbook. Actually, I did not even learn this new information until I was in graduate school in organic chemistry at Bryn Mawr College, working towards a master's degree, 4 years later. Regardless, this example represents an important paradigm shift in our thinking on noble gases and exemplifies the ever-developing understandings of science. Our ideas and theories evolve to incorporate new knowledge and therefore our teaching needs to acknowledge this process in scientific inquiry. Even though I had this experience on realizing that our understandings in science change, I pushed that thought to the back in my mind for many years, as I participated in the more positivist practices within the culture of science.

Another example, closer to my own area of expertise in biochemistry, occurred when I was a graduate student at University of California, Berkeley from 1968 to 1972. One of my biochemistry professors proclaimed that the sequence of deoxyribonucleic acid (DNA) could never be read. However, in 1980, a mere decade later, Walter Gilbert and Frederick Sanger shared the Nobel Prize in Chemistry with Paul Berg for developing the methodologies for sequencing DNA (Nobel Prize 1980). In fact, our current technologies make sequencing DNA far easier than sequencing proteins, a process achieved prior to DNA sequencing. Using technology developed from Gilbert and Sanger's discoveries, in February 2001 two groups (Venter et al. 2001; International Human Genome Sequencing Consortium 2001) sequenced the entire human genome. We are in a revolutionary time in science, one utterly unthinkable just 50 years ago.

Throughout my life, I have found that the implied certainty of science makes science less interesting to people, mostly because people suspect that life is more complicated than we can fully know. Primo Levi, a chemist, understood these complexities and wrote a wonderful set of short stories highlighting this richness of life (Levi 1984). Levi built these stories around various elements of the periodic table. Mirroring Levi's story on the element of carbon, I ask you, what makes an atom of carbon, which enters my bloodstream and then my brain, cause me to write these words on my computer that you then read while you metabolize another carbon atom?

We can begin to know the world through science, but we must know that our understandings, which may work for some time, are *constructions* in our mind. As we learn more, in the light of new data, we may see our former constructions and the world itself, in an entirely different manner.

Therefore, rather than being a positivist and focusing on the certainty in science as I once did in my teaching, I now prefer to emphasize the ambiguity or uncertainty in science. In this way, I encourage my students to challenge our current ideas and open new vistas for understanding through their current or future research and teaching.

While I could easily say that now I am a postmodernist, my transformation to postmodernism was an arduous and time-consuming journey. During the past 17 years, I have grown through a process of continual learning, and the slope of the learning curve has varied with time.

I reached a point in my professional career as a practicing biochemist when I became increasingly aware and involved in science education. This involvement became formalized in 1992 through a joint grant with Kenneth Tobin from the National Science Foundation (NSF). The goal of the grant was to improve teacher preparation in science for prospective elementary school teachers. Through this process, I became aware of my own positivist theoretical framework, a result of my professional training in organic chemistry, biophysical chemistry and immunochemistry and from my immersion in the culture of science for my professional career up to that point in time.

I became progressively more involved in the science education research that Kenneth Tobin directed with his graduate students at my university. I served as the faculty member representative from the College of Arts and Sciences on students' doctoral and master's committees. I read each graduate student's prospectus and thesis or dissertation about current constructions in the literature and the newest information from collaborative groups of science education researchers about teaching and learning. Still, I needed years to be able to think seriously about the tough epistemological questions concerning "the origin, nature, and limits of human knowledge" (Guba and Lincoln 1989, p. 83).

In the fall of 1995, I decided to register as a special student at my own university and take a course in science education. I committed to take this class because Tobin and I received a grant funded by the US Department of Education. While taking the special topics course in *Evaluation* for credit (with Tobin as the professor), I felt I had hit a brick wall while trying to read Guba and Lincoln's third chapter, "What Is This Constructivist Paradigm Anyway?" in *Fourth Generation Evaluation* (1989). The chapter tore at the very fabric of my beliefs as a positivist and traditionally trained biochemist. This chapter raised tremendous conflicts in my mind. I felt everything near and dear to me was cracking apart. I spent all day each Sunday writing short critiques related to the readings for our course. During that semester I wrote another student in the same class:

> I think that it is hard for those of us in science to switch back and forth from the positivism in which we are immersed [in our jobs], into constructivism [in our class with Tobin]. For instance, in one day you might move from attending a positivist seminar to working on a fourth generation evaluation. It is hard to switch gears away from the control used in science to empowerment when doing evaluation. (E-mail to Jackie Ballas, 7 September 1995)

With time, I came to an understanding of living within both cultures. However, the process was slow until I experienced an increase in the slope of the learning curve as my ideas changed on the nature of knowledge. This change occurred while conducting my first action research project as I taught *Honors General Chemistry*. I have already written more extensively about this period of time (Gilmer 2002). The essence of that paper recounted a dream in which I was able to bring my ideas about my three research areas (i.e., biochemistry, ethics in science, and science education), my three areas of responsibility in my academic job (i.e., teaching, research and service), and three aspects of myself (i.e., family, friends and self) together at my "triple point." At this triple point all interconvert and become one. I believe that confronting my ideas on teaching and learning while doing action research and taking my first science education graduate class catalyzed my dream. This dream allowed me to find the energy to recover from cancer and to learn the field of science education, with its differing epistemology concerning the nature of knowledge and qualitative methodologies that I would need to use to conduct my action research study and be able to write this book.

In my journey, I learned the value of qualitative data and different ways to represent data in research papers. For example, I wrote the following after reading a chapter of Susan Mattson's doctoral dissertation (1997) on the use of fiction to describe a college classroom (parts now published, Mattson 2002):

> I have found the readings on narrative very interesting. By fictionalizing characters, as Sue Mattson describes, you can protect the anonymity of the individuals who are studied in the research. You can also bring ideas and conversations together that might have been separated in time and space. The reader gets involved if the narrative rings true. (E-mail to fellow students in the Evaluation class, 1 October 1995)

In my quest for a second doctorate I developed a different theoretical framework than that of traditional scientists. Through this time period, I came to understand constructivism, a theory of knowing that utilizes the term *viability* rather than truth.

Understanding constructivism has been one important step along my pathway of becoming a science educator. One might ask, "What exactly is constructivism?" Constructivism posits that each of us constructs his/her own knowledge because each of us has a unique set of experiences. For instance, you and I may interpret data or signs differently depending on our prior experiences, culture, and day-to-day occurrences. A constructivist asks if a concept is viable rather than if a concept is true. By viability, I ask if the concept fits within one's experience. A constructivist realizes, of course, that in the light of new experiences, one's understandings and concepts may change with time.

Over the time of my transformation, I have come to realize that everything that I think is a construction in my mind. I find this construction to be viable within my personal and professional experiences. Sharing my constructions may facilitate other science educators trying to work with scientists, to encourage the scientists to think about teaching and learning differently.

During this period starting my doctoral study in science education in 1997 through to completing it early in 2004, and through to the present time as I finish this book, I slowly shifted my understanding from constructivism to social constructivism. Social constructivism focuses more on the construction of ideas within a social setting rather than an individual constructing ideas in isolation. Social constructivism led me to become more aware of sociological theories of human behavior and focus on cultural historical activity theory and a theory of structure (to be introduced in Chapter 3). These sociological theories became a powerful force in my understanding of the interactions and learning in my biochemistry classroom.

1.3.2 Power of Narrative

Using narrative is a crucial step in conveying my research because of the unique and innate power illustrative that narrative holds for a reader. For instance, Ellis (1997) elucidates on the power of narrative:

> Narrative truth seeks to keep the past alive in the present; through narrative we learn to understand the meanings and significance of the past as incomplete, tentative, and revisable according to contingencies of present life circumstances and our projection of our lives into the future. (p. 129)

Similarly, Bruner (1986) writes of narrative in a way that makes me want to write even more: "Discourse… must depend upon forms of discourse that recruit the reader's imagination – that enlist him [or her] in the 'performance of meaning under the guidance of the text.' Discourse must make it possible for the reader to 'write' his [or her] own virtual text" (p. 25). By sharing my fictional story with my former students a year after the biochemistry course ended, I learned more about their perspectives of the classroom environment and student group interactions because through the story my former students could remember their feelings again. Their feedback indicated the degree to which the story represents (or misrepresents) their experiences in our classroom.

Bruner goes on to describe three features of discourse: *presupposition* (creating implicit meanings rather than explicit meanings, which encourages imagination in the reader); *subjectification* (presenting the narrative, not through your own eyes, but through the consciousness (and subconsciousness) of the characters in the story); *multiple perspective* (using a set of prisms from the perspectives of various individuals, to bring out the multiple ways one can view experiences). The combination of these three features Bruner terms *subjectivizing reality*, which I utilize in my fictional account of the classroom. Part of the power for me in writing the story was that I had to think through, for each character, their perceptions of their roles and actions in my classroom, thereby enabling me to see the classroom through multiple perspectives.

Similarly, Gergen and Gergen (2000) address the power of literary styling, saying that writing fiction “is especially appealing because it offers a greater expressive range and an opportunity to reach audiences outside the academy” (p. 1029). I hope this book provides the opportunity not only for science educators to read my story (the fictional story and *my* story of growth) but also scientists teaching both at the K-12 and university levels.

While Gergen and Gergen (2000) claim that such fiction is “not appropriate for scientific presentations,” others have done so for scientific topics, including Djerassi (2000) and Levi whom I already mentioned. I address Gergen and Gergen’s denouncement by providing examples of the collaborative groups effectively working (in Chapter 5) and students trying to learn biochemistry while using technology (in Chapter 6) in my nontraditional biochemistry course. My data include sections of certain groups’ Collaborative Learning Surveys (CLS), student individual student interviews, e-mails between students and me, and summative questionnaires containing feedback from all of the students.

1.3.3 Crises in the Postmodern World

To write about my biochemistry classroom in the postmodern world, I needed to understand and learn the power of using a qualitative methodology. Therefore, I immersed myself in reading a large variety of qualitative studies (Denzin and Lincoln 1994, 2000a). Ellis’ (1997) writings particularly illustrated the power of qualitative research, and her work motivated me to attempt to utilize similar tactics.

These three crises – representation, legitimation, and praxis – are crucial to understanding the dilemmas educators face when teaching and conducting educational research. Therefore, I realized that in order to gain insight to my classroom I needed to address the three crises that exist within the postmodern world (Gergen and Gergen 2000).

1.3.4 Crisis of Representation

The first crisis concerns the voice one uses to represent fairly the actions and thoughts of those of others and of oneself. This choice of voice is the first crisis of the postmodern world, called the crisis of representation.

I did research in my classroom about students’ actions and responses to my methods of teaching and my learning through the process of doing the action research. Therefore, I wanted to choose methods that I could represent my students’ differing views along with my own.

To address this crisis, I utilize different voices in different parts of this account of my action research study. The crisis of representation deals with the difficulty of representing others’ voices in one’s own writing. Lincoln and Denzin (2000) ask, "Can we ever hope to speak authentically of the experience of the Other, or an Other?" (p. 1050). This question defines this crisis.

Therefore, the crisis of representation hinges on the concept of voice. According to Britzman (1991), the concept of voice is "the individual's struggle to create and fashion meaning, assert standpoints, and negotiate with others. Voice permits participation in the social world. Through the alterity of the speaker, voice affirms one's relationship to the world and to others" (p. 12). Hence, the voice I choose in which to write reflects my connections to others in the world.

Britzman (1991) was a powerful force in my own development as a science educator. Whenever I present my research, I quote her since she eloquently articulates my struggles with representing my students' voices, stating, "My dilemma as a researcher is to reconstruct and critically re-present the voices of others, and, in so doing, care for their integrity, humanity, and struggles" (p. 12).

For this book, I had to learn to express the students' experiences in my classroom as they struggled to learn biochemistry, while concurrently learning to collaborate and use new technologies. I chose to share my students' struggles in two ways: (i) by writing a fictionalized story with four student archetypes in my class, and (ii) by presenting ethnographic, qualitative data of students' statements.

Similar to my struggle to represent my students' voices, I puzzled over ways to express my colleagues' feelings. Most were upset by my radically revised biochemistry course for science majors and initially hostile towards my method of teaching in the classroom. I asked one colleague to write a metalogue with me, after reading my doctoral thesis, on the problematic issues of bringing reform in higher education. My biochemistry colleague, Robley Light, now retired as a professor in the biochemistry program in my department, had attended two of my biochemistry classes during the semester of the study and spoke with our other colleagues on their reactions to my alternative teaching methods in a mainline course for biochemistry majors.

Presenting Robley Light's and other's viewpoints gives me opportunities to expose the readers to the complexity of science education and permits a glance at others' feelings and opinions that might vary greatly from my personal perspective. Hertz describes the benefit of using multiple voices in one's writing as

> …a struggle to figure out how to present the author's self while simultaneously writing the respondents' accounts and representing their selves. Voice has multiple dimensions. First, there is the voice of the author. Second, there is the representation of the voices of one's respondents within the text. A third dimension appears when the self is the subject of the inquiry… Voice is how authors express themselves within an ethnography. (Quoted in Lincoln and Guba 2000, p. 183)

Just as Herz describes, I use three different voices throughout this book. My *authorial voice* can be heard in Chapters 1–3 and 5 and 6. In this chapter, I write the goals and rationale for the study. Chapter 2 contains my review of the literature and the way in which I interpret its findings as a college science professor. I provide my methodology in Chapter 3, including my theoretical underpinnings that frame the study. Chapters 5 and 6 consist not only of my students' comments about the learning environment in our classroom but also my authorial interpretations, as I tried to make sense of the students' responses to questionnaires and relate them to the literature.

As opposed to my authorial voice, my *personal self* can be heard in Chapters 4, 7, and 8. As I speak in my *personal* voice, I am speaking directly from my firsthand experiences. Since this is an action research study, I am one of the subjects of the inquiry. For example, Chapter 4 shares my *personal* experiences of being a student learner in the *Fiction Workshop* class and my *personal* response to the feedback I received from undergraduate creative writing majors on the fictionalized story I wrote about my biochemistry classroom. Similarly, in Chapter 7, I *personally* respond to questions, which my biochemistry colleague poses in the metalogue, concerning problematic issues on bringing reform to higher education. In Chapter 8, I summarize and write my *personal* conclusions, while examining the implications I perceive for improving college science teaching and learning.

In addition to using my personal voice in Chapter 4, the story within this chapter gives voice to Magnolia, a fictionalized character whom I envisioned as a student in my biochemistry class. In the story, I write from Magnolia's point of view. The other fictionalized characters, Heather, Bristol, and Charles, are members of Magnolia's collaborative group. I created these fictional characters based on my interactions with my students during the four months of teaching our biochemistry class. The fictional characters represent four student archetypes in my classroom: (a) the shy woman, Magnolia, who finds her voice and blooms through participating in the biochemistry course; (b) the outgoing woman, Heather, who generally does not follow through on her promises; (c) Bristol, who wants to get the assignment done efficiently; and (d) Charles, who is the quiet "ideas-man" and the tech expert. Both Magnolia and Bristol are African Americans while Heather and Charles are of European descent. The composition of the group in the fictionalized classroom represents groupings as in the actual class. Of my 34 students, I had eight African American students. I chose to focus on African American students since they are underrepresented in science. These African American students tended to cluster within collaborative groups, with one group of four students having three African Americans, two groups (each with four students) having two African Americans, and one group of four with one African American.

One compelling way I learned from my students was by reflecting upon their reactions to my fictionalized story. The story became a research tool to further my understanding of the learning environment in the classroom. Rather than asking my students to read a more traditional report of a classroom, I decided I could engage them more successfully by tapping into their emotions in the fictionalized story. One reason this tact was successful was my students could see that I had understood some of the dynamics of the classroom. Because they sensed my partial understanding, they decided to divulge more. Using pseudonyms, I also include students' reactions to my fictionalized story. I only made editorial changes to the fictionalized story after sharing with my students, so their responses to my story, which I include in Chapter 4, influenced me as I interpreted my students' comments in Chapters 5 and 6, and also my metalogic responses in Chapter 7.

Table 1.1 Summary of various voices utilized in each chapter

Chapter no.	Subject	Voice(s)
1	Introduction and problems of teaching and learning university-level science	Authorial self
2	Review of literature on science teaching in various fields of science	Authorial self
3	Theoretical framework and methodology	Authorial self
4	Fictionalized story	Four archetype students whom I developed and fictionalized
	Feedback on story	Personal self within *Fiction Workshop* class
		Creative writing undergraduate students
		Creative writing professor
		Biochemistry students responding to the fictionalized story (used pseudonyms)
5	Collaboration in the classroom	Authorial self
		Comments from biochemistry students
6	Teaching utilizing technology	Authorial self
		Comments from biochemistry students
7	Metalogue with biochemistry faculty colleague	Personal self
		Biochemistry colleague
8	What I learned from the study	Personal self

Table 1.1 is a summary of the various voices utilized in each chapter of this book.

In summary, I used the voices of my students, biochemistry colleague, creative writing fellow students, creative writing professor, as well as different aspects to my own voice in various chapters for differing purposes. The voices come through to contribute to the validity of the action research project.

1.3.5 Crisis of Legitimation

In my action research and doctoral work, I struggled to get a grasp of the meaning of epistemology[1] (i.e., the nature of knowledge). In my initial training as a physical biochemist, I viewed my research as the process of identifying "truth." However, as I read the educational literature, I confronted the idea that we cannot *truly* know

[1] When first confronting the word epistemology, I had to keep going back to read the definition from Guba and Lincoln (1989, p. 83): "Epistemology is that branch of philosophy that deals with the origin, nature, and limits of human knowledge."

"truth." Rather, we, as humans, construct all of our knowledge; thus, these human constructs are our best understandings at the present time.

Once I started to grasp the implications of human-constructed knowledge, I realized that the ideas that I had held as truths were not necessarily so. This foundational upheaval brings us to our next crisis, the crisis of legitimation (Lincoln and Denzin 2000, p. 1051). This crisis of legitimation arises from the question of whether epistemology is foundational or non-foundational.

Foundational epistemology conceives that knowledge is an entity that moves from one person to another; for instance, knowledge could move from a biochemistry teacher to his/her students, as if the knowledge were a rock handed from teacher to student, always retaining its exact properties. Most natural scientists possess this foundational understanding of the nature and authority of knowledge, as opposed to many social scientists that think of knowledge as non-foundational. One develops non-foundational knowledge through each individual's own lens or perspective. For instance, as the teacher explains his/her understanding of a concept, each student constructs the idea slightly differently as he/she relates the new knowledge to their individual webs of understanding.

Bruffee (1993) states, "Changing college and university teaching depends on changing teachers' understanding of what knowledge is" (p. 3). So far, social scientists are overwhelmingly embracing new methods of understanding knowledge, while most natural scientists reject these new methods and tend to cling to their positivist constructions.

Glasersfeld (1989) articulates this new conception of knowledge:

> For constructivists, therefore, the word *knowledge* refers to a commodity that is radically different from the objective representation of an observer-independent world[,] which the mainstream of the Western philosophical tradition has been looking for. Instead, *knowledge* refers to conceptual structures that epistemic agents, given the range of present experience within their tradition of thought and language, consider viable. (p. 124)

Mirroring this description, my reconceptualization of knowledge as *viable* constructs based on our previous experiences was critical in my own transformation. These constructs, as Glasersfeld maintains, constitute our means to survival.

Glasersfeld (1989) argues that use of constructivist theory of knowing changes education:

> Instead of presupposing that knowledge has to be a 'representation' of what exists, they [constructivists] posit knowledge as a mapping of what, in the light of human experience, turns out to be feasible. If the theory of knowing that constructivism builds up on this basis were adopted as a working hypothesis, it could bring about some rather profound changes in the general practice of education. (p. 135)

Each individual bases his/her own perspectives on prior experiences, interpretations and knowledge, and current positions of power. Applying this constructivist perception of knowledge to education, as Glasersfeld suggests, transforms teaching methodologies in momentous and beneficial ways.

1.3.6 Crisis in Praxis

The third and final crisis in the postmodern world is praxis. Praxis is the practice of a professional skill, such as teaching. An example of praxis is a teacher combining theory and practice coherently in his/her teaching. If the teacher believes that he/she can just pour knowledge into her/his students' heads, then he/she teaches in a way that reflects that perception. However, a teacher theorizing that students learn using prior knowledge may teach in ways that help students connect and create their own meanings.

Therefore, within the crisis in praxis both teachers and students may experience conflicts in university science classrooms. Teachers teaching didactically experience conflict in at least two major ways. One source of conflict is didactic teaching does not work for all students. Such students have trouble learning by memorization and would rather learn conceptually (Tobias 1990). The second source of conflict for the didactic teacher occurs if the students interact with other teachers who teach more constructively by actively engaging students in learning, which connects prior learning to new knowledge.

University science teachers who teach more constructively also feel conflicted and isolated by interactions with other faculty who teach more didactically. Moreover, constructivist teachers experience conflict while trying to teach students who excelled in the past by memorization but do not have the conceptual tools needed to apply knowledge.

Lather (1986) discusses praxis as the dialectic between theory and practice. She presents "the need for open, flexible, theory-building grounded in a body of empirical work that is ceaselessly confronted with, and respectful of, the experiences of people in their daily lives" (p. 139). This third crisis of the postmodern world lies in the development of a praxis that reduces conflicts both for the teachers and the students. Grenfeld and James (1998) interpret the practice in teaching as:

> …the dynamic of which is probably better captured by the word praxis, is a cognitive operation; it is structured and tends to reproduce structures of which it is a product. We are, of course, not simply repeating actions endlessly. Evolution and change *in practice* do occur. However, it comes about, not so much through the replication of action but its reproduction. Reproduction implies both variation and limitation in what is and is not possible in the behaviour, thought and physical action of people. (p. 12)

This quotation reflects part of Bourdieu's (1993) theory of social reproduction implying that a social system molds people. Therefore, the system tends to reproduce itself; however, similarly to biological evolution, variation can occur. The above quote simply put, echoes the commonly held idea that "one teaches as one was taught" – and is one part of Bourdieu's idea of social reproduction. Adamson et al. (2003) support this idea, contending that new science teachers do teach as they were taught. Prospective science teachers having more inquiry-oriented science classes as part of a reform effort at the undergraduate level incorporate more inquiry into their science lessons as they become new teachers. In contrast, other prospective science teachers with more traditional, didactic undergraduate science classes tend to teach more didactically and include less inquiry-oriented instruction in their classrooms.

The question here is how do I go about changing my praxis in the university science classroom as the practice in which I have been immersed has not changed appreciably, except for using technology, since I was an undergraduate student? For these past 40+ years I have been immersed in the *habitus*[2] or *strategies of action*[3] within the *fields* of biochemistry and chemistry. Here are the three questions that I asked myself and that focused my action research study:

1. How can I go about changing my *habitus* and *strategies of action* immersed in a science department whose primary interests lie in research rather than teaching?
2. How do I enact a transformative curriculum?
3. What are the sources of the transformation in the enacted curriculum?

As a preamble to my answers to the above three questions, I merge various theoretical lenses including interpretive/constructivist and feminist perspectives. I do this as I address the triple crisis of representation, legitimation, and praxis in my classroom and my growth as a science educator.

In order to address this triple crisis, I needed to find a methodology consistent with my growing understanding of my theoretical perspectives. Some scientists and science educators propose using triangulation to get at some defined truth. However, life is more complicated than three-point planar interpolation, especially dealing with human interactions. I prefer to use the metaphor of looking at life as a crystal, in which light comes into a crystal and refracts, showing both the crystal's and the light's richness. Similarly, as we can see many perspectives within a crystal, we can interpret life in multiple ways. One realizes this richness in life upon examining an audiotape of interactions with students. We can hear so much more to hear the next time around. If one watches a videotape of the same conversation, one sees even more. How can one miss so much as life unfolds?

Therefore, similar to other researchers (Richardson 1994; Janesick 2000), I attempt to use this metaphor of a crystal to understand learning in its relation to human interactions. Throughout this book I use various perspectives in an effort to develop a multidimensional understanding my classroom environment. Richardson (1994) says, "Crystallization provides us with a deepened, complex, thoroughly partial, understanding of the topic. Paradoxically, we know more and doubt what

[2] John B. Thompson, the editor of a collection of chapters by Bourdieu (1991), defines *habitus* is a "set of dispositions which incline agents to act and react in certain ways. The dispositions generate practices, perceptions and attitudes which are 'regular' without being consciously coordinated or governed by any 'rule'" (p. 12).

[3] Swidler (1986) defines strategies of action as "persistent ways of ordering action through time" (p. 273).

we know" (p. 522). Therefore, with this metaphor of crystallization in my mind, I could begin to address the triple crisis of representation, legitimation, and praxis in my classroom and my interactions with colleagues.

1.4 Organization of Chapters

Here I set the frame of reference for the case study of my own transformative growth, including struggles and epiphanies, coupled to the experiences of my biochemistry students in a Web-enhanced university-level classroom.

While typing the handwritten responses of my students to the Learning Environment Questionnaire (LEQ) on the learning environment in our biochemistry classroom, I was simultaneously writing a short story about my classroom as part of my doctoral study. Through writing the story (Chapter 4) and receiving responses not only from the fellow creative writing majors in the class but also from my own biochemistry students, I realized the major themes in my study. The students' responses in groups each week to the survey to the Collaborative Learning Surveys (CLS) were a rich source of data as well. At that point I learned to code all my qualitative data, which led to Chapter 5 (on collaboration) and Chapter 6 (on technology) in this book. I finalized Chapter 7 at with my biochemistry colleague in metalogue format, and then concluded with my summarizing ideas in Chapter 8.

Although I put the chapters in this particular order, reading them in this order is not necessary. I include a preview at the beginning of each of the following chapters.

1.5 Source of Questionnaires

The questionnaires and surveys from the course (Gilmer Downloads 2010), and the students' responses to these documents from the original doctoral thesis (Gilmer 2004) are available at http://www.chem.fsu.edu/~gilmer/downloads.html. These include the questionnaire at the end of the semester, the LEQ (now called the HEES for Higher Education Environment Survey), and the CLS, the survey the students answered in collaborative groups in class, in the heat of the moment, right as each project was due. This same URL: http://www.chem.fsu.edu/~gilmer/downloads.html.

Chapter 2
Researching Science Teaching and Learning

2.1 Preview

I frame my study on the problem of reforming the teaching and learning of science in higher education in the United States. I address the shift from modernism in science to postmodernism in science education research, and the need to address this shift in the teaching of science in college and university classrooms (National Research Council (NRC) 1997, 1999, 2001, 2003; Taylor et al. 2002; Sunal et al. 2004; Druger et al. 2004). Teaching science within a sociocultural frame influences not only future scientists but also encourages future science teachers to think differently about science, teaching, and learning (NRC 2001).

My own evolving research questions address, for example, methods to increase students' conceptual understanding and interest in biochemistry by using collaborative learning and technology.

2.2 Introduction

In this chapter, first I review some of the pertinent literature concerning educational research on college/university chemistry and biochemistry teaching and learning. I examine the US goal to improve science and mathematics K-12 education as well as the literature aimed at pushing the frontiers of science education reform at the college/university level. As opposed to strictly statistical studies, I focus on studies that incorporate ethnographic qualitative data.

Second, I examine issues related to preparing future K-12 science teachers within colleges and universities and highlight the importance of addressing future teachers' needs. In doing so, once the prospective teachers become teachers, our efforts will help to develop and prepare our K-12 students, including those planning to become scientists, science educators, or any other career.

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Finally, I provide an overview for the case study of action research in my own biochemistry classroom. I include my research questions and approaches to studying the learning environment I created for my students, and explain the importance of such a study.

2.3 What's Already Known?

2.3.1 Need for Reform

On January 31, 1990, President George H.W. Bush set a goal "to take American students beyond competence and to make them first in the world in mathematics and science achievement" (Cavazos 2002). US federal funding agencies embraced the goal to improve the STEM (Science, Technology, Engineering and Mathematics) fields in the United States. Professional organizations worked to develop standards and recommendations in order to help the United States reach this goal.

The NRC, the research arm of the US National Academy of Sciences, is one organization that obtains grants from Congress to write reports on various educational projects that Congress commissions. The NRC (2003) through its *Committee on Recognizing, Evaluating, Rewarding, and Developing Excellence in Teaching of Undergraduate Science, Mathematics, Engineering, and Technology* distressingly reports that "faculty who teach undergraduates in the STEM disciplines have received little formal training in teaching techniques, in assessing student learning, or in evaluating teaching effectiveness" (p. 2).

This report also highlights five characteristics that are fundamental to my own approach to learning about teaching undergraduates: (i) knowledge of the subject matter; (ii) skill, experience, and creativity with a range of appropriate pedagogies and technologies; (iii) understanding of and skill in using appropriate assessment practices; (iv) professional interactions with students within and beyond the classroom; and (v) involvement with and contributions to one's profession in enhancing teaching and learning (described in full, pp. 27–36). NRC documents, such as this one, are valuable because they analyze existing research, set principles that frame their conclusions, provide direction for future research and policy, and disseminate their findings to researchers and state policy experts.

2.3.2 Research on Teaching Science in Higher Education

Among many college students in the United States today is a growing disinterest in the pursuit of scientific learning. Currently, many college students change their majors from science to other nonscientific fields (Seymour 1992). Additionally, US college students in nonscientific fields enrolling in traditional science courses offered for liberal studies credit often become disengaged from science (Tobias 1990). At the core for the students' reasons for their decisions leaving the sciences are the methods employed by college faculty members to teach science. Seymour (1992) reports the most highly cited reasons for students leaving Science, Mathematics, and Engineering (SM&E) programs are:

1. Non-SM&E majors offer better education/greater intrinsic interest.
2. Rejection of SM&E career(s)/associated lifestyle.
3. Lack of/loss of interest in subject: "turned off science".
4. Overload/pace too fast/overwhelmed by curriculum demands.
5. Conceptual difficulties with one or more SM&E subjects(s).
6. Discouragement/loss of confidence in ability by low grades in early years.
7. Poor teaching and inapproachability of SM&E faculty. (p. 233)

College and university SM&E faculty generally teach science courses, such as biochemistry, in large lecture format (Leonard 2000; Wright et al. 2004). Typically, students work individually and competitively, using textbooks as the main source of knowledge, with the instructor "professing" to the students in large lecture halls. Even in advanced undergraduate classes, enrollment can be 60–100 students per section. College teachers, at least at state public institutions like my own, typically assess their students' learning in a summative evaluation, using in-class, written hour, and final examinations, with little or no alternative assessments of students' learning.

While learning individual disciplines in science is important, students need to develop critical thinking skills, solve real-world problems, and understand the interfaces between different fields within and beyond the sciences. College science students typically focus on one or two science subjects at a time. Often these students fail to see the connections between their current and previous studies. Students commonly cannot connect, even within a single course, one chapter's material to the next. Not all faculty members make the effort to help students make these connections, but the ability to make these connections is critical to the students' future endeavors.

2.3.3 Research in College Science Teaching

2.3.3.1 General Issues

Sheila Tobias reports on a number of case studies on higher education institutions, ranging from small colleges to large universities, in which researchers undertook studies in science education reform (Tobias 1992). Tobias acknowledges that no model would work for all institutions because each college and university has a different mission and attracts different types of students. However, Tobias promotes the development of a "*process model* that focuses attention continuously on every aspect of the teaching-learning enterprise, locally and in depth" (p. 160). By using the Japanese word for "process," *Kai Zen*, meaning, "change in the direction of the good," Tobias highlights her process model. Using this word, Tobias implies the instructive nature of this process and its general goal while also elucidating its inherent adaptability to the various science departments wishing to address the issue of improving the teaching of science at their respective institutions. Most importantly, Tobias (1992) concludes, "case studies suggest that what we need to do above all else is collect information on how successful faculty support and manage improvement" (p. 158).

Two stimuli are often the impetus for change in science departments. Either the change comes from a university-wide or college science department-wide commitment to change or the "lone ranger" (NSF 1996, p. 50) faculty member chooses to introduce reform without much peer or departmental support. In the first instance, a leader within the university administration or within the department usually rallies other faculty to work together using grant or administrative funds to develop goals and implement a plan for improving education. With a reward system for faculty succeeding in such reform, others also begin to see a place for themselves in the project and join forces. Contrastingly, if the "lone ranger" is the impetus for change, often the change is less successful. With little or no support from the department or institution, these professors work in isolation from others, trying to enact change in science education (Sunal et al. 2004).

My goals as an educator are to encourage students to (i) connect their thinking within their own and across other disciplines, (ii) use the discourse of science, and (iii) be able to think critically. Here are a few studies that I found of particular interest towards pursuing these goals: Lord (1997) on collaborative learning; Allen and Stroup (1997) on enhancing critical thinking; Siebert (1997) on coordination of learning experiences; Truchan et al. (1997) on connecting teaching and learning by assessment; Druger et al. (2004) on various innovations by individual faculty on undergraduate science teaching; and Siebert et al. (1997) on college science teaching and the new methods and ideas that some faculty members bring to the teaching and learning of science.

In addition to these studies, the National Aeronautics and Space Administration (NASA) organizes workshops for higher education science and science education faculty, at which administrators in higher education developed nine categories of factors that can influence reform in higher education. Wright and Sunal (2004), examine these nine categories: (i) accreditation and certification; (ii) budget and resources; (iii) coordination; (iv) curriculum; (v) faculty; (vi) instruction; (vii) leadership; (viii) management; and (ix) students. Wright and Sunal, analyzing the barriers to enact change in instruction in higher education, state, "Change is slow to occur in higher education because institutional organization, expectation, and roles inhibit risk taking, ambiguity, and the inquiry required for change to occur" (p. 34). NASA requires both the science and education faculty with their administrators to attend the same funded workshop, so the attendees can address the nine factors to influence reform.

The most significant barriers to reform recognized by faculty are resources, time, and turf conflicts. Faculty members often feel that these barriers are beyond their control. Other barriers less frequently cited include students, personal resistance to change, lack of training, and curriculum materials (Wright and Sunal 2004). Forty-two percent of the science content faculty members who participated in their survey and were trying to foster change claim, "their effort was not recognized by the tenure/promotion guidelines" (p. 46).

One approach Wright and Sunal (2004) suggest to initiate the improvement of teaching science in higher education is for faculty members to design and conduct action research projects in their own classrooms. By doing so, "one learns to assess the effectiveness of various aspects of one's curriculum in meeting stated goals and objectives, particularly one's learning outcomes for students" (p. 50). This idea of conducting action research is the path I undertook to improve the learning environment in my own biochemistry classroom – this book describes the study.

Usually, chemists or other scientists, for that matter, are generally reluctant to have peer reviews of their teaching. Atwood et al. (2000) cite fear as the main reason for this stance. However, Atwood et al. (2000) also acknowledge that peer review of teaching chemistry has "taken root at 16 institutions across the country" (p. 239), through a project coordinated by the American Association for Higher Education (AAHE) and supported by the William and Flora Hewitt Foundation and the Pew Charitable Trusts (AAHE 1994). This effort is encouraging, but peer review on a regular basis is still not a widespread practice among institutions of higher education.

One example of a successful peer review chemistry program occurs with the University of Wisconsin. The staff at the Learning through Evaluation, Adaptation, and Dissemination (LEAD) Center observes a traditional class and also a class with active learning. The staff members interview the faculty members and students from both sections. As part of this study, faculty members from a variety of departments also interview these students in groups of seven to ten, to ascertain the students' "competence" in the subject matter. Conclusively, the students from sections with active learning demonstrate "higher competence" (AAHE 1995).

A study in engineering education (Thompson et al. 2003) indicates that a "design research paradigm" (Edelson 2002) helps engineering faculty at a Research I institution collaborate with science education researchers in order to improve the curriculum throughout the engineering program. Edelson uses this design to indicate a "strategy for developing and refining theories" (p. 105). Wright and Sunal (2004) also suggest having content faculty and education faculty work together in a collaborative team. Through collaborative efforts these teams of scientists and science educators would feed off each other's suggestions, hopefully reaching for and attaining goals from a variety of perspectives.

For faculty with little or no training in pedagogical theory, skills, and practices, the NRC has four excellent resources about university science teaching. I include them here because they were helpful to me as I learned science education. The first was by the NRC Committee on Undergraduate Science Education, which published a handbook for college faculty members interested in improving the teaching and learning in their classrooms (NRC 1997). The same committee issued another report (NRC 1999) that highlights six visions for transforming education at the undergraduate level. Each vision connects to strategies for new partnerships "for improving teacher education in science, mathematics, and technology" (p. 88), including partnerships between K-12, 2- and 4-year colleges and universities, and the professional scientists, mathematicians, and engineers. The NRC Committee on Recognizing, Evaluating, Rewarding, and Developing Excellence in Teaching of Undergraduate Science, Mathematics, Engineering, and Technology issued the third book (NRC 2003).

However, the NRC book that I found the most useful and informative, entitled, *How People Learn: Brain, Mind, Experience, and School*, collates the best research on learning (Bransford et al. 1999). This book highlights the importance of pre-existing knowledge in the learning process and the power of constructivism as a theory of knowledge construction.

2.3.3.2 Using Impressionistic Tales

So, how can scientists encourage other science faculty in higher education to engage in research in order to improve their teaching and their students' learning? One compelling way to understand the critical issues in teaching and learning is to evoke emotions in the writing of the climate within university science classrooms. Utilizing fiction can be an effective approach to writing about these critical issues. Taylor, Geelan, Bowen, and Mattson are four authors who compose a fictional but impressionistic tales of college science classrooms, and who are taking this approach.

Taylor (2002), using a "tales of the field" approach, describes the learning environment for learners in college science and mathematics classrooms. He paints impressionistic tales of salient issues that allow the reader to visualize and perhaps even remember similar scenes of ineffective as well as effective teaching, in which he compares an ineffective biology teacher with a more effective mathematics teacher. The scene varies from teachers who embrace a transmission model of teaching (in which the teacher tries to pour knowledge into the heads of the learners) to other teachers who help students make connections between new and prior knowledge. Taylor uses composite characters as a means to share impressionistic tales of teaching and learning. These tales of the field evoke among its readers critical or reflective thinking. This method also brings to the front burner the importance of teaching and empowering students to learn for themselves. Writing in this insightful way helps to disseminate educational research. Taylor's style of writing influenced me considerably in the methods I chose to portray my own classroom in the study described in this book.

Similarly, Geelan (2003), one of Taylor's graduate students, vividly illustrates high school science classrooms in Australia, through his book, *Weaving Narrative Nets to Capture Classrooms: Multimethod Qualitative Approaches for Educational Research* (Geelan 2003). These impressionistic tales convey the typical events in the classroom that Geelan studies, but also these tales depict some of the emotions that Geelan and the other stakeholders felt during the year of his research study. Geelan (2003) himself finds this fictional approach effective in conveying these feelings to others, stating:

> In this postmodern world, I don't want to claim that I can capture the Truth about my experiences at Arcadia, but I want to assert that the story I'm telling you – the selections I've made – conveys something of the truth of my life at Arcadia High School during 1996. (p. 83)

Geelan writes this story using his own point of view, obtained from interviews of students and teachers while he was part of the science classroom for an entire year. By writing the story this way, he brings to the surface the voices of teachers and students, often unheard. By sharing the story with teachers and students for correction/reactions, by conducting "member checks" (one of the quality criteria for fourth generation evaluation in Guba and Lincoln 1989), he gets feedback on the verisimilitude of the story.

Bowen (2002) utilizes a similar but slightly different method, writing a fictionalized story concerning a student's learning in an undergraduate chemistry class. However, Bowen chooses to write from the point of view of a woman student, Diane, in the class. In the story Bowen includes a letter he had Diane send to her friend about her experiences in the class. As part of the story, Bowen conducts educational research in the classroom, and Diane connects to ideas on teaching and learning that Bowen promotes in his interviews with her.

Diane is a dance major, and she wants to emulate the tactics she uses in dance in the chemistry classroom. She dichotomizes the two ways one might teach dance class: "Somebody either teaches class or they give class" (p. 55). To her, giving class means only demonstrating a specific task or move, which results in only some students understanding. Similarly, Diane's experience in the chemistry class consists of the teacher only 'giving class,' unaware if students were learning the concepts. On the other hand, for Diane, teaching class involves (i) breaking down the components so the students learn the components, and (ii) comprehending the interactions to facilitate the students fitting those components together.

Writing from Diane's point of view is effective because Bowen highlights ways that students may view the learning environment in the classroom. This technique is also powerful because it evokes our emotions. Diane's depiction reminds us of similar classrooms in the past, when we were students or teachers.

Mattson (2002) uses a similar genre, as she writes about a group of biology college science teachers and educators trying to work together to negotiate methods to assess students in a biology course designed for prospective elementary teachers. As Mattson states, "the purpose of this research was to learn more about interdepartmental collaboration between those situated in science departments and those in science education" (p. 264). In a published chapter from her dissertation, Mattson uses a fictionalized story of the transpiring events in order to "engage the readers in thinking about and, hopefully, making progress toward goals for reform in science education" (p. 264). With the inclusion of the story, she provides the reader with an added dimension while also including the critical and propositional elements of her story.

As these examples illustrate, using fictionalized stories can evoke emotions, allowing the reader to understand the classroom atmosphere, and opening the door to bringing reform to higher education. While these four authors, Taylor, Geelan, Bowen, and Mattson, each employ slightly different writing tactics in conveying their stories, each author successfully gives the reader access to multiple perceptions and reactions to the learning environments in these fictionalized science classrooms.

2.3.3.3 Looking at Chemistry Teaching

Since the focus for this book is on the teaching of biochemistry at the undergraduate level, the literature discussed principally concerns research on chemistry and biochemistry education at the undergraduate level. While considerable research in the teaching and learning in other areas of science exists, I have not included a review of these studies in this book. The reader may refer to edited books by Taylor et al. (2002) and Sunal et al. (2004) for research in other fields of science for studying teaching and learning at the university level. In this discussion, I include articles that influenced my own thinking about the design, implementation, analysis, and ways to present my action research.

For instance, Abbas et al. (2002) examine the metaphors a college chemistry professor utilizes in his physical science classroom and their subsequent influence on the students' learning and the teacher's view of himself. Utilizing work from Tobin and Tippins (1993), Abbas et al. cite three aspects of metaphors:

> First, metaphors can be used as a way to describe teaching. Second, metaphors can be used as a referent to constrain teacher and student actions in the classroom. Third, metaphors can be used as a generative tool to build new knowledge. Using metaphors as referents to understanding teaching and learning has the potential to change what happens in classrooms. (p. 198)

My first action research project (in 1995) in a college science classroom in honors introductory general chemistry course involves using a metaphor as an empowering tool (Gilmer 2002). I describe a chemical metaphor of a triple point, which still empowers me, to focus my energies of research, teaching, and service at a single point (with the three domains in rapid equilibrium). This metaphor allows me to accomplish much more in life (Gilmer 2002). This triple-point metaphor emanates from a dream of mine, which occurred just a week after teaching about states of matter during the honors chemistry course. Dreams are a powerful mechanism (LaBerge 2000) for analyzing the critical issues in our lives, including our professional lives (Williams 2002). Exemplifying the effectiveness of using metaphors, an organic chemistry colleague at University of Missouri, Rainer Glaser, commented to me on my use of my metaphor of the triple point:

> I really like your triple point metaphor. To read all your beautiful thoughts about learner-sensitive environments with such clarity was very enjoyable. What you say resonates well with me. (E-mail, 8 July 2002)

In the classroom, I focus on engaging my students to learn chemistry beyond their regular coursework by attending chemistry seminars for extra credit (Gilmer 2002). By encouraging my students to attend those seminars, I hoped to encourage them to connect material from our chemistry classroom with other ideas proposed in the chemistry seminars. For the extra credit, students needed to write at least two paragraphs about the new connections they formed through this experience. In reading the students' reflections, I learned many of my students' goals, interests, and aspirations; all, in return, greatly influenced my teaching of college science. In that class, I focused on individual student's discourse with me, although, at that point in my development as a science educator, I neglected to encourage students to communicate with one another. Regardless, this course became the stepping-stone of discourse between my students and me and opened a pathway for me to continually change and modify my teaching strategies.

I hope by sharing my experiences, the desire to change *resonates* with other college science faculty, so that they too might conduct action research in their own classrooms. College science faculty like Glaser is already committed to active teaching (Glaser and Poole 1999; Glaser 2003; Glaser and Carson 2005), but other science faculty could learn too from studying their own teaching.

Glaser and Poole (1999) examine methods to build collaborative learning communities in an organic chemistry class, using electronic communication tools. Their approach had some similarities to the approach I took, but in their case they developed the Web site where students posted their ideas (and more than half of the students developed a Web site within their class Web site). In Glaser and Poole's study, students work together as part of small learning communities, using resources from the Internet. Students in groups peer assess other groups' reports. Many of their students comment that they enjoyed learning from each other.

To encourage students to see the connections of chemistry in the classroom to chemistry in the real world, Glaser and Carson (2005) develop a Web site called *Chemistry Is in the News* (CIITN) at http://ciitn.missouri.edu/. For the Web site, students work together in groups to identify interesting news articles that relate to the organic chemistry that they learned in Glaser's class. Since conducting the study reported in this book, I too have employed the CIITN Web site for the teaching and learning of biochemistry and found the site to be an effective tool.

O'Sullivan and Copper (2003) evaluate active learning strategies, such as problem-solving worksheets, creative testing strategies, hands-on learning activities, "explain the demo" worksheets, student presentations, and competitions, in a general chemistry curriculum. They conclude that students in active learning classrooms learn significantly more than those in lecture-based classrooms. For two other accounts of college science faculty employing active learning strategies in the classroom, see White (2002) and Humerick (2002). White (2002), a biochemist, uses problem-based learning in his classrooms. Humerick (2002), a teacher at a community college, shares her action research project in her small chemistry classroom or laboratory.

Coppola and Jacobs (2002) emphasize the need for more scholarship in the teaching of chemistry, particularly in evaluating "student learning and its alignment with instructional practice" (p. 203). Similar to the growing pains experienced 200 years ago as chemical research first started, Coppola and Jacobs point out difficulty in developing accepted methodologies for scholarship and learning in chemical education. One of the numerous research studies cited is by Wright et al. (1998), showing that students were better able to use different representational forms of knowledge if they worked as part of a collaborative group within the analytical chemistry classroom.

Gabel (2004) reviews the central ways that chemists use three forms of representation: the macroscopic, the particulate, and the symbolic, to help students learn chemistry. For example, from the macroscopic perspective, water has certain chemical and physical characteristics, which reflect the nature of the particulate molecule, with its bent geometry with two hydrogen atoms in covalent linkage to the central oxygen atom. Water molecules interact with each other by hydrogen bonding, making water a liquid at room temperature (in comparison to hydrogen sulfide), because the oxygen atom is an electronegative atom and interacts with hydrogen atoms in another water molecule. The symbolic representation is H_2O that a chemist uses in writing chemical equations and thinking about the molecule.

Gabel (2004) highlights the importance of including inquiry in chemistry classrooms and shows the significance of social interactions among students themselves as well as between the teacher and the students in learning the chemistry concepts. Gabel includes a summary of the more prominent reform movements in chemistry, including NSF-funded efforts as well as other projects. She highlights the powerful, positive effect that collaborative learning can have on student learning in chemistry classrooms, citing her own work (Gabel 1999), that of Bowen (2000) and Springer et al. (1999).

Bowen (2000) reports a meta-analysis[1] of a series of published, quantitative studies on cooperative learning in high school and college chemistry classrooms. These studies indicate that, "while median student performance in a traditional course is at the 50th percentile, the median student performance in a cooperative learning environment is 14 percentile points higher" (p. 118). The effect is even higher (20 percentile points) with meta-analysis conducted only at the college level classes.

Bratton and Gilmer (2009) provide a review of the literature in undergraduate biochemistry education, focusing on traditional and modern methods of teaching to enhance learning while using technology. All these studies support the idea of conducting further educational research on improving undergraduate teaching of science and highlight the need to explore new methodologies. This statement provides the framework for my own study reported in this book.

[1] Meta-analysis is a retrospective analysis of a variety of studies that address related research hypotheses (Wikipedia 2010).

2.3.4 *Preparing Future Teachers of Science and Mathematics*

2.3.4.1 United States' Goal for K-12 in Science and Mathematics

In 1991, the United States set a goal, "by the year 2000, United States will be first in the world in mathematics and science achievement" at the K-12 level (Goals 2000, 4, p. 1, 2010). As a measure of the international standing of participating countries, the Trends in International Mathematics and Science Study (TIMSS)[2] conducted studies internationally in 1995, 1999, 2003, and 2007. In all four studies, the basis for comparison among the participating countries included both qualitative and quantitative data.

TIMSS concludes for 2007 at the eighth grade level, the US average score (520) in science is higher than the international average (500) of the countries reporting (National Center for Educational Statistics, n.d.). However, the United States is not in the top group of nine statistically higher scoring countries[3] but in the middle group,[4] with scores not measurably different from each other. Thirty-five countries statistically score lower than the middle group's scores.

The performance of US fourth graders in science is ahead of 25 peer countries from 35 participating countries reporting (National Center for Educational Statistics, n.d.). The US average (539) is higher than the international average (500) of participating countries. Three countries are ahead of the United States: Singapore, Chinese Taipei and Japan. The US average score for fourth graders in science is comparable to that of six other countries: Russian Federation, Latvia, England, Hungary, Italy, and Kazakhstan.

When comparing the upper echelon of students in each country reporting (National Center for Educational Statistics, n.d.), the United States does score 15% of its students at the advanced benchmark in fourth grade science, with the international average at 7%. At the eighth grade science level, 10% of US students scored at the advanced benchmark, compared to the international average of 3%. These data at the advanced benchmark are a hopeful sign for the United States.

Although the United States set the goal in 1991 to be first in the world in science, we still are in the middle group of countries. Therefore, the United States is not in the upper echelons of science with K-8 students, which was our goal.

In comparison with TIMSS, an international group, in 2006, the Program for International Student Assessment (PISA), uses more theme-based questions than discipline-based questions in their assessment of science literacy of 15-year-old

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[2] TIMSS, formerly the Third International Mathematics and Science Study, is now called Trends in International Mathematics and Science Study: http://nces.ed.gov/timss/.

[3] The nine countries performing statistically higher in eighth grade science than the USA include Singapore, Chinese Taipei, Japan, Republic of Korea, England, Hungary, Czech Republic, Slovenia and Russian Federation.

[4] There are three countries whose scores are not statistically distinguishable in eighth grade science from that of the United States: Hong Kong SAR, Lithuania, and Australia.

students in 55 countries. PISA focuses on testing students within a 1-year age span rather than at a particular grade, as used with TIMSS. PISA found that US 15-year-olds are below many other industrialized countries. The average international score is 500, with the top country, Finland, scoring at 563. The next tier of six countries include Canada, Japan and New Zealand, Hong Kong-China, Chinese Taipei, and Estonia, with mean scores between 530 and 542. The next tier, still above the international mean, include Australia, the Netherlands, Korea, Germany, the United Kingdom, the Czech Republic, Switzerland, Austria, Belgium and Ireland, and the partner countries/economies Liechtenstein, Slovenia and Macao-China. The US scores at 489, below the international average.

These data show that the scores of our budding population of students in high schools are well below those of most industrialized countries (refer to Table 2, available at http://nces.ed.gov/timss/, which compares National Assessment of Educational Progress (NAEP), TIMSS, and PISA in Mathematics and Science). Many of these 15-year-olds plan to attend college; however, they are not prepared to learn science at the college level at the competency that we in the United States expect or desire. Green and Forster (2003) indicate than only 70% of US students graduate from high school, and only 32% are ready to attend 4-year colleges.

The US high school graduation rate pales in comparison to the rate in Singapore where over 90% of the population graduates from high school. Singapore is one of the top countries in the world in mathematics and science. I spoke with Leo Tan, Director of the National Institute of Education, at their *Redesigning Pedagogy: Research, Policy, Practice* international meeting in June 2005 in Singapore. Tan said that Singapore's most important natural resource is its people; consequently, that is the resource in which Singapore invests. For instance, Singapore's Ministry of Education encouraged and financially supported over 2000 K-12 teachers (which is 10% of all K-12 teachers in their country) to attend and many to present their action research at the pedagogy conference. Conference organizers selected a group of the world's best educators to speak at the conference for their teachers as well as for the approximately 400 others from around the world, choosing to attend, like myself.

The United States could improve the standing of its K-12 students in numerous ways if it: (i) improves teacher preparation in science; (ii) enhances alternative teacher certification of practicing scientists and other professionals; (iii) augments teacher professional development for practicing teachers; and (iv) involves more scientists, especially younger ones like those in the NSF-funded GK-12 programs, involved in K-12 education. College science faculty should become involved in such K-12 efforts. If college science faculty members take the time to learn about teaching and learning and bring those ideas to their own classrooms, their college students would benefit. If some of these college faculty's students were prospective or practicing K-12 science teachers, the K-12 teachers could bring ideas for enhanced science learning to their K-12 students.

In comparing K-12 science curricula of the United States with those from countries that do better in international assessments, the US curriculum covers many more topics than from other countries, particularly Japan. At first, having expansive curricula might appear to be optimal, but, in fact, this practice makes gaining depth of understanding in a subject very difficult for our US students (TIMSS 1999, 2003). The US schooling system is diverse with over 15,000 school districts. These districts make their own curricular decisions using local authorities, school boards, and committees (Berliner 2001). Some US cities pay to be tested separately by TIMSS, and some of these schools have students among the top in the world. The theoretical purpose of the US mandate of *No Child Left Behind* (NCLB) is to remove inequities for students in mathematics and reading. However, while implementation of the law may help the lowest achieving students, in my opinion, the highest achieving students are not challenged sufficiently. Darling-Hammond (2007) evaluates the NCLB initiative:

> As Gloria Ladson-Billings, former president of the American Educational Research Association, has noted, the problem we face is less an "achievement gap" than an educational debt that has accumulated over centuries of denied access to education and employment, reinforced by deepening poverty and resource inequalities in schools. Until American society confronts the accumulated educational debt owed to these students and takes responsibility for the inferior resources they receive, Ladson-Billings argues, children of color and of poverty will continue to be left behind.

Since the United States, on average, is weakest in science with the 15-year age group (approximately, tenth grade of high school), many researchers focus their energy on improving teacher preparation for secondary (sixth through 12th grade) science teachers. Preservice secondary science teachers generally take their undergraduate science courses along with future scientists. Therefore, the methods we employ in teaching undergraduate science classes affect these future teachers' ideas on their understandings, processes, and conceptions of science. Scientists teaching undergraduate science courses should be aware of implementing new theories concerning (i) how people learn (Bransford et al. 1999), and (ii) the seven principles of learning (NRC 2003). If college and university science faculty members did improve teaching and learning using these techniques, the effects could influence not only the future scientists but also our future science teachers (and their future students).

2.3.4.2 Improving Teacher Preparation in Science

The charge of the NRC-constituted Committee on Science and Mathematics Teacher Preparation was to identify "critical issues in existing practices and policies for K-12 teacher preparation in science and mathematics" (NRC 2001, p. xiii). The committee focused on preparing future teachers of science and mathematics. Additionally, the committee addressed the methodologies by which the university and college faculty teach Science, Mathematics and Technology (SM&T). The basic responsibility of this committee was to review the research literature and make recommendations in five categories for: (i) governments; (ii) collaboration between institutions of higher education and the K-12 community; (iii) the higher education community; (iv) the K-12 education community; and (v) professional and disciplinary organizations.

The first three recommendations (out of five) on teacher preparation in science, mathematics, and technology from the NRC for the higher education community include:

1. Science, mathematics, and engineering departments at 2- and 4-year colleges and universities should assume greater responsibility for offering college-level courses that provide teachers with strong exposure to appropriate content and that model the kinds of pedagogical approaches appropriate for teaching that content.
2. Two- and 4-year colleges and universities should reexamine and redesign introductory college-level courses in science and mathematics to better accommodate the needs of practicing and future teachers.
3. Universities whose primary mission includes education research should set priority on the development and execution of peer-reviewed research studies that focus on ways to improve teacher education, the art of teaching, and learning for people of all ages. New research that focuses broadly on synthesizing data across studies and linking it to school practice in a wide variety of school settings would be especially helpful to the improvement of teacher education and professional development for both prospective and experienced teachers. The results of this research should be collated and disseminated through a national electronic database or library. (NRC 2001, p. 12)

The fourth and fifth recommendations, while not pertinent to my work, relate to interactions between 2- and 4-year colleges and universities.

I served on the NRC committee that issued this report at the same time as I was conducting the action research in my biochemistry classroom for this book. The NRC staff sent each committee member a different set of readings and asked each of us to read them critically and write no more than a two-page report. I list below my conclusions from the readings for the NRC Committee. I provide these points here to show my thinking during the semester in which I did the action research reported in this book. Many of my suggestions cited below became part of the NRC report (2001).

1. Encourage teachers to become reflective practitioners, using self-reflection in classroom-based research to enhance their teaching and encourage lifelong learning.
2. National Science Teachers Association (NSTA) Standards for the Education of Teachers of Science (NSTA 1998) were comprehensive, incorporating ideas from the National Science Education Standards, and included the following aspects: content; nature of science; inquiry; context of science; pedagogy; science curriculum; the social context; professional practice; learning environments; [and] assessment.
3. NSTA (1998) delineates the importance of prior cognitive states of the learner, encouraging a constructivist epistemology; and Shulman's pedagogical content knowledge: knowing how to teach the content so students learn.
4. Teachers should introduce the context of science back into science courses. This can be done utilizing technology or selecting topics that impact the community of students.

5. It is important to develop a community of learners, in which everyone can learn, and students can learn from each other. Collaborative learning encourages students to communicate, make sense of data, and learn from each other.
6. The methods of assessment drive what students learn; utilizing multiple forms of assessment using diagnostic, formative, and summative strategies, encourages multiple ways for students to learn.

Two of the ideas listed above, I incorporated in my biochemistry classroom. The fourth suggestion listed above relates to Chapter 6, where I discuss the use of technology to improve learning in my class. Using technology helps students communicate ideas and see the relevance of biochemistry in the real world. Also the fifth suggestion listed above relates to Chapter 5. In that chapter, collaborative groups improve the students' learning. Through group work, students need to use the language of science, both spoken and written, to help them construct meaning that makes sense to them so that they can understand and apply this knowledge. The NRC (2001) published our final report as a book, *Educating Teachers of Science, Mathematics, and Technology: New Practices for the New Millennium*.

The NRC (NRC 2003) published another book, *Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics*, that recommends "a set of strategies to evaluate undergraduate teaching and learning" (p. 1) in STEM fields. This includes recommendations to university/college presidents, overseeing boards, and academic officers; deans, department chairs and peer evaluators, as well as granting and accrediting agencies, research sponsors and professional societies. Because preservice science teachers, especially those preparing to teach in middle and high schools, take science courses with science majors, this NRC book is an important resource for faculty who teach such classes and for those evaluating such faculty.

Three other more recently published books also have research on teaching science to future teachers.

One is a book on which I am one of the co-editors with Peter C. Taylor and Kenneth Tobin is *Transforming Undergraduate Science Teaching: Social Constructivist Perspectives* (Taylor et al. 2002). Eight of the 17 chapters relate to teaching prospective teachers. A handy table in the preface shows the site and other specifics of each research project.

A second one on this topic is *Reform in Undergraduate Science Teaching for the 21st Century* (Sunal et al. 2004), which focuses on (i) lessons from research on reform, (ii) perspectives on reform, and (iii) innovative models for reform, in undergraduate science. Many chapters from both books comprise research funded by grants from the NSF or the NASA to improve undergraduate teaching.

In a third book, Druger et al. (2004) co-edited *Teaching Tips: Innovations in Undergraduate Science Instruction*, which contains short, practical pieces on methods to improve college science teaching. These ideas could be useful in a variety of science classrooms, including those attended by prospective science teachers.

Therefore, by consulting the suggestions from the NRC books and the three other edited books mentioned above, college and university science faculty gain fuller insight into ways to improve the teaching and learning in their classrooms.

2.4 Introduction to Case Study of a Biochemistry Classroom

My goal for my students was not merely for everyone to pass all the tests; but rather, I wanted my students to learn *how* to learn. Based on the ideas of social constructivism, I hoped that my students would connect the new material to their prior learning and see the relationships between biochemistry and other sciences as well as biochemistry's connection to the world around us. I wanted my students to use the language of science while they constructed meaning through a multifaceted approach of: (i) discussing science concepts with each other; (ii) making presentations and listening to other group's presentations, and (iii) writing about learning on their group-constructed Web sites. I provided opportunities for my students to construct their own connections, enabling them to weave the various strands of biochemistry together as if it were a beautiful quilt or basket.

So, I asked myself, how could a teacher accomplish these goals? How could I teach my students *how* to learn? To accomplish this task, I needed to find new ideas. Initially, I read literature from across the spectrum of science education. Eventually, I realized that the sociological literature provided me the framework I needed. After reading extensively, I began to formulate ideas on methods I might use for implementing these goals in practice.

One possible way to help my students learn *how* to learn was immersing them in a peer-collaborative setting. Using collaborative learning resonated with me because of my prior experiences as a graduate student in biochemistry, conducting collaborative research at the interface of two research areas (Gilmer 2004, 2007). Also because of the insight of cultural historical activity theory (CHAT, discussed more in Chapter 3), I grew more interested in providing my students with a community of learners – or a "structure" as Sewell (1992) states to enhance the students' sense of agency. Through CHAT, I could encourage collaborative learning, a fair division of labor among the students within a group and between my students and me, and provide tools such as technology and use of the language (Wertsch 1998) of science for learning.

Utilizing theories in education provides a critical framework for creating high quality studies. Not until after I became immersed in science education did I fully realize the importance of educational theories in practical education. Of course, in scientific research, using scientific theories is commonplace; however, educational theories were new territory for me, and I suspect that similarly, many other scientists teaching undergraduates know little of educational theories. For those readers wanting to learn more about available educational theories, let me refer you to a book edited by Bodner and Orgill (2007). In Chapter 3, I also discuss in more detail the educational theories that I used as the framework for this study.

One motivation for my study is to better prepare future secondary science teachers. As a university professor, I am in a position not only to change the way that I teach my own students (Macala 2003; Adamson et al. 2003), but also, to develop a model for university and college faculty members on transforming their teaching methodologies so their students become active, lifelong learners. This book is part of my effort to disseminate my learning to help other scientists change their teaching so students become more engaged in learning. By teaching students thinking-skills in addition to science facts, students can connect better with the material and utilize critical thinking skills in their lives as professionals and as individuals.

Overall, in order to report on action research in my own biochemistry classroom, I utilized three frameworks: (i) social constructivism (Tobin and Tippins 1993; Taylor et al. 2002) as a referent for transforming student learning; (ii) cultural historical activity theory (Engeström 1999); and (iii) the theory of structure|agency (Sewell 1992, 1999; the symbol, |, denotes a dialectic between structure and agency). Additionally, I encouraged my students to use the discourse of science in collaborative learning groups, in oral presentations and through use of electronic portfolios. Each student group developed ten Web sites and presented three of them to the other students during class. Some collaborative groups displayed a fair division of labor within their groups, and others did not (note: I did help two groups with intergroup communication and division of labor). I tried to provide my part of the division of labor, as the teacher, through organizing and presenting overviews of chapters. I also provided the students with evaluations on their presentations in a timely fashion.

Typically, the rules or schemas that three examples of feedback given to one collaborative group are at http://www.chem.fsu.edu/~gilmer/downloads.html) influence human interactions in current college science classrooms encourage students to memorize facts. However, I am attempting to change the teaching and learning culture by encouraging my students to construct meaning in an open learning environment (Hannafin et al. 1999). This book chronicles my attempt by providing a case study of the action research I undertook in my classroom.

2.4.1 How Do I Frame the Study?

This study provides a sociocultural theoretical perspective that includes ideas, such as agency, cultural capital, habitus, strategies of action, social production and reproduction, autonomy, power, voice, negotiation, sense making, descriptions of experience, and mediation of learning. Some of the critical works that influenced my thinking include those of Bourdieu (1991, 1993, and a helpful summary of Bourdieu's ideas by Grenfell and James 1998), Bruffee (1993), Engeström (1987, 1999, 2001), Engeström et al. (1999), Gallagher (2000), Glasersfeld (1989, 1995), Lemke (1995, 2001), Mezirow and Associates (2000), Roth (1993), Schön (1983), Sewell (1992, 1999), Swidler (1986), Taylor (1993), Tobin and Tippins (1993), Tobin et al. (1994), and Vygotsky (1981).

The theory of social constructivism (Taylor et al. 2002) summarizes my new approach to education. Through implementing this theory in my classroom, I transformed my teaching and, consequently, my students' learning. My focus was on the discourse of teaching and learning, utilizing collaborative learning, reflective writing in electronic portfolios, and use the technology to enhance learning. I encouraged my students to use the language of science, and the process facilitated their constructed meanings in learning. In these portfolios, students needed to write their own biochemistry question(s) still in their minds after concluding their research of a biochemistry topic. This provided me insight in terms of their learning progress. Additionally, I had the students make oral presentations on biochemistry. In my analysis of the research, I focused on addressing sociocultural issues, such as agency, tools, communities, division of labor, rules or schemas, co-participation, shared language, and discursive resources. In Chapter 3, I discuss these ideas in greater depth.

Sewell (1992) also highlights the sense of "agency" of the subjects (e.g., my students), learning their "objects" (i.e., learning biochemistry), and moving toward their "outcomes" (i.e., graduating and moving to the next phase of their lives). In Chapter 3, I interconnect cultural historical activity theory and a theory of structure|agency in order to organize, analyze, and make sense of the qualitative data.

The final data chapter, Chapter 7, contains a metalogue between a biochemistry colleague and me. By our discussion, he helps me understand several problematic issues taking place in the teaching and learning in my biochemistry classroom. Bateson (1972) developed the idea of a metalogue as "a conversation about some problematic subject. This conversation should be such that not only do the participants discuss the problem but also the structure of the conversation as a whole is also relevant to the same subject" (p. 1). Bateson's daughter described metalogue in another way, as "a conversation that deals with some aspect of mental process; ideally, the interaction between the interlocutors exemplified the subject matter" (Roth et al. 1998, p. 108). In our case, this interaction encouraged reflexivity and allowed my colleague to address issues he wanted to address. He and I took the time and effort to examine these issues in writing. Using the format of a metalogue, I utilized the hermeneutic circle, which empowered my biochemistry colleague, a stakeholder, to address his concerns and suggestions, so we could learn from each other's perspectives. Also, hopefully, this metalogue provides insight to the reader into the culture of teaching in a university science department.

2.4.2 What Are My Research Questions?

In this action research study, I delve into the environment in my classroom in the context of both teaching and learning. Also, I examine the impact of my research on my biochemistry colleagues at my university.

To thoroughly investigate these topics, I construed two evolving research questions that address methods that might enhance my students' conceptual understanding and interest in biochemistry:

1. How does work in collaborative groups influence learning?
2. How do the uses of technology and the Internet influence students' learning of and interest in biochemistry?

I devised two additional research questions, addressing my own personal transformation as a university teacher:

3. What can I learn about my teaching through doing action research in my classroom?
4. What are the sources of the transformation in the enacted curriculum?

These four questions guided the study I conducted and from which I learned.

2.4.3 What Options Could I Choose to Transform My College Teaching?

Some options that college faculty have to change the ways we teach science to undergraduates include:

1. Conducting action research in our own classrooms (Gilmer 2002; Gardner and Ayres 1998; Humerick 2002; White 2002)
2. Attending workshops, conferences, and forums on the new methods of teaching, such as at the annual meetings of the American Association for the Advancement of Science, the National Association for Research in Science Teaching, the Association for Science Teacher Education, or a Gordon Conference on college science teaching
3. Reading and learning from the educational research literature (Taylor et al. 2002; Sunal et al. 2004), or helpful tips on teaching at the undergraduate level (Druger et al. 2004), and science education journals, such as the *Journal of Research in Science Teaching*, *Science Education, International Journal of Science Education,* or the *Journal of College Science Teaching* (plus other journals within the professional disciplines, such as the *Journal of Chemical Education*)
4. Inviting science educators to conduct an evaluation of our teaching (Abbas et al. 2002)

From these four possibilities, I decided that conducting an action research study provided me with the opportunity for personal growth as a science educator. I did also incorporate the second and third options listed above; however, individually, these were not enough stimuli for me to grow sufficiently. I chose to focus my attention on conducting action research with my own students. Through this research, my classroom became a testing ground for ideas about which I was reading. Instead of the fourth option, having someone else evaluate my teaching, I chose to study my own classroom.

Action research is a way to study a situation in which you are immersed. In essence, I conducted the research while I participated actively. Action research is a form of research in which the researcher studies his/her own situation, which may be a classroom. Collins and Spiegel (1997) define action research in relation to its founder, Lewin (1946), a social scientist:

> Lewin described action research as a spiral of circles of research that each begins with a description of what is occurring in the 'field of action' followed by an action plan. The movement from the field of action to the action plan requires discussion, negotiation, exploration of opportunities, assessment of possibilities, and examination of constraints.

> The action plan is followed by an action step, which is continuously monitored. Learning, discussing, reflecting, understanding, rethinking and replanning occur during the action and monitoring. The final arc in the circle of research is an evaluation of the effect of the plan and action on the field of action. This evaluation in turn leads to a new action plan and the cycle of research begins anew. (p. 61)

You might be asking, what drove a full professor of chemistry and biochemistry to undertake action research in her science classroom? To be honest, I became interested in improving education when I saw K-12 teachers engaging in action research in our NSF-funded Science FEAT Program from 1993 to 1995. I thought if the middle school teachers in our program could do action research (Spiegel et al. 1995) and learn so much, should I not be able to do the same? Some examples of K-12 teachers engaging in action research include: Spiegel et al. 1995; McDonald and Gilmer 1997; Sweeney et al. 2001. University and community college faculty (Gardner and Ayres 1998; Glaser and Poole 1999; Gilmer 2002; Humerick 2002; White 2002; Williams 2002) utilize action research in their classrooms.

I conducted action research for the first time in 1995, but I did not start to write any of the research for presentations and publication until 1999 (Gilmer 1999a, b, c, Gilmer, 2000a, b, c, 2002). Just as I felt inspired by the action research and its results for K-12 teachers, I hoped with this work to encourage other college and university faculty to participate in action research in their classrooms.

The focus for this action research study reported here was finding a way to get my students see the relationship between the science they were learning in the classroom and the real world by using the language of science. To accomplish this goal, I pondered the questions, how do collaboration and use of technology influence my students' learning? How does action research affect my teaching and my own learning? After much contemplation and analysis of my data, I realized I needed to make changes to succeed in my goals. Some of these changes occurred during the semester I taught the course, and others came afterwards, once I had a chance to reflect on my experiences in the classroom.

Moreover, my initial writing in this case study (Gilmer 1999a) involved my interacting with former students by e-mail after the conclusion of the class and several years later conducting the first segment of a metalogue with one of my biochemistry colleagues. These interactions coupled with my own personal reflections continued to influence my teaching. Instead of gaining insight once from my study, this study continued to provide ongoing development and understanding of my teaching, which continually altered both my learning and my teaching.

My educational research took place at Florida State University (FSU), where I serve as professor of chemistry and biochemistry. Undergraduate juniors and seniors, majoring in chemistry, biochemistry, food and nutrition, engineering, and biology, typically enroll in the biochemistry course in which I conducted my action research. Most of my students were undergraduates, for whom this course was a requirement for graduation. However, additionally, several graduate students enrolled in the course as well. Four of my 34 students were prospective secondary science teachers. I decided to model my biochemistry class on current research in science education and learning theory, utilizing materials that I have referenced in this book as a model.

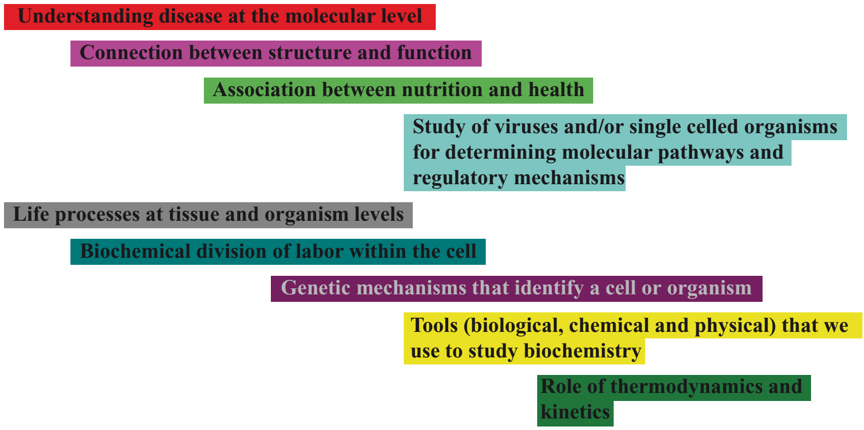

Fig. 2.1 Common strands in biochemistry (the nine strands that I hoped my students would be able to weave together to construct an understanding of the basic processes of biochemistry)

I wove these critical ideas, which are described in this book, into my teaching. Instead of devising a controlled, positivist-framed study (as I had done for my first doctorate in biochemistry), I chose to incorporate many research findings. With Ken Tobin's advice, I enacted multiple changes into my classroom, such as collaborative learning, use of technology, use of language of science, and relevance to the real world. Because of the multiple aspects I incorporated, a direct comparison to my earlier classrooms is hard to accomplish. However, perhaps because of the multiple changes, teaching in my classroom worked better than if I had just enacted one change in one semester and another change in another semester.

One of my goals was to convey to my students the big ideas or common strands in biochemistry (Fig. 2.1), so that the students could synthesize for themselves the "unifying concepts and processes in science" (NRC 1996, p. 6). Early in the semester, I had a dream in which I was teaching the class. In the dream, my students wove together a beautiful braid using the common biochemistry strands! In the classroom, the morning after having the dream, I explained my dream and presented the strands and different colors for each strand to my students (Fig. 2.1).

By the end of the semester, I hoped my students could weave these different strands or concepts together, seeing the components but also simultaneously picturing the whole of biochemistry.

2.4.4 What Genres Should I Use?

In order to share my learning, I had to choose engaging formats for you, my reader. I became a bricoleur, a person creating her own ways using a variety of genres. For this book I chose three different genres with which to illustrate my university-level biochemistry classroom. From these accounts, the reader can synthesize the full experience within my classroom. The different genres are:

1. I write a *fictionalized story* in Chapter 4 (Goldberg 1990; Stern 1991; Burroway 1996; Polkinghorne 1997) from the perspective of an undergraduate student on the learning and social environment in my classroom. In the story, I focused on problematic issues of using technology in collaborative groups in my classroom.
2. I use ethnographic tools to combine my students' opinions of the class. Using the Learning Environment Questionnaire (LEQ), Collaborative Learning Surveys (CLS), e-mails, and electronic portfolios, students shared their thoughts about collaborative learning (Chapter 5) and use of technology (Chapter 6) in our biochemistry classroom.
3. I have a *metalogue* in Chapter 7 (Bateson 1972) with one of my biochemistry colleagues, Robley Light, on the problematic issues of bringing reform in the teaching and learning of science to higher education.

Using these three genres, I gained insight from my students and colleague about their opinions and perceptions on the class and ideas on methods I might employ to improve my teaching in the future. While those genres greatly aided my efforts, I wonder if this variety of genres enhances or inhibits learning for other scholars, for the information this study provides.

Additionally, I originally utilized a fourth autobiographical lens, as part of my doctoral thesis (Gilmer 2004). While this autobiographical piece is not within this book, I publish the account elsewhere (Gilmer 2007), and the autobiographical lens integrates well with the three genres presented here. I comment further on the autobiographical lens in this book in Chapter 8.

In order to push the envelope for science education reform beyond K-12 to the university level, I experiment with various literary representations in my research. By breaking from the more traditional, positivist ways of reporting science education research at a university level, and instead, framing such research in a postmodern context, I believe that we can grow more fully and can progress more holistically in the education of our undergraduate students and future K-12 teachers. In such a context, I hope to break disciplinary boundaries between the College of Arts and Sciences and the College of Education. I try to reach these borders (Davis 2001; Roth and Tobin 2002) and then become a "border crosser" (Giroux 1992), moving back-and-forth between the cultures of science and of education, learning from both, but also not closing the door on either one.

Throughout constructing this book, I continued to reflect further. What were the constraints on students' learning? What were the contradictions and the coherences in the students' learning? And what more could I learn about my teaching and about myself? Motivating me to use these different genres, in part, was reading Schön's work (1983) in which he writes about "reflection-in-action." Schön professes:

> The dilemma of rigor or relevance may be dissolved if we can develop an epistemology of practice which places technical problem solving within a broader context of reflective inquiry, shows how reflection-in-action may be rigorous in its own right, and links the art of practice in uncertainty and uniqueness to the scientist's art of research. (p. 69)

The task before me is to utilize reflexivity by looking critically at myself as the teacher and action researcher. As Lincoln and Guba (2000) say so concisely, "[Reflexivity] is a conscious experiencing of the self as both inquirer and respondent, as teacher and learner, as the one coming to know the self within the processes of research itself" (p. 183). By using these different genres in my writing, I am able to engage in dialogic[5] interaction with the genres I used, concerning various aspects of myself and of my roles in this study. Through these qualitative approaches, I am able to reflect and gain insights from these various points of view, which, in turn, help me to improve my teaching of the sciences.

2.4.5 What Is This Study's Significance?

The significance of my study is threefold; action research can be expressed in terms of (i) improving the teaching and learning in my own classes; (ii) providing insight on using social constructivism, cultural historical activity theory, and theory of structure|agency as theories for exploring one's teaching; and (iii) using these theories as referents for developing learner-sensitive pedagogy.

Through this action research concerning both teaching and learning, I hope to make a positive impact on my students, including future science teachers in my classroom. By examining various perspectives on teaching and learning, we could come to some understanding on ways to improve science education. Instead of remaining at the current status quo for college education, I hope my action research will inspire others to thoroughly investigate their own teaching practices, their students' learning successes and failures, and their role in the process of shaping future scientists and science teachers. Additionally, I hope my research reflects the need for colleagues from the Colleges of Arts and Sciences and the Colleges of Education to collaborate with each other.

The teaching methods that university scientists use influence the toolkit of ideas that our future K-12 science teachers employ in their own classrooms, thereby influencing the learning of future K-12 students (Adamson et al. 2003). Instead of merely practicing cultural reproduction, we ought to continue to grow and remain flexible to new currents and ideas (Bourdieu 1993; Grenfeld and James 1998).

The NSF boldly states in its report, *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering and Technology* (1996), that in our undergraduate science, mathematics, engineering, and technology education, "we can no longer be satisfied with incremental improvement in a world of exponential change" (p. 60). This powerful charge from the NSF shows the drastic need for continual improvement in the teaching of the sciences and continues to motivate me to constantly enhance the learning environment in my own classroom. I hope my action research also provides the impetus for others to get involved in improving science education.

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[5] Dialogic pertains to an ongoing dialogue with various works of literature, or in this case, genre.

Chapter 3
Developing a Research Practice

3.1 Preview

This chapter describes the development of my research practice, which includes my theoretical framework, methodology, method of analysis, and quality criteria in my study. The theoretical framework is critical as it sets the stage for the methodology, which in my case was qualitative and thereby influenced my method of analyzing the data and my quality criteria.

My professional background before starting this study was as a practicing, quantitative biochemist, yet I chose to study my teaching and my college students' learning of biochemistry. Therefore, I needed to become a qualitative educational researcher. To do so, I needed to learn theoretical frameworks and associated methodologies in order to design, conduct, and analyze the activities and learning in the classroom.

Taking part in discourse communities in Web-enhanced courses in science education helped me shift from being a practicing scientist to becoming a science educator using a qualitative methodology. Interacting with my fellow science education graduate students in a hermeneutic[1] dialectic circle in which we would explain ideas and concepts to each other, while reading Guba and Lincoln's 1989 *Fourth Generation Evaluation*, allowed me to begin this change. During my initial reading of Guba and Lincoln's text, as a quantitative scientist, I felt I was driving into a brick wall – since for a positivist like me, engaging in ontological and epistemological questions about the nature of knowledge was difficult. Through these struggles I found the energy to think about knowledge differently and to learn to value qualitative data.

Lemke (2001) was particularly influential in my choice of a sociocultural perspective in this research project. His ideas about how we construct our knowledge in a social setting with social interactions shaping our ideas, fit with my growing epistemology. As Lemke says,

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[1] Hermeneutics means all within the interpretive process, including all written, verbal, and nonverbal forms of communication.

P.J. Gilmer, *Transforming University Biochemistry Teaching Using Collaborative Learning and Technology: Ready, Set, Action Research!*, DOI 10.1007/978-1-4020-4981-1_3,

> I am writing from a particular social position, making meanings that are shaped by the kinds of life experiences people in my position tend to have. Whatever I write is written from a viewpoint within the culture and subculture to which I belong. I do not, no one can, write from an objective God's-eye view. No one sees *the* world as *it is*. We see the worlds our communities teach us how to see, and the worlds we make, always a bit uniquely, within and sometimes just a bit beyond what we've been taught. (p. 4)

Therefore, my theoretical perspective influenced the questions I asked, the observations I saw, the reflections I made, the methods I employed, and the conclusions I reached. Therefore, theories are critical in guiding our educational research.

I describe three theoretical referents that influenced my thinking and were critical theoretical referents for me: social constructivism, cultural historical activity theory (CHAT), and a theory of the structure and agency dialectic (written as structure | agency).

3.2 Choosing Theory as a Lens to Inform Research Practice

Over the course of becoming engaged in educational research, which took me a significant period of time (6 years directing educational research grants, followed by 6 years in my degree program), my theoretical framework changed significantly. My ideas not only changed greatly during the study, but also shifted during the analysis and final writing of the doctoral thesis. However, a theoretical perspective implies an internally coherent system, free of contradictions.

3.2.1 Matrix of Theoretical Frameworks

Table 3.1 displays a matrix, indicating various theoretical frameworks that I used, which allowed me to seek answers to my research questions. Using these theoretical frameworks I became a bricoleur, "a maker of quilts" (Denzin and Lincoln 2000b, p. 6), as I pieced together aspects of various theoretical frameworks or referents.

In this section, I discuss the theoretical perspectives that I used. I utilized two theoretical frameworks during the study, but as I analyzed the data, I realized that I had to additionally use sociocultural theories to understand the human interactions. The following is a description of these theoretical perspectives, starting with the ones I first used.

3.2.2 Theoretical Perspectives Utilized

3.2.2.1 Radical and Social Constructivism

Constructivism is a theory of knowing in which the knower constructs his/her own knowledge. Constructivism had its start in metaphysics almost three centuries ago in a treatise entitled, *De antinquissima Italorum sapientia* (Vico 1710, described by

Table 3.1 Theoretical referents utilized for the four research questions

Theoretical referent	Question 1: collaboration	Question 2: technology	Question 3: action research	Question 4: transformation
Glasersfeld: radical constructivism	Perturbation by interactions with others		Bodner: key to fit a lock	Piaget: perturbation to equilibrium; Bodner: key to fit a lock
Solomon; Tobin and Tippins: social constructivism	Solomon: social influences are pervasive; Tobin and Tippins: constructivism as a referent	Solomon: social group mediates knowledge construction	Solomon: use discourse of discipline; Tobin and Tippins: empowerment of teachers	Evolution rather than revolution
Tobin: communities of practice	Gallagher: Mercedes model; students in groups move toward deeper learning; Erickson: science as new dialect	Lemke: Using discourse of science; Wenger: ways to engage students	Tobin: co-participation; Wenger: learning as part of a learner's life	Giroux: reason and science as part of broader struggle over relationship between language and power
Habermas: communicative action	Taylor and Williams: communicative action to emancipate teachers and students from disempowering frames of reference		Taylor and Williams: communicative action to emancipate teachers and students from disempowering frames of reference	Habermas: critical discourse on hidden frames of reference
Sewell's theory of structure | agency	Sewell: components of structure to set up a conducive environment for collaborative learning so students can develop their own sense of agency	Sewell: addressing the tension between the structure I set up in my classroom and my own agency as the teacher		

(continued)

Table 3.1 (continued)

Theoretical referent	Question 1: collaboration	Question 2: technology	Question 3: action research	Question 4: transformation
Engeström: cultural historical activity theory	Bruffee's ideas on non-foundational knowledge; Vygotsky's emphasis on dynamics of learning through social interactions; community of students	Students worked in social groups to develop Web sites; Vygotsky: culmination of the ideas into a powerful system of thinking about social interactions; tools include technology, WWW, and language of science; community of students with common goals	Polkinghorne: "call attention to the sphere of culture as a shifting social and historical construction;" subtle changes within science to get best understanding; "blurring of the genres;" multiple dimensions of life experiences; contradictions; division of labor among students and with me	Polkinghorne: Loss of faith in logical reasoning; "transgress the borders sealed by modernism;" a "plurality, difference and multinarratives;" postmodernism "reflects and contributes to the unstable cultural and structural relationships"

Glasersfeld 1989), but was disregarded until Piaget (1967) independently proposed a constructivist theory of cognitive development and cognition. Glasersfeld (1989) summarizes Piaget's contribution:

> The learning theory that emerges from Piaget's work can be summarized by saying that cognitive change and *learning* take place when a scheme, instead of producing the expected result, leads to perturbation, and perturbation, in turn, leads to accommodation that establishes a new equilibrium. (p. 128)

In this way, constructivism shows learners striving to adapt and connect new knowledge to the surrounding world. Instead of knowledge existing in a vacuum, constructivism points to "the manner in which knowers construct *viable* knowledge, that is knowledge that enables an individual to pursue goals in the multiple contexts in which actions occur" (Tobin and Tippins 1993, p. 4). Therefore, knowing becomes an active pursuit as does understanding knowledge itself.

A way to think about the difference between radical constructivism and realism is that with radical constructivism learning knowledge is searching for a *fit* with reality rather than searching for a *match* with reality. Bodner[2] (1986), another chemist, uses the analogy of a key, saying that constructivism allows a number of keys to *fit* a lock, so that for given knowledge more than one construction exists among individuals. However, with the traditionalist or realist view of knowledge, the key has to *match* the lock, so *only* one key is the right shape for that lock, implying only one view of reality or a "Truth." This epistemological difference, whether knowledge has many keys or just one key, has many ramifications on the way in which one approaches one's own understanding of epistemology and the ways by which humans come to know.

Solomon (1987) combines the importance of social interaction in the construction of knowledge, creating social constructivism. As the founder of social constructivism, Solomon states:

> All aspects of this subject indicate that social influences are pervasive and strong, and that they spring from a familiar uneradicable style of knowing which can discourage access to the realm of scientific thinking. But the problem cannot be avoided. Our pupils are strongly social beings for whom the teaching of a rigidly insulated science[,] which makes no contact with the everyday context is simply not an option. Social influences of every kind permeate both the learning of science and its application. (p. 79)

The major difference between radical and social constructivism involves agency. In social constructivism, the social group is the agent that devises a *viable* knowledge construction, while in radical constructivism the individual constructs the knowledge.

Tobin and Tippins (1993) provide two statements on constructivism: "Constructivism, as a set of beliefs about knowing and knowledge, can be used as a referent to analyze the learning potential of any situation," (p. 8), and "Constructivism,

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[2] George Bodner writes about radical constructivism for a chemical audience. He specifically addresses understanding chemical concepts using constructivism as a theoretical referent. He refers to earlier publications by Cobb and Glasersfeld (1983) and by Glasersfeld (1984).

as a reflective tool, empowers teachers and enables them to fashion learning activities to the circumstances in which they find themselves" (p. 8). Reading Tobin and Tippins, as a teacher and professor, empowered me to think about my classroom differently. Instead of wanting my students simply to import my own understanding of the subject matter, I realized students needed to construct their own meanings, in order to understand and remember the science content. Therefore, I, the teacher, can use a theory of learning to help me to construct the learning environment in my classroom.

Tobin and Tippins (1993) reiterate the power of social constructivism:

> To be a viable theory of knowing, constructivism must have explanatory power in all situations where knowledge is constructed or cognizing beings are deemed to know… Similarly, constructivism ought to be useful in predicting how any given set of circumstances might be changed to improve the opportunities of persons who wish to learn in such situations. (p. 8)

Tobin and Tippins' bottom line is that "knowledge is personally constructed but socially mediated" (p. 6).

Social constructivism was the most important theoretical perspective for me during the study, in part, because I was co-editing a book on college science teaching with my two co-major professors (Peter C. Taylor and Ken Tobin), focusing on social constructivism (Taylor et al. 2002). I kept social constructivism in mind while teaching the biochemistry class for my action research study. I was aware of the pervasive social influences in my classroom, which were heightened by the collaborative strategies that I employed. Students had to use oral and written language to communicate with each other. Because of this communication, students could create meaning through these social interactions, whether online, in groups, or during class presentations. Constructivism, especially social constructivism, fits all four of my research questions (Table 3.1). Therefore, social constructivism became an important tool for me to create an interactive and collaborative learning environment.

3.2.2.2 Communities of Practice

Tobin and Tippins (1993) highlight the importance of social interactions and dialogue in the scientific community's arrival at new conceptions in science. Since scientists themselves communicate as they come to new understandings, we need to encourage our students in the sciences to learn within a community as well. Instead of encouraging students to work individually and competitively towards making sense of science, Tobin (1997, 1998) encourages co-participation[3] while using the discourse of science.

Co-participation and communication are important in learning anything. Erickson (1998) argues, "Learning science is learning a new dialect and, as with the acquisition of other aspects of language, learning the dialect of science occurs in

[3] Tobin defines co-participation as "the presence of a shared language that can be used by all participants to communicate with one another such that meaningful learning occurs" (Tobin 1997, p. 371).

face-to-face conversations with others" (p. 1157). Even a familiar word, like energy, has a different meaning in science than in everyday life. By properly hearing and using the words of science in a discussion, students can construct meanings consistent with science. Additionally, if someone in the group uses the word incorrectly, another group member may challenge the meaning, and once straightened out, all can profit.

During my action research study, I created communities of practice by organizing the students into ten collaborative groups with two to four students per group. Students worked together to learn biochemistry on ten topics. For each topic, student groups created and posted a Web site online. Each group additionally presented three topics orally to the rest of the class. These communicative activities not only allowed the students to engage actively in the discourse of science, but also helped the students to comprehend and connect the relationships between the material presented in class and their existing webs of knowledge.

3.2.2.3 Habermas' Theory of Communicative Action

The culture in science departments, which professionally and academically surrounds me, dictates that science is purely rational; and in undergraduate education, conveying the "facts" to students is many faculty members' main goal. Instead of acknowledging that humans construct knowledge, scientists tend to place science on a pedestal, viewing science as the highest form of knowledge. Habermas' *critical* discourse aims to "make visible and subject to critical scrutiny the largely hidden frames of reference that constitute the dominant ideology of traditional [science] teaching" (Taylor and Williams 1993, p. 16). These hidden frames include technical curriculum interest (Habermas 1972) and rationalism. Taylor and Williams' central concern is for a balanced rationality "by establishing communicative action that aims to emancipate teachers and students from these intellectually disempowering cultural frames of reference" (p. 16). While technical interests exist in science, if we can balance those technical interests with human interests, we can tap into the potential that we all possess as human beings, trying to make sense of the world (Gilmer 2002).

Central to my study was allowing my students to select topics of interest to them that I had suggested on biochemistry, thereby giving students a voice in their learning. By providing them freedom, I hoped to fuel my students' ownership of their biochemistry topics, so that they would want to share their learning with the other students and me. I wanted my students to realize that they could learn and develop a confidence in learning so that they would want to continue learning on their own.

3.2.2.4 Sewell's Theory on Structure|Agency

I realized when I began to analyze my action research data that I needed more than social constructivism to figure out successful and unsuccessful interactions in my classroom. I needed a sociocultural theory that would help me make sense of my data.

I was resistant to learn a new theory at that point, but at the same time, I realized that I needed to know more. Tobin introduced me to Sewell's idea on culture. In Sewell's theory of structure|agency, a dialectic exists between the structure of a social situation and the agency, which individuals experience, with the structure and the agency influencing each other.

The importance of educational culture in my biochemistry classroom became apparent as I started to read Sewell's papers. In the beginning of my classes, cultures clashed, mixed as well as oil and water. The students, accustomed to the competitive atmosphere of traditional science classrooms, were suddenly in the middle of a collaborative milieu in which they had to construct a meaning together with fellow students. Through this observation, I started to realize the importance of understanding educational culture in order to communicate effectively in a classroom. Sewell (1999) writes about coherences in his concept of culture.

> [Culture] should be understood as a dialectic of system and practice, as a dimension of social life autonomous from other such dimensions both in its logic and in its spatial configuration, and as a system of symbols possessing a real but thin coherence that is continually put at risk in practice and therefore subject to transformation. (p. 52)

Like my classroom in which two predominant cultures, competitive versus collaborative cultures, met and conflicted, Sewell argues that when multiple cultures are present, they are contradictory, loosely integrated, contested, subject to constant change, and weakly bounded.

Sewell's (1992) theory of structure|agency addresses culture as the result of the dialectic tension between *agency*, the power to act, and *structure*. As Sewell states, "Structures shape people's practices, but it is also people's practices that constitute (and reproduce) structures" (p. 4).

According to Sewell (1992), agency has two components: *access* and *appropriation of resources*. Gender, underrepresented populations, language, and technology influence a person's access. Individual's knowledge and perceptions from culture, and one's ability to use resources to meet individual's goals, which include relevance, interests and objectives, all affect one's *appropriation of resources*.

Sewell argues that structure consists of three components: (i) *human*, including social networks, practices, communities, and division of labor; (ii) *material*, including technology and other tools (see Section 3.2.2.5); and (iii) *symbolic,* including a person's status and cultural constraints. A dialectic relationship exists between structure and agency, with both influencing the other. By utilizing Sewell's ideas on structure and agency, I underpin my research with this theory, which "restores human agency to social actors, builds the possibility of change into the concept of structure, and overcomes the divide between semiotic and materialist visions of structure" (Sewell 1992, p. 1).

To bring these ideas into a pictorial representation of the dialectic between structure and agency (each with their components), please see Fig. 3.1. For example, an African American female student majoring in science education may have started my biochemistry class with reduced access to agency due to her gender, ethnicity, and technological tools available to her. However, through the structure of our classroom with emphasis on collaborative learning and access to tools

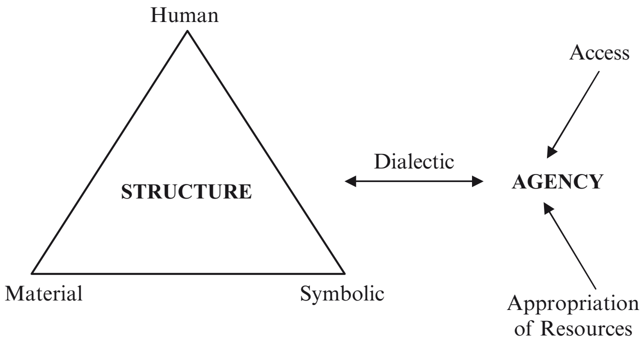

Fig. 3.1 A diagrammatic representation of Sewell's theory of structure|agency with the dialectic between *structure* (with the three components of structure: material, symbolic, and human) and *agency* (with the two components of agency: access and appropriation of resources)

(i.e., technology and language), not only did she influence the structure of the classroom, but her sense of agency expanded.

Implementing Sewell's theory helps me construct a learning environment in my classroom with a structure that encourages students to develop their own agency. Similar to my role of structuring the classroom, the students' sense of agency, in turn, influences the very structure of the classroom. In this way, my awareness of this dialectic tension allows the classroom to be dynamic to the students' goals and interests and my personal learning goals for them.

3.2.2.5 Cultural Historical Activity Theory

I find in my classroom that cultural historical activity theory (CHAT) is a useful framework "to analyze… complex interactions and relations" (Engeström and Miettinen 1999, p. 9). Using an activity theory diagram (Fig. 3.2) allows me to examine the following components' ability to work together and create a successful learning situation. These components are: the *tools* which are available to my students; the *rules* or *schemas*, in which my students and I immerse ourselves in the institution and profession of biochemistry; the *community* which is created by my students as they work together (or not) in their collaborative groups (as well as the communities of scientists disseminating their own constructions of science); and the *division of labor* which exists among the students as well as between the students and me.

The focus of CHAT is the *subjects* under study (Fig. 3.2). Subjects vary depending on the study, but for my purposes the subjects were my students. I focus on my subjects being my students. My students have certain *objects* that they want to learn from the biochemistry classroom. These objects are more than just one student's objects, but the objects of all the students. With those objects, my students can move, or flow, toward their *outcomes* of graduating with a major in the sciences and

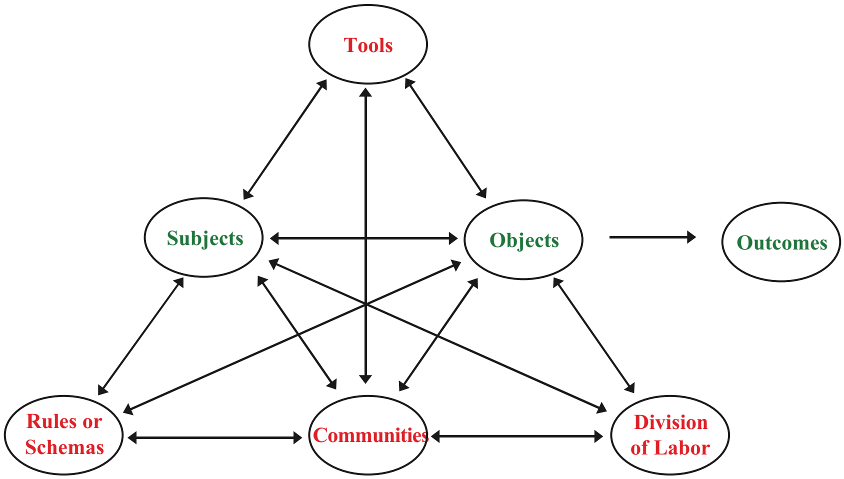

Fig. 3.2 Cultural historical activity theory (CHAT) diagram. The point is for the subjects to go to their objects and then to their outcomes. The other four components, tools, rules or schemas, communities, and division of labor, may provide coherences or contradictions for the subjects reaching their outcomes. The other nodes in the triangle are mediators of the direct link between subject and object. All nodes of the triangle interact and influence each other

moving to their next career goal, such as getting a job or proceeding to graduate or professional school. In parallel with students as the subjects in one CHAT diagram is another diagram the subject being the teacher with her set of objects, or with my biochemistry colleagues as the subjects with their set of objects. Socially, we influence each other's objects and outcomes.

The power of the CHAT is the ability to focus on both the coherences and contradictions (i.e. what succeeds and what fails) to the flow of the subjects to their objects and outcomes. As a teacher, I modulate the tools, division of labor, communities and rules or schemas that influence my students' sense of agency. By focusing on the coherences to the flow, I can help my students reach their desired objects and outcomes. Even more important than the coherences, however, is an examination of the contradictions to the flow. Through examining and identifying the impediments, the teacher can move to change these contradictions into coherences that work successfully in moving my *subjects* to their *objects* and to their *outcomes*. When teaching, I always keep in mind, "coherence is variable, contested, ever-changing, and incomplete" (Sewell 1999, p. 57). These other nodes in the triangle mediate the direct link between subjects and objects, and my effect upon those nodes enables my students to move toward their aspired outcomes.

In addition to using cultural historical activity theory for examining my students, I apply CHAT to my action research data to find the coherences and contradictions in the events that took place in my classroom. By peering through various lenses at my biochemistry classroom and in my own role as the teacher, I work to resolve the sources of the contradictions. Through these efforts, I am in a constant pursuit of improving my teaching by paying attention to the insight provided by this action research.

3.2.2.6 Multiperspective Approaches

In an effort to have a "discourse of plurality, difference, and multinarratives" (Giroux 1990, p. 14), I utilize various ways to represent the learning environment in my biochemistry classroom. The perspectives that I provide in this book include:

1. A fictionalized story I wrote from the perspective of an African American female student in my classroom within her collaborative group (Chapter 4)
2. The voices of my students from the LEQ and the CLS in Chapter 5 (on collaboration) and Chapter 6 (on technology)
3. A metalogue with a biochemistry faculty colleague on the problematic issues of bringing reform in science teaching and learning to higher education (Chapter 7)

By "blurring the genres" (Geertz 1988, 1993) in my literary accounts, I try to present the reader with a multiperspective approach to my biochemistry classroom and subsequent work. Through such an approach, the writer can bring out the multiple dimensions of life's experiences, examine the possible contradictions of life, and look for ways to enhance the coherences and diminish the contractions, thereby moving the subjects (including the researcher) towards their object(ive)s and outcomes.

3.2.3 Conducting a Qualitative Study

Throughout my venture into science education, I have undergone major changes in my epistemology. Consequently, my conception of my dual roles as a teacher and a learner has also changed dramatically. Such conceptual changes include my perception of the nature of knowledge, my teaching approach and methodology, the technology that I use in my teaching, the very concepts I communicate with my students, and my ability to assess my students' learning and understanding.

In seeking a proper methodology for assessing my students' sense of agency, I realized that I needed to utilize a qualitative methodology to conduct my action research. Only through this approach could I comprehend the actual meanings that students established and enacted in the learning environment I provided.

I chose a qualitative methodology of interpretive design. I needed to interpret the signs from my students in order to decide about ways of changing the learning environment to enhance my students' flow towards their objects and outcomes (Guba and Lincoln 1982; Denzin and Lincoln 1994, 2000a, b; Erickson 1998; Lincoln and Guba 2000). Using social constructivism and communities of practice as my main epistemologies for action research practice, I focused on the words that my students used while trying to construct meaning from biochemistry concepts and understand the role of biochemistry in the context of their lives (Lemke 1995; Schaller and Tobin 1998).

In preparation, I read many different styles and contexts for presenting educational research (Richardson 1994; Ellis 1997; Lincoln 1997; Mulholland and Wallace 2000; Schaller and Tobin 1998; Taylor and Timothy 2000; Tobin 2000; Bowen 2002).

I learned to express myself in writing using alternative forms of representation (Gilmer 2000a, b, c, 2002; Scantlebury et al. 2001; Duggan-Haas et al. 2003). Through utilizing different styles of writing, I could include the voices of the stakeholders in my study. Also, by focusing on the perspectives of my students, I learned to place myself in their shoes, thereby allowing me to learn to teach my students with their goals in mind.

3.2.3.1 Fourth Generation Evaluation

For the evaluation of the learning environment in my classroom, I chose to utilize the hermeneutic dialectic process,[4] as described for fourth generation evaluation (Guba and Lincoln 1989). Guba and Lincoln (1989) describe the process as hermeneutic because of its interpretive qualities and as dialectic because divergent ideas can come to the fore, in order to build a higher-level synthesis.

In my development of the characters for the fictionalized story, I tapped into my students' interests and perceptions of each other, the technology-enhanced classroom, and me, in part by analyzing the students' responses in the LEQ. By sharing my fictional story, I learned more from using the hermeneutic process in which students gave me feedback not only on the story but also some were stimulated to tell me more about the classroom.

In Chapters 5 and 6, I analyzed the student quotes obtained from the qualitative questions on the LEQ (Gilmer 2004) and the CLS (Gilmer 2004) and organized these quotes into categories, so that I could address my research questions. For these two chapters I got feedback from one student, Suzanne, who reviewed her weekly-posted portfolio responses and provided other feedback from her perspective.

In Chapter 7, I conclude the results of this study by including the voice of one of my biochemistry faculty colleagues in a metalogue, which we wrote in two phases, several years after the study concluded. In this way I heard the voice of one of my biochemistry faculty stakeholders, Professor Robley Light, who read my dissertation and wrote the metalogue with me.

The stakeholders included the 34 students from my classroom, eight biochemistry colleagues and the director of the first year medical school program. I interacted with the three sets of stakeholders during the action research, and I continued the interactions during the summative evaluation. For instance, during the action research, I had a meeting with the director of the medical school program to alert her that I was not teaching in the usual lecture format. Stakeholders are part of the hermeneutic dialectic circle in my study. I address and share all claims, concerns,

[4] The hermeneutic dialectic process is a methodology in which each stakeholder and the evaluator hears the "different constructions, and different claims, concerns and issues" of the other stakeholders, so that the issues can be "understood, critiqued, and taken into account" (Guba and Lincoln 1989, p. 72).

and issues with the stakeholders. Many of my students have since graduated from medical school or graduate school; luckily, I still have contact with a few of them. In searching on the Web, I found that both Manny and Rebeka, two of the graduate students in the class I studied, now have doctorates in Exercise Science, and Manny is an assistant professor in Kinesiology at a major university. Michael, one of the undergraduates from my classroom that I highlight in this study, is now a Radiology Fellow.

I continue to keep abreast of the effect that the students' experience in the biochemistry classroom played later in their lives. For instance, the one student, Mary, whom I interviewed in depth, was extremely weak in technology at the beginning of the biochemistry course, but now she is a high school biology teacher and working towards her doctorate in education. The second student, Suzanne, I interviewed in depth is finishing her doctorate in science at a prestigious US university.

Of the 34 students in my class, four were prospective science teachers for secondary schools, and four were graduate students in the sciences. The rest were undergraduate science majors. The size of the collaborative groups varied from two to four individuals. All undergraduates were juniors or seniors and had already passed two semesters of organic chemistry and, generally, a number of advanced biology courses as well. A number of students planned to go to medical school.

3.2.3.2 Qualitative Data for the Action Research

Data sources

I utilized a Web site designed for developing a community of learners and encouraging students to use the discourse of the discipline (Tobin 1998, 2002). During the action research, I collected students' electronic postings on a Curriculum and Instruction Web site. Each student had a location within an electronic portfolio to enter his/her reflections on personal goals in the course and on learning biochemistry. Within each electronic site was a location for me to post grades and provide private comments and constructive feedback to each student throughout the semester. Each collaborative group of students posted ten group Web sites on topics of interest that related to the chapters in the curriculum. During the summative evaluation, I analyzed the data sources using the qualitative data software program called QSR N4 from the QSR (Qualitative Software Research, QSR 1997) Company (Gilmer 1999c); now this program is called NVIVO.

I accessed the following data resources during either the action research or the summative evaluation:

1. Approximately 100 Web sites developed by collaborative student groups on biochemistry topics
2. Students' individual questions at the end of each of their research topics (from within their electronic portfolios)
3. E-mail correspondence with students and my own doctoral research mentors

4. Optional final examination (that approximately half of the students took) (sample given in Fig. 6.2b)
5. Written feedback on Web site presentations (self, peer and instructor assessment) (Gilmer 2004)
6. Written feedback from each group on the CLS (adapted from MacCallum and Macbeth 1996) (Gilmer 2004)
7. Students' responses to the LEQ (available at http://www.chem.fsu.edu/~gilmer/downloads.html) at the end of the semester, focusing on the responses to the 11 qualitative questions I designed for my students
8. Written forms from each student on their evaluation of others and self in their collaborative groups (as a learner, as a teacher and from 'being there') (samples given in Fig. 5.1),
9. Member checks of data sources, for checking on interpretations with participants
10. Metalogue with a biochemistry faculty colleague about problematic issues in the teaching and learning in the course
11. Interactions with my students during and after the semester, including some meetings with groups that were having trouble being collaborative, and interviews with two students after the end of the semester

I generated and analyzed data continuously while I taught the Web-enhanced biochemistry course, piloted in the fall of 1998 at my university. I modified my plans, based on data I gathered, so, to a degree, this evaluation was formative. However, because so much more was involved in teaching this course with my innovations and with a larger class than originally planned, I was not able to analyze all the data at the time. I wrote this book a number of years after teaching the course, so the report is mainly summative.

Table 3.2 shows the data sources for each of the chapters.

3.2.3.3 Categorizing and Sorting the Qualitative Data

By typing all 453 responses from the qualitative data gathered from the LEQ, I reflected on each student's anonymous statements. Reading their responses encouraged me to write my own fictionalized story (in Chapter 4, but also within references: Gilmer 2000a, c) about the functioning of the collaborative groups in our biochemistry classroom.

I used qualitative data software program, the NVIVO available through QSR International (1997), to sort the students' responses into five categories: Web sites, learning, teaching, collaboration, and assessment. A student's comment might be categorized into more than one category, if more than one topic came up in the comment.

Each of the five main categories had subcategories and further subcategories (Table 3.3). I read all the comments I made tentative categories and subcategories. I did this diagrammatically on a large sheet of paper. Then I entered the category for each entry into the QSR program. Sometimes I combined subcategories together. In my final categories, I show the percentage of all the text units in each category or subcategory in Table 3.3.

Table 3.2 Data sources for this study

Data source	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8
Syllabus					+	+	+	
Historical documents			+					
Photographs			+				+	
E-mail from students				+	+	+		
E-mail: co-major professors	+		+	+	+	+	+	+
E-mail: chemistry colleague			+					
Metalogue: biochemistry colleague							+	
LEQ				+	+	+		
CLS				+	+	+		
Student Web sites			+	+		+	+	
Portfolio-contributions to Web sites					+	+		
Portfolio-student's Goals						+	+	
"Final question"						+		
"Being there" forms				+	+		+	
Recollections/reflections	+	+	+	+	+	+	+	+
Interview with two students				+	+	+		
Interview with medical school director				+				
Fiction workshop				+				
Literature	+	+	+	+	+	+	+	+

Since some comments fell into more than one category, the sum of all the percentages (109.5%) is greater than 100%. An example of a student response categorized into more than one subcategory is, "The Web sites? They helped, but, in honesty, I only know well what it was that I did." I sorted the above students' response into three categories: (i) Technology/Web sites/Group Web sites/Science information; (ii) Technology/Web site/Web learning; and (iii) Collaboration/Real World/Too focused. However, I categorized most student responses into a single category.

The five main sections of Table 3.3 are: (i) Technology/Web sites; (ii) Learning; (ii) Teaching; (iv) Collaboration; and (v) Assessment.

I used a similar method to categorize the data from the CLS, with two main categories: Academic/Task Achievement and Process. Of the 619 text units, 18% dealt with technology and 47% dealt with collaboration.

I decided to focus on the data from both the LEQ and the CLS on collaboration (for Chapter 5) and technology (for Chapter 6) because these themes I could see most clearly in my classroom and fictional story. I also utilized other data, like the interview and e-mails from students and co-major professors.

Table 3.3 Categorization by QSR of qualitative data: learning environment questionnaire (LEQ)

Category sorted from the qualitative data[5]	Text units (%)
Technology/Web sites	1.50
Group Web sites	
Scientific information	2.00
Computer Skills	5.50
Time spent	2.60
HTML writing	0.66
Curriculum and instruction Web site	0.22
Own posting	1.30
Other uses	0.22
Class Web-MC Web site	
Contribution to Web site	0.22
Web learning	11.0
Learning	
Innovation	0.22
Conceptual	0.66
Time/reflection	0.22
Reflection	0.22
Applications	
Scientific/Technical	1.30
Medical	0.22
Mood	0.44
Style of learning	1.80
Adjustment of learning	0.88
Confusion	0.22
Needs structure	0.66
Classroom	
Peers	1.30
Own interests	0.88
Questions asked	0.66
Biochemistry	3.30
Teaching	
Lectures	2.20
Lack of lectures	4.90
Teacher	
Compassion	0.44
Flexibility	0.22
Other traits	2.40
Peer teaching	0.44
Structure	
Biochemistry	1.10
Physical classroom	0.44

(continued)

[5] The subcategories from which I quoted students in Chapters 5 and 6 are typed in bold. About 70% of the students' entries were sorted.

Table 3.3 (continued)

Category sorted from the qualitative data[5]	Text units (%)
Computer facilities	0.22
Textbook	2.00
Collaboration	
Group presentations	3.80
Responsibility	0.44
Learning by teaching	0.66
Co-learners	3.50
Strong points	4.00
Headache	2.90
Accomplishments	0.22
More individual	0.22
Real world	0.44
Too focused	0.44
Conflicts	
Time	0.44
Effort	0.44
Cooperation	0.22
Assessment	
Writing	0.22
Reinforcement	1.30
Too much time	0.44
Stating goals	6.60
Contributions to Web site	4.40
Final (optional) question	0.22
Work to accomplish	0.44
Too much to do	2.00
Peer evaluation	0.66
Rubric	0.22
Not clear	0.66
Clear	0.22
No required note-taking	0.22
Problem sets	3.10
Books – no examples	0.88
Too much time	1.10
Good learning	3.10
Answers in back of book	0.88
Explanations needed	2.40
Deadlines	1.50
Credit hours	3.80
Attendance	0.66
Exams	1.80
Lack of exams	2.40

3.3 Examining Criteria for a Qualitative Study

I outline the three types of quality criteria for this study:

1. For conducting an ethnographic, interpretive action research study of my biochemistry classroom (Chapter 5 is the collaborative component in my classroom, and Chapter 6 has the technology component).
2. For writing fiction (Chapter 4 is a fictionalized story of my biochemistry classroom that also focuses on the students utilizing technology and collaboration).
3. For writing a metalogue (Chapter 7 is the metalogue with one of my biochemistry faculty colleagues).

3.3.1 Quality Criteria for Ethnographic, Qualitative Data

By using the word ethnography, I mean, "the study of lived experience," which thereby "examines how we come to construct and organize what has already been experienced" (Britzman 1991, p. 9). Guba and Lincoln (1989) delineate three quality criteria in an ethnographic, interpretive inquiry: (1) *trustworthiness* (also called the *parallel* criteria, analogous to the quality criteria from a positivist, foundational tradition but modified for interpretive research); (2) the nature of *hermeneutic process*; and (3) *authenticity*, considered non-foundational. Schaller and Tobin (1998) and Lincoln and Guba (2000) address these same criteria for various genres of interpretive research. I address each criterion here.

1. Trustworthiness

Trustworthiness includes four criteria, called the *parallel* or foundational criteria because they parallel the positivist reliability criteria: (a) credibility (which has six subcategories), (b) transferability, (c) dependability, and (d) confirmability, described.

(a) Credibility

Credibility in qualitative research is analogous to the conventional criterion of internal validity in quantitative research. To increase the credibility of qualitative data sources, Guba and Lincoln (1989, 1994) encourage: (i) prolonged engagement, (ii) persistent observation, (iii) peer debriefing, (iv) negative case analysis, (v) progressive subjectivity and (vi) member checks, which I explain now in more detail.

Prolonged engagement requires the researcher, me in this case, be at the research site for a sufficient amount of time, 15 weeks for my study, to experience the culture of the classroom and to "make sense of what is happening" (Schaller and Tobin 1998, p. 46). I take the time to have *persistent observation* in the classroom to decide the most salient issues and to study the issues deeply over the five years to finish the doctoral thesis and five more years to publish this book. I engage fully during the semester of teaching the course and spend many years afterwards interpreting and reinterpreting the data, coming to understand nuances. I communicate with my peers through *peer debriefing* at science education conferences, including with my two major professors, to get critical feedback, both during the actual study but also during the analysis. Through *negative case analysis*, I carefully examine cases that are different that the others I study, to make sense of occurrences in my classroom. By implementing *progressive subjectivity*, I monitor my constructions as they change with time during the action research and summative evaluation. Through the process of *member checks*, I solicit the reactions of my stakeholders to my constructions during the process of teaching and during the summative evaluation. Schaller and Tobin (1998) emphasize member checks as critical to the quality criteria, stating "it is possible to refer those texts back to the [stakeholder] groups, providing opportunities to authenticate them and reflect on their content" (p. 46).

(b) Transferability

Transferability in qualitative research is similar to the conventional criterion of external validity or generalizability used in quantitative research. In a qualitative study such as my own, transferability implies that others could transfer learning from my study to their situations. The transferability depends on the degree to which I write "thick descriptions" from the data, so that others can see the connections to their lives. By providing a thorough data set, others wanting to apply the ideas to new situations would be apprised of the details, including the "time, the place, the context, the culture in which those hypotheses were found to be salient" (Guba and Lincoln 1989, pp. 241–242).

(c) Dependability

Dependability in qualitative research parallels the conventional criterion of reliability in quantitative research. To maintain dependability I keep track of the texts and catalogue them to allow another researcher the ability to examine my data. I use the software program like QSR to help me sort the data into categories for analysis.

(d) Confirmability

Confirmability in qualitative research is analogous to conventional criterion of objectivity in quantitative research, and says that my "data (constructions, assertions, facts and so on) can be tracked to their sources, and that the logic used to assemble the interpretations into structurally coherent and corroborating wholes is both explicit and implicit in the narrative of a case study" (Guba and Lincoln 1989, p. 243). Therefore, I quote the sources of all my original data.

2. Hermeneutic Process

The *hermeneutic* circle involves a continual negotiation with stakeholders with feedback occurring with and among the stakeholders during the study and during the analysis and writing stages.

3. Authenticity Criteria

The *authenticity* criteria include the non-foundational components, such as (a) fairness, (b) ontological authenticity, (c) educative authenticity, (d) catalytic authenticity, and (e) tactical authenticity (Guba and Lincoln 1989; Schaller and Tobin 1998), described:

(a) Fairness

The *fairness* component of authenticity deals with soliciting and honoring different constructions during the action research and during the summative evaluation. For example, in my study I deal with the fairness criterion by providing my students feedback during the course as they wrote in their electronic portfolios or in the CLS. Also I correspond with my former students who read my fictionalized short story a year after the course ended and gave me feedback. I respond to my colleagues' concerns while teaching the course, and afterwards when I asked a colleague to write the metalogue with me (Chapter 7).

I learn more about my teaching and the learning environment in our classroom by honoring their different constructions, as each of us has a different perspective on events.

(b) Ontological authenticity

The *ontological authenticity* component of authenticity relates to whether my own and other stakeholders' constructions changed through the process. For this component of authenticity, I ask these three questions:

1. Would my writing have been the same without the input of the students and other faculty throughout the process?
2. How have my constructions changed?
3. How did my constructions enhance the constructions of the students and my biochemistry faculty colleagues?

Through these ontological explorations, I, as the researcher, was able to understand the processes by which I learned about others' constructions of our classroom and allowed that learning to enhance my study. Also I could see the process by which the constructions of some of the students, especially those of Suzanne and Magnolia, and of my colleague, Professor Robley Light, changed by interacting with me through the process.

(c) Educative Authenticity

Guba and Lincoln's (1989) *educative authenticity* addresses the educative learning by those involved in my study and those who read my study now in its completed form. My stakeholders include my students, biochemistry colleagues, two co-major professors, and a medical school colleague.

As I engaged others in the data collection and analysis, opportunities arose to educate others as to the nature of educational research and the quality criteria. I remember some scientists saying to me upon hearing my study that they did not realize that educational researchers had quality criteria. I was glad for the opportunity to explain the quality criteria that I used.

(d) Catalytic Authenticity

Catalytic authenticity means that through the action research and the summative evaluation, I, the researcher, become stimulated into action. What do I do to improve my learning? What is catalytic for me? How do I engage in reflexivity (Hertz 1997)? Reflexivity is an important component of action research. By reflexivity, I mean "the process of reflecting critically on the self as research, the 'human as instrument'" (Lincoln and Denzin 2000, p. 183). Therefore, I became critical of myself, seeing and interpreting, in part, through other stakeholders' voices, eyes and hearts. I became a human instrument who selected, gathered, and analyzed the data, and who wrote this book, based on the data I interpreted in this research study.

(e) Tactical Authenticity

Tactical authenticity means stimulating action and empowering others, especially those individuals unable to help themselves, so that they feel the *power to act* and they consequently take action (Guba and Lincoln 1989, 1994). The concept of tactical authenticity overlaps with Sewell's idea of *agency*. I want to give my students the power to enact their learning of biochemistry, to see the connections between topics, to understand the whole, and to move to their objects and outcomes.

3.3.2 Quality Criteria in Fiction Writing

Lincoln and Denzin (2000) look to the future of qualitative research in the "The Seventh Moment: Out of the Past." Lincoln and Denzin cite the center of qualitative research as "the humanistic commitment of the qualitative researcher to study the world always from the perspective of the gendered, historically situated, interacting individual" (p. 1047). To aim at the seventh moment, I chose to write a fictionalized account from my students' perspectives, to focus on the struggles (and epiphanies) that my biochemistry students experienced within the collaborative groups while learning to use technology to enhance their learning of biochemistry.

Lincoln and Denzin (2000) also "anticipate a continued performance turn in qualitative inquiry, with more and more writers performing their texts for others" (p. 1048). I have experienced such a "performance turn" only once, when Professor Carl Djerassi, an organic chemist and developer of the birth control pill, invited a woman from the audience at a presentation at the annual meeting of the American Association for the Advancement of Science to read with him part of his new play on the "immaculate conception" (all via in vitro fertilization methods) (Djerassi 2000). I found that their reading part of his play was very effective, and Djerassi personally motivated me to include my fictionalized story in both my doctoral thesis and this book.

3.3.2.1 Fiction Workshop Guidelines

To learn to write a story, I enrolled in an undergraduate class called *Fiction Workshop* taught at my university in 1999. I read two prerequisite books by Burroway (1996) and Goldberg (1990), before starting the fiction workshop.

Fictionalized writings, like the works of Taylor (2002), Bowen (2002), Geelan (2003), Mattson (2002) and Dawson (1999) in educational research are powerful models that guided me in my own narrative writing. Ely et al.'s book (1997) on writing qualitative research also helped me fictionalize my observations about my students and my own experiences.

Lincoln and Denzin (2000) state:

> As Richardson makes clear, writing is not merely the transcribing of some reality. Rather, writing – of all the texts, notes, presentations, and possibilities – is also a process of discovery: discovery of the subject (and sometimes of the problems itself) and discovery of the self. (p. 184)

I found the process of writing was a discovery, not only of my own experiences and reflections, but also by putting myself in their shoes, I could understand the scenes in my story through their eyes.

3.3.2.2 Richardson's Evocative Fictional Representation

Richardson (2000) writes of *coherence*, *verisimilitude* and *interest* as being the important quality criteria for evocative fictional representations. Adler and Adler (1994) describe *verisimilitude* or *vraisemblance* as "a style of writing that draws the reader so closely into subjects' worlds that these can be palpably felt" (p. 381). Adler and Adler (1994) write on coherence and vraisemblance:

> When such written accounts contain a high degree of internal coherence, plausibility, and correspondence to what readers recognize from their own experiences and from other realistic and factual texts, they accord the work (and the research on which it is based) a sense of 'authenticity.' Thus observational research derives validity from the *vraisemblance* of its textual renderings. (p. 381)

The criterion of *interest* is critical to engage the reader with a topic that relates to the life of the individual. Interest combined with coherence and verisimilitude help to capture and engage readers' imaginations and help them to tap into their former experiences and experience the *déjà vu* feeling.

Richardson (1994) also mentions various literary devices that are important for telling a "good story." These devices include, "flashback, flashforward, alternative points of view, deep characterization, tone shifts, synecdoche, dialogue, interior monologue, and sometimes, even the omniscient narrator" (p. 521).

Richardson (1994, 1997) also discusses the concept of crystallization, as a way to address validity in postmodern texts. Instead of thinking in terms of triangulation (in a plane) as a way to approach "truth," she states the "central imagery is the crystal" (1997, p. 92). Richardson continues, "Crystals are prisms that reflect externalities *and* refract within themselves, creating different colors, patterns, arrays, casting off in different directions. What we now see depends upon our angle of repose" (1997, p. 92). By getting away from triangulating to reach a concrete understanding and utilizing the concept of light behaving as both a wave *and* a particle, we can come to a fuller understanding. By thinking of crystallization and using alternative ways of thinking to present our texts, we get away from "truth" as a goal, and instead focus on a deepened understanding of the social situation under study (also see Lincoln and Denzin 2000).

The ideas of Richardson's three criteria overlap at least partly with those of Guba and Lincoln (1989). Table 3.4 shows the overlap in these quality criteria.

Table 3.4 Comparison of quality criteria: Guba and Lincoln's 4th generation evaluation versus Richardson's for fiction writing

Guba and Lincoln's quality criteria	Richardson's coherence	Richardson's verisimilitude or vraisemblance	Richardson's interest
1. Trustworthiness (parallel)			
(a) Credibility			
Prolonged engagement			
Persistent observation			
Peer debriefing			
Negative case analysis			
Progressive subjectivity			
Member checks	+	+	+
(b) Transferability			+
(c) Dependability	+		
(d) Confirmability		+	
2. Hermeneutic circle	+	+	
3. Authenticity			
(a) Fairness			
(b) Ontological authenticity	+	+	
(c) Educative authenticity			
(d) Catalytic authenticity			
(e) Tactical authenticity			+

A plus symbol (4) in Table 3.4 indicates some form of correspondence between the quality criteria for qualitative research by Guba and Lincoln (1989) with the quality criteria for writing fiction by Richardson (2000).

Richardson's (1994) and Adler and Adler's (1994) criteria overlap with my English professor's criteria that I actually utilized when writing my story (Fig. 3.3, from Professor Sheila Ortiz-Taylor, Fall, 1999, Fiction Workshop). I initially utilized Ortiz-Taylor's criteria to evaluate the writing of the other members of my own collaborative group in the fiction workshop. As I focused on the criteria, I learned to evaluate my own work using the same criteria before distributing the draft of my story, to get feedback from members of my collaborative group from the writing workshop. After having a chance to incorporate the feedback from my collaborative group, I distributed copies of my next draft to my entire class for critiques from all the creative writing majors and my professor.

I found Ortiz-Taylor's criteria (Fig. 3.3) helpful because of the overlap with the criteria for fictional writing from Richardson and for the autobiographical writing by Ellis (which I had used in the doctoral thesis but have not included in this book, but is a book chapter; see Gilmer 2007). When I first saw the criteria, I realized the depth of human experience that could be expressed in a fictional story. As we constructed stories in the fiction workshop classroom, I could see my experienced creative writing majors as classmates utilize these criteria in their stories. Consequently, I learned from them.

FICTION WORKSHOP SHEILA ORTIZ-TAYLOR

1. **Initial impression:** Be aware of your responses as you read the first paragraph or the first page. What are your expectations? Are you feeling interest, curiosity? Are you fairly confident any mystery is the result of the writer's plan, or are you just plain confused?
2. **Point of View:** appropriate, consistent; are shifts effective?
3. **Character Development:** at least one round character; obsession? idiosyncrasy? too many?
4. **Dialogue:** lifelike? Does everybody sound alike?
5. **Setting:** clear, detailed, integrated? Symbolic? Does weather exist? Season?
6. **Detail:** symbol, image, sense appeal? Pointless detail = Red Herrings? Is blocking clear?
7. **Style; Pattern:** repetition of objects, words, images, phrases, actions. Is there symbolism? What is the tone? Are there tone shifts? Do they work?
8. **Time, Structure:** Clarity of fictional clock time. Narrative pace too fast or too slow? Does sequence of events work well? Is the plot or story line coherent? Flashbacks used well? Inappropriate tense shifts?
9. **Conflict;Tension:** through paradox? Goals & obstacles? Power struggle? Departure from the ordinary? Enough action? Crisis? Moment of understanding? Expressed in an action?
10. **Theme:** appropriate weight of significance? Is the story about something? Is theme expressed too directly? Has it been reduced to a moral?
11. **The Ending:** is there a sense of an ending? Too tidy? Effective ambiguity? Has some important issue been neglected? Do the ending, beginning, and title form a pyramid?
12. **Overall evaluation:** Did the author try for something valuable and unusual? Was this probably a challenging story to write? Did the author take calculated risks? Does the story seem to accomplish its aims? Will you **remember** this story?

Fig. 3.3 Criticism checklist from undergraduate level Fiction Workshop, taught by Professor Ortiz-Taylor (words in bold are in the original)

3.3.3 Quality Criteria in the Metalogue

For the metalogue that I have with my biochemistry colleague (in Chapter 7) on the problematic issues of bringing reform to higher education, the only quality criterion that Bateson (1972), originator of metalogue, writes is the following: "This conversation should be such that not only do the participants discuss the problem but the structure of the conversation as a whole is also relevant to the same subject" (p. 1). The structure of the conversation in the metalogue is central to my study as the structure reflects the culture of science departments in institutions of higher learning in the United States. Therefore, the structure of the conversation is very relevant to the subject of trying to transform the teaching of biochemistry.

Professor Light and I had our "conversation" (Bateson 1972, p. 1) by responding to each other's writing, by sending Word documents back and forth to each other. We answered each other's questions and posed new questions. In that way, we could both think about the questions and our responses before we sent the document back to the other to respond. We had our initial set of written "conversations" after I finished teaching the course and then a final set after the conclusion of the writing phase of the first six chapters of the book. Our metalogue became Chapter 7, concluding the data from the action research study.

3.4 Handling and Managing Data

3.4.1 Ethical Issues

The authenticity criteria, outlined in the quality criteria for the qualitative data section, served as the ethical guidelines for this research.

Being a professor of chemistry and biochemistry, I submitted the forms for use of human subjects in research at my own institution. The consent letter was for the students in my biochemistry class. The Human Subjects Committee at my university approved the consent form. I assigned pseudonyms to all the participants in the study. All the students in my story in Chapter 4 are fictionalized.

I appreciated my students' willingness to engage in an experiment in teaching and learning, which may have affected (I hope positively) their future outcomes.

3.4.2 Facilities and Resources

3.4.2.1 Curtin University of Technology

While on sabbatical at the Curtin University of Technology campus near Perth, Western Australia in September–December 1997, I read extensively on the background knowledge in college science teaching. This was my first semester at Curtin enrolled as a doctoral student. I enrolled in one graduate class on constructivism at Curtin for the semester I was in residence.

Curtin accepted four graduate courses in Science Education I had taken earlier as a special student at FSU. After returning from Curtin, in 1999 I enrolled in a Fiction Workshop course at FSU, which counted as a course at Curtin.

I wrote the doctoral thesis for Curtin while working full time at FSU while engaged in my research in science education, teaching of chemistry and biochemistry, and service in my profession and community.

My doctoral co-major professors were Kenneth Tobin and Peter Taylor. I earned the degree, Doctor of Science Education, in 2004 and went to Australia for my graduation in our outback of Australia on the Kalgoorlie campus in 2005.

3.4.2.2 Florida State University

The technology part of the biochemistry course for this study was possible due to the College of Business's generosity by allowing my biochemistry students to access one of their high technology computer-assisted classrooms twice a week during the semester.

The university provided me with the expertise to develop the university course Web-Mediated Course Assistant (Web-MC) Web site and the Curriculum and Instruction Web sites. Curriculum and Instruction provided a Web master for its Web sites.

3.4.2.3 National Research Council

I experienced many influences during the semester that I taught the biochemistry course, but being a member of the Committee on Teacher Preparation in Science and Mathematics (organized by the NRC, the research arm of the National Academy of Sciences) was pivotal. While serving on this committee, I had extensive opportunities to learn more about teacher preparation and about the teaching of science and mathematics to undergraduates. We had extensive readings and assignments for each committee meeting. Other committee members and invited speakers to our committee contributed greatly to my learning. Our NRC committee members used the discourse of science and education, arguing ideas and listening to the others as we formulated and developed our ideas, helped me in my own action research study. Our report became the book, *Educating Teachers of Science, Mathematics, and Technology: New Practices for the New Millennium* (NRC 2001).

3.4.2.4 National Association for Research in Science Teaching

During the period I was intensely writing the doctoral thesis (2002–2003), I started serving a 3-year term on the Executive Board of the National Association for Research in Science Teaching (NARST) as a regular board member in spring of 2003, during my last year of writing the thesis. This process of serving in NARST engaged me more in science education and with prominent science educators and opened my view of the larger picture of science education.

After finishing the doctorate and at the conclusion of my 3-year term on the Board, the NARST membership elected me to the presidential team. I served for three additional years, finishing my term in spring of 2009. I was so fully engaged in leadership of the organization, with the subsequent changes in the NARST management of the organization in 2006 and related needs for online resources, that I delayed finishing this book until now. Here I became immersed in issues in science education across the spectrum of all strands of NARST, and I learned considerably through this time.

Concurrent with serving on the NARST Presidential team from 2006 to 2009, I served on the Executive Board for the Association for Science Teacher Education (ASTE) as Chair of Awards. Although this was a demanding task, I learned from all the nominees submitted for member awards and the manuscripts nominated for the paper awards.

I realize now reading the text of this book and seeing the data again that I feel renewed. Even though my involvement in NARST and ASTE meant that this book was delayed in publication, I feel that I still have something powerful to say. Time will tell if the ideas and synthesis in this book catalyze changes in others' teaching and empower them to act.

3.5 Summarizing the Chosen Methodologies

The contents of Chapter 3 provide the theoretical underpinnings of my research through using social constructivism, theory of structure | agency and cultural historical activity theory as my main theoretical referents. These three theoretical perspectives work together and reinforce the lens through which I observe and make sense of my experiences.

I explained my choice of a qualitative methodology and of my study, including some background on the classroom, my data sources and the process by which I analyzed the data.

I chose to utilize a qualitative methodology (using fourth generation evaluation), attending to the quality criteria, using data from a variety of sources (Table 3.2). In essence for collecting the data, I used the following criteria for qualitative methodology (Guba and Lincoln 1989; Schaller and Tobin 1998):

1. Foundational criterion, modified for qualitative data, of trustworthiness, with four components: (a) credibility (with six types), (b) transferability, (c) dependability, and (d) confirmability)
2. Hermeneutic process of engaging with the stakeholders, which was integral to my study
3. Non-foundational criteria, including five components: (a) fairness, (b) ontological authenticity, (c) educative authenticity, (d) catalytic authenticity, and (e) tactical authenticity.

In addition, I outlined the quality criteria for fictional writing (Richardson 1994, 1997, 2000; Ortiz-Taylor 1998) of (a) coherence, (b) verisimilitude (or vraisemblance) and interest, and of metalogic writing (i.e. discussing the problem in a conversation that has a structure that relates to the same subject) (Bateson 1972).

Using these methodologies and quality criteria I was able to conduct my action research study and learn about teaching and learning of science.

Chapter 4
Writing a Story About Teaching University Science

4.1 Preview

This chapter contains a fictionalized story about my students and their work in a collaborative group in my biochemistry classroom. I express the emotions of my students and address their frustrations (and joys) of learning in our biochemistry course, which I taught through a social constructivist lens in which collaborative learning was central, with students sharing their constructions with each other.

I chose to write a fictionalized story for two reasons. First, writing this story allowed me to consider the multiple perspectives of several students in my biochemistry classroom by reading their comments critically and then applying them to the narrative. Secondly, I could get in touch with my biochemistry students after the semester ended, so I could get their feedback on my portrayal of the learning environment in our course. I utilized this story as a research tool to unearth deeper levels of experience as my former students read the fictionalized story and commented about their experiences in the classroom. The story also became an educational tool, giving me insight into successful teaching strategies.

Aside from the narrative and student feedback, I also include feedback from the creative writing majors in the *Fiction Workshop* class as I wrote my story. This feedback comes from my journal from that class, which shows my changes and growth in the 3-month period from September until early December 1999. This story allows me to delve into the interworkings of my classroom, and conceptualize issues that are hard to address outside a narrative structure, as well as provide insight into my personal growth in the realm of becoming a constructivist teacher of science.

4.2 Analyzing a Classroom by Writing a Story About It

The modernist movement, which had its start in Western society at the end of the nineteenth century, generally portrayed science as a set of absolute truths. Since the start of the postmodernism movement in the 1960s, however, we are learning

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to break away from such representations. We are learning to share science with others (Capra 1996, Shepherd 1993) and teach science in a better manner (Taylor 1998, 2002; Taylor et al. 2002). About this paradigm shift, Lincoln (1997) states:

> As we absolve ourselves of the modernist fancy that texts can stand as memorials to the truth about the world, we let go of the last measure of certainty to which we might have clung… But the postmodernist textual analysis suggests that all texts are created from partial perspectives, and that furthermore, that is the best we can hope for. (p. 37)

The goal of this postmodern movement is to experiment with various representations in education, in order to push the envelope for science education reform beyond the K-12 level to the university level and to get beyond the more traditional, modernist ways of reporting science education research.

As mentioned in Chapter 2, I include three lenses into my university-level biochemistry classroom: fictional, ethnographic, and metalogic. In Chapter 4, I focus on the first of the three perspectives, the fictionalized story of my classroom. In Chapters 5 and 6, I present the second perspective, an ethnographic view of my classroom. The third perspective, a metalogue with my biochemistry colleague, can be found in Chapter 7.

As the researcher-teacher, I ask, do different genres of writing enhance or inhibit your learning from this education research? Bruner (1986) highlights the differences between two modes of thought: the *narrative* (more storytelling with drama) and the *paradigmatic* (more structured and categorical, to “achieve a sequential, action-oriented, detail-driven thought,” based on logic) (Wikipedia 2009). My goal in providing various genres in my writing is for you, the readers, to see and understand my classroom through different eyes with different modes of thinking.

Fiction allows the feelings, emotions, and dynamics of interactions to be more visible than traditional modernist accounts of university classrooms (Tierney 1997). Stern (1991) proposes, “The shapes of fiction inspire [readers] by presenting ways to embody your experiences, memories, and imaginings” (p. 3). Correspondingly, Burroway (1996) highlights this point:

> Whereas the hierarchical or “vertical” nature of narrative, the power struggle, has long been acknowledged, there also appears in all narrative a “horizontal” pattern of connection and disconnection between characters[,] which is the main source of its emotional effect. (p. 35)

I utilize this “horizontal” pattern of connection among the group members in the fictionalized story to portray the emotions and interactions of my biochemistry students.

4.2.1 *How I Chose to Depict Learning*

The audience for this research varies from scholars in educational research to scientists having interests both in teaching and research. To reach such a wide audience and to paint the differing perspectives from my classroom, I employ different genres of writing in this book. Writing fiction is the first of my three methods reported here.

To write fiction, I need to understand the various perspectives of my students. In class, instead of focusing on assessing my students using "objective" tests, in comparison to some control group, I chose a qualitative methodology. I focused on the *words* that my students used while they were trying to understand the context of biochemistry in their lives. Through their words not only during class, but also in their writing and in interviews I learned their perspectives.

All the words my students wrote in the LEQ are available (at http://www.chem.fsu.edu/~gilmer/downloads.html), but I want to provide an impressionistic view (Taylor 2002) of my classroom. I believe my story is consistent with the data, which comprised student assignments and group Web sites, electronic group meeting rooms, student meetings and interviews, activities during class time and artifacts from student interviews and faculty conferences.

I learned to write fiction by taking an undergraduate level *Fiction Workshop* class at my own university. My teacher, Sheila Ortiz-Taylor (1998), and the creative writing majors in my class gave me considerable feedback to improve my writing and to allow me to reflect on the multiple layers of interaction in my biochemistry classroom.

Additionally, we experienced the culture of fiction writing to hear various authors read their fiction, by attending a local bar establishment, called the *Warehouse*. This gave me a sense of the interactions among writers, and the meaning of being a fiction writer.

Goldberg's (1990) advice on writing every day helps me gain momentum in my writing and stay in touch with all of my being,

> wild mind surrounds us. Western psychology calls wild mind *the unconscious,* but I think *the unconscious* is a limiting term. If it is true that we are all interpenetrated and interconnected, then wild mind includes mountains, rivers, Cadillacs, humidity, plains, emeralds, poverty, old streets in London, snow, and moon. A river and tree are not unconscious. They are part of wild mind. I do not consider even a dream unconscious. A dream is a being that travels from wild mind into the dot/monkey mind/conscious self to wake us up… So our job as writers is not to diddle around our whole lives in the dot but to take one big step out of it and sink into the big sky and write from there. Let everything run through us and grab as much as we can of it with pen and paper. Let yourself live in something that is already rightfully yours – your own wild mind. (pp. 32–33)

By writing the story, I realized the cornerstones of my action research, which included encouraging students to learn by:

1. Writing and speaking using the discourse of biochemistry, in class, within students' collaborative groups and on the World Wide Web (WWW)
2. Learning while using technology, through Web site searches and development
3. Co-participating with other students in group projects within collaborative groups
4. Writing reflexively in electronic portfolios, thereby, encouraging their personal and professional growth
5. Thinking critically, by having students ask research questions at the end of their research on the Web site on biochemical topics

Realizing these cornerstones allowed me to focus the writing of the rest of the doctoral thesis and now this book. I chose to highlight the collaborative learning and the use of technology rather than on other potential foci.

4.2.2 The Fictional Characters

The characters in the story were not actual students from my classroom but rather, archetypical students. I gave each fictional character a voice. However, Mulholland and Wallace (2000) state, “it has been argued that all stories are restories, the teller selecting from among many possibilities in lived experience to create a story in which a self is invented and other stories are repressed or forgotten” (p. 1). With that thought in mind, here is the story I wrote as a special student in *Fiction Workshop*, taught in Fall 1998, one year after teaching the biochemistry course in which I conducted my action research.

I enclose the story in a box to differentiate it from the other data.

Fictionalized Story from Biochemistry Classroom

Within, Without and Together

Bristol breaks the hushed tones, as he insists to his three group members from their Web-enhanced biochemistry class, “We haven’t been effective in creating this group Web site because we haven’t met to get our links together. So far only three of us have communicated by e-mail.”

Bristol, born in the Bahamas of African descent, lived in England for eight years before emigrating to Miami. Now he’s an American citizen, currently attending Mabel Clark University. Bristol rubs his short cropped, black beard back and forth with his left hand, while tapping the forefinger of his right hand, waiting to see who responds in his collaborative group.

There’s a long pause after Bristol’s statement. I decide to break the ice by introducing myself. “My family calls me Magnolia. I was born and raised in Homestead, just south of Miami. I’m American and proud of my African heritage. However, I myself don’t feel I’m good at confrontation.” I lower my head and look down at the floor, hoping that someone else in my group also responds to Bristol.

Finally, Heather pipes up, “Bristol, I sent you an e-mail last week. I wish we could sit down as a group more often and talk in depth about the content for our Web site. My schedule is just *so* busy”

I mock Heather, “Yeah, my schedule’s *real* busyv too.”

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We are finally meeting late this afternoon as the winter sun angles in the front windows at Barnes & Noble's Café, setting a soft glow on us, as we and other patrons sit in small groups at round tables. Several versions of Sunday's *New York Times* lie folded on the corner stand. Wafts of coffee aroma mixed with Orange Pekoe tea, with sprinkles of cinnamon and vanilla fill the room. The sweet smell of cookies and chocolate covered wafers encourages and tempts us to purchase something to eat and drink.

Heather just goes on, as if she hadn't heard me, "This business of becoming an Earth science teacher requires a large commitment of *my* time, with mentoring the high school students while doing my internship and teaching practicum at Royal Palms High."

Heather is petite and has a carefree type of haircut. She sports casual clothes like Cargo pants and Old Navy T-shirts. She wears a colorful visor, whether it's night or day, and you can see her full head of cropped auburn hair with streaks of blond. Sometimes she uses the visor to cover her eyes while she reads an assignment from another class during biochem class.

Heather sits upright in her chair, moving to face Bristol. With her hand on her chin, Heather strokes her cheek with her right forefinger, saying, "The discussions we've had so far usually help me link ideas between Web sites. Having you guys to talk to helps me. Just using the terms we're reading in books now in a conversation or in our electronic dialogue journal makes it easier me summarize my ideas."

"That's fine, Heather," responds Bristol. "You talk a good line. Our conversations have helped me too, but last week we had a specific task to do in our group. We had decided that we'd each search for Web sites on our group topic. I needed to look at the Web sites that we all had found so I could put together part of our group site. It's good that you're learning from us, but *you* need to contribute to help the rest of us learn. We're all in this thing together."

"You've got a point, Bristol," she responds seriously, with her eyes downcast and moving her hands back down to her lap.

"We get a group grade, Heather, so helping us helps you too. By the way, I never did get the e-mail you mentioned that you sent me last week." Bristol is just managing to contain the full extent of his anger. The dark hairs are standing up on the backs of his hands. Sweat is breaking out above his upper lip.

"OK, Bristol, OK," Heather blurts out, "You're right. I *didn't* e-mail you and the others with information I found. I *meant* to. I'm sorry. Next time I'll use the electronic dialogue room on our class Web site that our teacher, Valerie, set up for us. I'll just copy and paste Web site addresses into our group's dialogue room, with a note of interesting facts about each one. We'll have a record of our notes for everyone"

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Charles interrupts, “Bristol’s right, Heather. We need to be honest with each other. I don’t appreciate your saying you did something when you didn’t. Also each of us needs to contribute.”

Heather squirms in her seat and whines, “I *tried* to, Charles, but remember my cat was sick last week, and I needed to attend to her. I wanted...”

Charles rolls his eyes, and then looks Heather right in her eyes, “The rest of us get our parts done, and things come up in our lives too. Our project for the next biochem chapter needs to be really good. We’ll be presenting that one in class this coming Friday. We need to pull together before then.”

Taking some of the heat from Heather, I interject, “You know, guys, I’m actually progressing in all processes I can do on the Web. I’m finding that using HTML is much easier than I imagined. Thanks, Charles for teaching me.”

“No problem, Magnolia, you’re a good learner,” replies Charles, sitting back in his chair, “it’s my pleasure to teach technology or *biochem* to any of you. I got interested in computers when I was a teenager and still love using them. That’s one reason I wanted to be in this Web-enhanced course.”

Agreeably, I respond, “Uh huh, me too.”

Charles continues, “In fact, the course was closed when I found out. I pleaded with Valerie to open the enrollment so I could take the class. It’s quite an opportunity!”

“Constructing the Web sites is helping me *learn* the material instead of just memorizing and forgetting,” I add, lifting both my shoulders as I raise both of my hands. “Like when I did the section on the structure of different classes of complex carbohydrates within our group’s Web site, I was able to pull in vegetables from my own African culture, pointing out the structure of carbohydrates in sweet potatoes.”

“Yeah, that was really cool. I never knew the pigments make the sweet potato orange, so thanks for teaching me,” adds Heather.

“Uh huh,” I continue, as I raise my outstretched arms, joyously, above my head, “I had always wondered the differences between complex and simple carbohydrates. Now I have a much better idea. I will remember the content too, because I explored the domain myself. I find when I can link ideas to my culture and experience, and then I can connect the ideas into my lifeworld.”

I sit forward with my elbows on the arms of my chair. I cross my hands in front of me, as I’m ready for the next project. *I’m anxious to get beyond happenings in the past with Heather’s not helping and address our future projects we still need to do.* “So…for our next project, we need to pick the topic first, decide our individual contributions, and develop a plan to bring the concepts all together.” I bluntly state, then pause to sip my large café latte and nibble at the one single, large chocolate chip cookie I allowed myself, trying to make the cookie last, while awaiting a response. Somehow they keep the chocolate melted inside the cookie, even when the cookie is not hot.

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"I have an idea!" explains Charles, with his right elbow on the table, while raising his hand, pointing up with his forefinger. "In my biology class our teacher mentioned that forces between molecules shape life as we know them. I'd love to understand that idea better, so that's a possible focus."

"Uh huh!" I wholeheartedly agree. "Someone mentioned something similar to me too. Each of us could focus on a different class of molecules and the intermolecular forces shaping life. I'd be interested to follow up more on the carbohydrates, and go beyond their structure and more to their interactions with each other and with other macromolecules. I really want to learn this stuff so once I get a job teaching high school biology, I'll be better able to teach my students."

Bristol responds, "I sort of like your idea of studying different classes of macromolecules, Magnolia," while enjoying his English shortcake and piping hot Earl Grey tea with milk. Just as he learned in England, Bristol asks for a second pot of hot water, to keep his tea at just the right strength and temperature. He pours the brewed tea from one pot and the hot water from the second, both at the same time, into his teacup … quite an art!

The Barnes & Noble's server offers everyone a free sample of Godiva chocolate. Each one is in a small plastic container. I exclaim, "God, I've never tasted Godiva like this before, but I'll go over my self-imposed dose of chocolate today!" The sun's final rays are making everyone facing the west appear rosy and warm.

I question the others, "Does my idea that each of us focus on a class of molecules in Charles' framework of forces 'Within and between molecules,' interest anyone else?" I sit back in my chair, looking relieved that I've thought of bringing Charles' idea to a practical solution, but now nervously wondering about the responses of the others. I finish my café latte and last bite of my cookie, while patting the corners of my mouth with a napkin.

"I think that's a good idea, Magnolia," affirms Bristol. "I'd like to study lipids, if we do follow up with that topic. Lipids are really neat because the interactions between molecules allow them to form a layer just two molecules thick that separates the inside from the outside of our cells. It's a very dynamic system"

Heather interrupts, scratching her nose. *I can tell she's afraid that someone else will pick her desired topic.* "I'd be interested to follow up on the forces that shape proteins and control their functions. Proteins are the workhorses of our cells – they do so many tasks and so quickly that I'd like to understand them better. Proteins also provide structure to living things, like the collagen in our skin and the specific set of proteins in our muscles."

Charles happily chimed in, "Luckily nobody picked the topic I was thinking! I want to focus on nucleic acids. I'm interested in them because they provide

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the instruction and control to our cells that make everything else happen. For instance, a certain gene leads to a higher incidence of a disease, like hemophilia. Through learning the human genome project, we may learn to help those with diseases caused by genetic differences. Choosing nucleic acids for my focus in our presentation fits well with my interest in medicine and becoming an MD."

Enthusiastically, I concur, "Um, huh! That sounds good, Charles," nodding my head.

Charles, leaning forward, adds, "We could look for common themes that each of us find, and bring all the ideas together on our Web site."

"Sounds good. So do you have plans for this weekend? Are you going to the game?" asks Heather, as she quickly changes the subject.

I respond, "Well, I'm not the football type. I don't like crowds. I've already decided this weekend to go to the Collier Seminole State Park with Friends of the Earth on a bird count. It's a beautiful place. The only problem is the mosquitoes – you have to wear 'Off,' so the mosquitoes don't get you. I love the peace and quiet with the nature all around me."

Heather sighs, "Yeah, that sounds great, Magnolia."

Reminiscently, I continue, "Away from the city lights I can see the stars from my sleeping bag. I miss seeing the stars back home in Homestead, but the sky doesn't get dark enough with all the lights from Miami. On Sunday afternoon when I get back I'll research my topic, and post my learning by Sunday night in our dialogue journal on the class Web site."

Heather sits up in her chair, looking back and forth at each of us, and says, "You know, this weekend author, Ursula LeGuin, will be signing her new book, *Exploring Phobos*, here at Barnes & Noble's on Saturday afternoon. She's one of my favorites. I can't miss the chance to meet her."

Interested though, I ask Heather, "What's Phobos?"

"Phobos is one of the two moons of Mars. Phobos is a way station for getting to Mars. There's so little gravity you'd need to tether yourself, so you don't accidentally float away. I would love to be able to jump off the surface of Phobos and be caught by a tether. If the book signing weren't happening this weekend, Magnolia, I'd be interested to go with you."

"Perhaps we could think about the weekend of the Autumn Festival next month," I suggest.

"I've heard about that weekend. That would be fun!" says Heather excitedly.

"Yeah, we should!" I concur. "But continue. Tell me *more* about elsewhere in the universe," I say, wanting to get back to the topic of Mars.

"The recent reports of planets, found using radio telescopes, in other solar systems really gets me excited. It's the whole question about the possibility of life existing elsewhere in the universe that drives me. I feel like the probability is real high…" sighs Heather.

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Charles interrupts, pointing towards the ceiling again with his right forefinger, "So do I."

Heather continues, "I'd love to see that demonstrated in our lifetime. If teacher certification programs offered 'solar system science' instead of 'Earth science,' I'd be the first to sign up." Heather looks smug and really proud of herself for thinking up that line.

I ponderously respond, "If we do find life elsewhere in the universe in our lifetime, wouldn't the biochemistry of life at that site be neat to study? Wow!" *I wonder if life will be found elsewhere in my lifetime, maybe I can help make that happen.*

Heather continues, "That would be *cool*! Would life be based on carbon like on Earth? Would the molecules have the same handedness that we have here on Earth? How would the genetic code for other life forms be made? Would life elsewhere have 20 amino acids in proteins like we have? Is the life we see here on Earth mirrored elsewhere in the universe?" Each one thinks about the implications, but no one responds.

I break the silence, "What are your plans for the weekend, Bristol?"

"I'm working up my short story for Professor Housewright's *Fiction Workshop* class," Bristol responds. "I've got to figure out my story to write. Perhaps I'll fictionalize our group and class with Valerie, as we try to learn biochemistry. I want to incorporate more than I can easily do in writing a story. I am limited in space – after all I am writing just a *short* story. I've got my work cut out for me this weekend, with the short story to write and research to conduct for our biochemistry group Web site. I hope to catch some music at that new club, Jazzerine, on Saturday night. I could listen to that saxophone all night."

Amazed, Heather comments, "Bristol, your being a double major in biochemistry and English fascinates me. You're the epitome of an interdisciplinary person, bridging the worlds of art and science. How do you learn the analytical thinking of science while tapping into your creativity through writing?"

"Yeah, using both sides of your brain," I chime in, remembering this concept from my educational psychology class.

Bristol replies proudly, "I guess it's just my thing. I like the feel of tapping into both sides of my brain. It's the interactions between them that are most stimulating. How about you, Charles, do you have weekend plans?"

'I plan to go to the coast, to take my girlfriend, Sara, for a sail. MCU has a boating club, and we go out on the Gulf on Saturday mornings. I love the feel of the boat in the water, gliding past all these life forms underneath me. Horseshoe crabs look so primitive while they scour the bottom in the shallow waters. We also see jellyfish bobbing on the surface or dolphins playing in the water beside our boat. The light is beautiful in the morning, and the breeze allows us to glide over the water. When we get back on Saturday afternoon I'll do my Web research on nucleic acids and post my results by Sunday night."

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By this time, the sun has set, the mall's lights are on in the parking lot, and everyone is thinking about going home for dinner. Realizing the time, I ask, "When should we get together next, in person, to discuss our findings?" Jokingly, I quip, "We could call it, '*Monday* Night, LIVE!'" raising my hands above my head in a V-formation.

"Aw," responds Charles to my pun.

"We could meet at the Technology Center," I suggest. We can talk in one of the meeting rooms about integrating our learning. Each of us could be on-line together, to follow up on finishing our project. We could talk again right there 'fore leaving. When's best for you?"'

"Tuesday or Wednesday night would be good for me," replies Heather.

"Of those two nights, I'd prefer Tuesday, because we'd still have time to construct our group Web site and prepare our presentation before next Friday's class," pipes in Bristol.

"That's fine with me, too," I add. "But what time?"

Charles responds, "Could we meet at 8 PM? Then we'd have a solid two hours to work before finishing up. OK?"

Everyone nods OK. "Have a good weekend then," I wish to all, "and don't forget to post your research findings with active hyperlinks to sites of particular interest in our electronic dialogue room. Remember… by Sunday night." *I'm sure that Bristol and Charles will respond but we'll see about Heather.*

Sunday night comes and goes, and Charles, Bristol and I post our research, but predictably there's no word from Heather.

On Monday, I lament on-line within our group's electronic dialogue room, "Heather still hasn't responded. She talks big, but doesn't produce. It's part of a pattern, and you picked up on the issue, Bristol, the last time we met. Heather hadn't responded to our e-mails. She doesn't answer her telephone, and her voice mailbox is full. She wasn't even in class today. Regardless, I propose that the rest of us still meet on Tuesday night as planned."

Bristol, Charles and I meet on Tuesday night in a discussion room at the Tech Center. The soft light from the rising full moon offsets the smell of new carpets and furniture as we meet. We sit together at a round table and start our discussion, hoping that Heather will come, even late.

The university has just finished renovating the Technology Center. The place used to house some standard lecture-style classrooms. The university gutted the entire floor and put in a whole bank of computers, all laid out in neat rows. Most of the computers are IBMs, but two per row on the far side of the room are Macs. The natural light comes from the Mac side of the room. You have to show your student ID to the attendant to be able to use the computers. The only sound in the room is that of the computer keys clicking away from 50 or more students working.

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The Tech Center has two electronic classrooms plus a series of small discussion rooms with a warmer feel to them. Each small room has a large round table and four comfortable chairs. Web-enhanced courses like biochem meet in the larger electronic classrooms. Every two students share a computer. There's a main computer and screen with LCD projector that everyone can see in the front of the classroom.

Bristol has a disgusted look on his face and angrily lets loose, "I'm sick of it. Heather sounds so sincere, but she doesn't follow through. She doesn't communicate either, to let us know why, or anything! I bet she'll pull in at the last minute. What can we do to resolve this?"

"Well, we can't control Heather. We could speak to our teacher, Valerie, about the situation. For now, however, let's just get our work done," I suggest. "First though, let me tell you that I did have a wonderful weekend because I got to see two wood storks. I'd never even seen one before. They're so primitive. They reminded me of storks on new baby cards. I know babies don't come that way, but I didn't realize that storks actually still existed…"

Bristol interrupts, "Did you know in Europe many different species of stork migrate from South Africa, funneling over the Sinai Peninsula past Israel, en route to Germany? Closer to Florida, I have seen wood storks on Little St. John's Island off the southern Georgia coast once too. They are beautiful creatures."

"Yeah,' I agree and continue, "I got up early Saturday morning before any others were stirring. On that quiet morning, with mist coming off the wetlands as the sun was just rising, with my binoculars I saw two wood storks right in the swamp. I was shivering, as I felt damp and cool in the early morning. I was shaking enough that I had to brace my arms against a nearby fence so my binoculars wouldn't shake. The storks looked so peaceful and beautiful."

"I've never seen a wood stork, Magnolia," says Charles. "But my weekend was good, too. We saw some dolphins that came up to our boat, and seemed to laugh with us. I felt like jumping in the water with them. One of the dolphins even seemed to smile at me. But one thing was really neat, but scary, was a storm, just north of us."

"Oh, yeah," I recall, "I think I heard about the waterspout and ensuing tornado on the news."

Charles' face turned white while he recalled, "We actually saw a waterspout, reaching down into the water, pulling up water, and then moving into a residential area, just south of the Naples' pier. We heard on the evening news that 35 homes were damaged."

"Charles, I know the feeling," I break in. "In the summer 1992, Hurricane Andrew disintegrated my family's house in Homestead, Florida, just south of Miami. As the storm approached, I watched the weather channel and saw that angry eye of Andrew barreling down, heading straight for Homestead. We got

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out just in time and went to a shelter that, thank goodness, survived intact. I'll never forget the sound of the storm – the hurricane sounded like a train was going over the roof of our shelter, and you could hear branches and other objects hitting the walls. I was afraid we wouldn't survive."

"Whoa, that must have been horrendous, Magnolia," Charles sympathizes, "How old were you then?"

"Fifteen," I almost whispered. My hands were visibly shaking as I remembered that awful night. "I was at a time in my life when I had just been thinking of becoming independent of my family. After the storm I helped my parents and brother and sister to reconstruct our lives. The hurricane brought my family closer together," I say, with a far away look in my eyes, remembering the horror of the storm and the weeks and months of chaos afterwards.

"You know, our teacher, Valerie, was on the news, too," notes Charles. "Apparently, she was visiting her parents' home when the waterspout hit their residential area. A waterspout is actually a mini-twister, and it pulled her parent's home apart while they were inside the house. She looked dazed on the TV news. She said that she figured that a tornado had hit from the speed of the wind coming in her window. She got her parents and herself into the hallway moments before the tornado hit. She said that after an intense noise, she peeked through the hallway door into the living room area, and the room was totally gone. Everything was topsy-turvy. The walls were down, and the roof was pulled off half the house. She could see the palm trees where their roof used to be. They were just lucky they had all gotten into the hallway, as that part of the house was still intact."

"Phew, that is lucky!" I say, "I've always heard to get into an interior room with lots of support."

"Valerie mentioned being in the tornado in class on Monday, but I think the full reality of the tornado hasn't hit her yet," Charles noted.

"I saw that news broadcast, too on Sunday morning," acknowledges Bristol. "One other thing that Valerie said was that she remembered the tornado that carried Dorothy away in the *Wizard of Oz*. She said the tornado sounded like a vacuum cleaner in the sky, sucking up anything and everything in its path. My own weekend was much less eventful, with writing my fiction short story and researching our biochemistry Web site. I did go to the jazz club and relaxed some on Saturday night. Would any of you be interested to give me a critical review of my story?"

"I would love to read your story, Bristol. I have always loved to read fiction, so I might be of some help, and I would be interested to see your interpretations of our group interactions. I have a narrative I could share with you too." I respond enthusiastically.

To get back on task, I quiz the others, "What did you find out about molecular interactions with lipids and nucleic acids? I posted my Web sites first in the dialogue room, and haven't had a chance to read your postings

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yet. Should we all just go look at them now, deciding on a common theme we can develop? We can go into the main room and each have our own computer on-line."

"OK," responds Charles, "We'll talk again in about 30 minutes."

Even though we're having this crisis in our group, with Heather not coming, I feel this provides me an opportunity to grow. I pull my two group members back together after reading their Web links in the class' virtual dialogue room. "So, what do you think? Do you have an idea on our theme?"

Bristol rubs his well-defined beard with his left hand and holds a clipboard with tabulated paper in his other, while drawing the structure of a lipid bilayer. "I think it might be neat is for us to focus on interactions within a molecule and compare them to interactions between molecules. The interactions within a molecule control its shape and electron density, and basically the interactions with other molecules."

"Uh huh, oh, I understand," I say, nodding my head.

"I'd like to focus my part of our presentation on biological membranes." Bristol continues, "We could call our presentation, *Intra- versus Intermolecular Interactions*. In my project I found that small molecules, generally phospholipids, interact with each other to form flexible structures that are generally impermeable, except to water and molecules that have specific receptors."

I interrupt, "It's amazing that the membrane surrounding our cells is just two molecules thick."

Bristol continues, "But looking at the links you had, Charles, for nucleic acids, you can see *intra*molecular interactions between the two strands of DNA that exhibit complementarity between the bases on each strand. But the packaging of DNA and proteins into chromosomes constitutes *inter*molecular interactions."

"Uh huh, I can see that same theme in the carbohydrates!" I say, obviously excited about the linkage. "Carbohydrates are important on the cell-surface, as they attach covalently to many proteins and certain lipids. The *intra*molecular interactions influence each molecule's shape and the molecule's mobility in the membrane. These molecules can identify 'self' to other cells, so the carbohydrate links to the *inter*molecular interactions. I'm starting to see our theme emerging."

Glad that these topics are coalescing, Bristol points out, "I think the three of us are going to be OK on our topic. Let's put together the HTML code that connects some of the neat diagrams we have found on the Web. Remember to credit the Web site where you found your figures. That's one of the criteria on which Valerie assesses us. If you're bold, you could try making a table summarizing your results."

"Yes," agrees Charles, moving forward in his seat, and raring to write the HTML code, "I can set up the main page for the group Web site, providing links to your page. We still have the problem of Heather, but we must just go

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ahead. It's too bad, because the proteins that she was going to do would have emphasized our learning."

I suggest to Bristol and Charles, "Can we all get together on Thursday night to practice, same time, same station…?"

They both agree, so it's set.

"Just in case Heather finds our writing, I'll post our ideas now in our dialogue room." I sigh in parting.

On Thursday night, surprisingly, all four members of our group show up in the Tech Center. We meet in one of the discussion rooms. Bristol purposefully shuts the door, just after Heather arrives. He faces Heather directly, and raises his voice, "Where are your contributions, Heather? We've done our part, and you didn't come or even tell us anything."

"My modem blew in that storm on Saturday morning, so I was incommunicado. I couldn't log on. I live right on the fringe of the location that waterspout hit. We had emergency vehicles on our block to help the people whose homes were hit. I helped a man whose house was blown apart. All his computer disks were blown all over, and some of us helped to gather them."

Astounded, Charles sympathizes, "That must have been something, you must have felt scared, Heather'.

"You're right, Charles, I was," Heather continues, still obviously shaken. "But for now, I need to concentrate on our group project. I did read about proteins in our textbook but didn't get out to the library because of all the confusion once the waterspout hit. I finally got back to school earlier today and checked our dialogue journal. Thanks, Magnolia, for posting our meeting time tonight. May I contribute, or am I too late?"

I, still annoyed by her last absence, retort, "You could have called *any* one of us on the telephone. Remember we exchanged telephone numbers when we first formed our group?"

"Magnolia, you don't understand. I've been through a lot. Being in an experience like that shook me to the core," replies Heather, earnestly.

Backing down a little, I continue, "I know the storm and aftermath must have been tough. I've been through a category-4 hurricane, so I know the feeling. At least you had a house over your head, Heather."

"You're right. But the storm still shook me," explains Heather, while looking at the floor.

"Heather we're all feeling the pressure from our group assignment," I maintain. "We've got our group project to present, and it's tomorrow! We've already chosen our theme of looking at intramolecular-intermolecular interactions in each one of the domains we've discussed."

"If it's OK, I'll put mine together later tonight and send Charles my Web address," Heather suggests. "In the presentation tomorrow, I'll let the

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three of you go first, and I'll take any time remaining, trying to tie all our ideas together."

Pausing for a second, I agree, "That's OK with me," but ask the others, "How do you two feel?"

Charles smiles, concurring, "Let's give the process a whirl," while giving us a big wink.

But Bristol rolls his eyes, looking annoyed. "I still feel let down that you didn't even try to call any of us. I recognize that you had an experience you will not forget, but you need to learn to be responsible too. For instance, our teacher, Valerie, was in the tornado too, and her house was destroyed, and she came to class on Monday. We do need to work together. Well…OK…but don't let this sort of thing happen again, Heather."

I am starting to see the pattern of occurrences in our group, and almost jokingly quip, "I guess our own group has both intra-personal and interpersonal interactions in a way, like the molecules we're studying. If we allow both types of interactions, self-reflection and group interaction, and harness the energy, then we'll tap into the life force that keeps us all together, growing and learning."

4.3 Writing the Story

4.3.1 Data Sources – My Students

One primary data source for my fictional story included the open-ended responses from my students on the LEQ (available at http://www.chem.fsu.edu/~gilmer/downloads.html), given during the last week of classes. As I typed the students' hand-written responses, I remembered both the positives and negatives of teaching our class and the learning experience. I typed these responses shortly before enrolling in the *Fiction Workshop* class with Dr. Sheila Ortiz-Taylor as my professor. My students' responses gave me fodder for the fictionalized story.

Also during the semester that I taught the biochemistry course, each week I read the student responses from the CLS (available at http://www.chem.fsu.edu/~gilmer/downloads.html). Students wrote about the coherences and contradictions of working in their group as well as commenting on needed improvement for their group work. My learning from reading the students' answers on the CSL form was a chance for me to respond and adapt in a formative manner to the weekly pressures and students' issues in our classroom.

Other primary sources that informed my fiction writing include a transcribed interview with Mary (available at http://www.chem.fsu.edu/~gilmer/downloads.html) at the end of the semester, portions of Suzanne's electronic portfolio (Tables 5.1 and 6.4) from class, and Michael's response in the optional final examination (Fig. 6.2b).

4.3.2 My Reflective Journal – When Writing the Story

Most students in the Fiction Workshop were upper division, creative writing majors. One student double majored in creative writing and chemical science and, therefore, was the closest to me professionally.

4.3.2.1 Worksheets as a Tool to Writing

One assignment for this fiction workshop was to keep a journal of the fiction-writing process. As I would get ideas, I would write about them first in the journal, explore the ideas, and then put them into my fictional story.

I provide the worksheets in order to show the reader the process of reflection in my writing. I needed time to write and learn in order to express ideas about my classroom. Writing helped me understand the interactions in the classroom and awakened me to the emotions that surfaced between students, the dealings I had with my students, and the relationships they developed with each other. Writing amazed me because I became so much more aware of interactions with others; the non-verbal messages among people; and the scene, including the lighting and arrangement in the room; the clothes people wore; and even the smells in the room. Life truly is so rich.

The worksheets drastically increased the amount we wrote for the class and provided us with a new way to work through each story. After writing the first "story," I realized that, in fact, my first attempt was not even a story – I had the students in the class meet each other, but I provided no conflict to resolve. I had no "hierarchical or 'vertical' nature of narrative, the power struggle" (Burroway 1996, p. 35).

I tried again and wrote my second story, utilizing feedback from my fellow students and our teacher. The actual worksheets for story 2 were about twice as long (2,000 words) as the abbreviated version provided below. The benefit of writing worksheets is that I identified and reflected on the occurrences in the classroom and worked through various issues that I needed to address.

Below is an abbreviated version of the worksheets that I wrote in my journal for my second fictional story, which is part of this book. The worksheets are set within the shaded boxes to differentiate them from the rest of the text.

Abbreviated Worksheets for CRW 4120, Story 2

18 October 1999

What did I learn from writing the first story, receiving critiques from Sheila Ortiz-Taylor and my fellow students, and critiquing my fellow student's first stories? First, I [really] learned the criteria that Sheila Ortiz-Taylor has spelled out for us on our *Criticism Checklist*.

My fellow students have had English classes here (in fact, many are majoring in English), and for me my last English class was in 1962. I finally figured out the term, POV, which means Point of View (I kept thinking of POW, for prisoners of war – that dates me – and wondering what they meant). Also I had not really heard the term a "round" character before, but the idea makes sense…to see the character from several vantage points. The term, "red herring" is a good one for information given that is unnecessary.

I guess I'm still not clear what is meant by tone and tone shifts.

Before I wrote my story I was unaware of the importance of conflict and tension in a short story. Of course, I've read much fiction in my time, but had never sat down and thought what makes good fiction. I guess that is one reason why I decided to take this course. If I want to write good fiction, I need to learn what makes good fiction. It probably sounds silly to writers, but that is what I needed to learn. I sort of knew it [in my first story I had portrayed no conflict at all], but I avoided the conflict – I think that is a pattern in my life. If I learned to pay attention and deal with the conflict, it would help in other domains of my life.

Critiquing the stories of others and listening to the critiques by others were particularly helpful for me to learn what makes good fiction. Many of these key points came up and became clarified in my mind.

28 October 1999

I did have a chance to get feedback from my two group members, present in the last class (Danaé and Rachel). I also sent my "draft zero" chapter [of my second story] to one of my students (Suzanne) from biochemistry (the class which I am studying for my doctorate) and to one of my major professors for this degree in science education.

What was important to me was getting Suzanne's reaction since she was in my classroom, and she would know if I captured what was happening. Some of Suzanne's comments included:

(i) "nice use of imagery and an accurate portrayal of a student type" (about Bristol);
(ii) "intelligent simile" (about the tornado like a vacuum cleaner);
(iii) "another accurate portrayal" (about Magnolia not being good about confronting problematic issues);

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(iv) "adds drama to the situation" (about Bristol breaking out in a sweat);
(v) "I see her" (about Magnolia lowering her arms and then addressing the business of building a Web site);
(vi) "consistent thing for Magnolia to say considering she is the character that doesn't deal well with conflict" (after Magnolia had said let's get back to work);
(vii) "LOVE THE ENDING!! It's scientific, creative, and philosophical."

What meant the most to me was Suzanne writing in her e-mail:

> Your paper is excellent … you really understand your students. The attitudes of your characters were excellent and their conversations were realistic as well. I especially enjoyed reading the physical descriptions of the students as they displayed their feelings (Bristol getting mad and frustrated—Magnolia in charge and confidant). These were really amusing – as were the dialogues they shared, a lot of it sounded all too familiar. (E-mail, 24 October 1999)

Suzanne also had some ideas on presenting the science (some of which I addressed, and some of which I will probably do after the general read by the students in the fiction class). With the feedback I've received so far, I have reconstructed the story, and I think it's improved. I'm still not sure of the title.

I've incorporated much [of what] I learned from my first story. To help me learn from the feedback from you, Sheila, and my peers, I constructed an annotated corrected copy, with everyone's corrections included within one electronic file, at the appropriate place. This allowed me to see what everyone had said about the same section of my story. This was the biggest help.

I plan one other chapter in which the group members will find Bristol's short story, in which he presents his own view of my classroom in fictional form. This will allow a look at Valerie (the teacher) as well as at his group members (again fictionalized). I'm trying to figure out what names to use for them. Do you have any ideas on that?

7 December, 1999

I have made many changes to my story 2, getting feedback from my class members and you, Sheila. I worked on it for a whole day of Thanksgiving weekend, and read my story to my husband and children while we drove home to Tallahassee.

I have a friend, Bonnie Armstrong, who's taking the other [section of] *Fiction Workshop* this semester, and she read my story 2 also. It was especially helpful for Bonnie to read my revisions since I made the ones from my class members. It was interesting that Bonnie thought the story would be stronger with the point of view of Magnolia or Bristol. I told her that my first story was from Magnolia's point of view (POV), so I decided to return to that in story 2. This required a rewrite. I'm sure I could do more (and probably

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will as I get feedback from my major professors and as I write the rest of my dissertation), but time is running out.

I find as I reread Janet Burroway's *Writing Fiction* book now, I get so much more out of it, now having tried to write fiction and having read my peers' fictional writing. I found this especially so in her chapter on *Characterization: Part II* (Chapter 5).

I've added more setting (but perhaps still not enough). I've also added about what the character speaking is doing. I realize that I could add what the listeners are doing too. It seems like it could go on forever. It's probably like having a child, with a long pregnancy while the ideas are incubating, and then a labor and delivery, getting ready for the delivery tomorrow when the papers are due.

4.3.3 Critical Feedback to Others in Fiction Workshop

I gained immeasurably in my effort to learn to write fiction by reading and providing critical feedback on the 'draft zero' and later drafts of the stories written by the three other members of my collaborative group in the fiction workshop. During class we would spend time reading each other's stories, and then examine one student's story at a time, with feedback from the others. In addition, for the penultimate draft before submission for grading, we commented in writing on the short story of every student in class (about 25 students). Additionally, we focused orally on reviewing each short story, one at a time, to get feedback from the entire class. So, not only did this course require writing, but also demanded that I read and critique the writing of others.

Dr. Ortiz-Taylor provided a set of written criteria for fiction writing (Fig. 3.3) that we used to evaluate our peers' and our own writing. As I did this, I became more aware of the criteria that make a story work well.

4.3.4 Point of View in Fiction

A friend, Bonnie Armstrong, was sharp to notice that the point of view makes a significant change to the story. Burroway (1996) dedicates about a sixth of her book on writing fiction to writing about the point of view. Point of view means the vantage point, or "Who is standing here to watch the scene?" (p. 199), rather than simply meaning someone's opinion.

Burroway (1996) starts her first chapter on point of view as follows:

> *Point of view* is the most complex element of fiction. Although it lends itself to analysis, it is finally a question of relationship among writer, characters, and reader – subject like any relationship to organic subtleties. We can discuss person, omniscience, narrative voice, tone,

> authorial distance, and reliability; but none of these things will ever pigeonhole a work in such a way that any other work may be placed in the exact same pigeonhole. (p. 199)

Concerning my own fictionalized story, I respond to Burroway's five questions on point of view:

1. Who speaks?
2. To whom?
3. In what form?
4. At what distance from the action?
5. With what limitations? (p. 199)

4.3.4.1 Who Speaks?

My final rewrite of the fictionalized story has Magnolia, an African American female student, as the first person and peripheral narrator. I chose Magnolia since she has an important point of view, as an underrepresented minority in my classroom. I identify myself as an underrepresented woman in science, so I empathize with other minorities. I chose Magnolia as the central character, emphasizing the caring that I felt for African American students. Magnolia became more assertive and self confident through the story line. I saw this evolution occur with a number of students in our class, including other African American students. Magnolia, the central narrator or protagonist was one, "the *I* telling *my* story" (Burroway 1996, p. 206).

4.3.4.2 To Whom?

I had in mind several audiences when I wrote my story. These audiences include:

1. The former students of my biochemistry class. I used the fictionalized story as a tool to help me get in better touch with the happenings in our learning community in the Web-enhanced class. My hope was that my account would touch the emotions of my students and help them remember their experiences. Through their critical dialogue, I wanted to learn more on new avenues to improve teaching and learning for future classrooms. I fictionalized the characters with the idea to incorporate aspects of various people in the story. I wanted the story to seem familiar to my former students, to trigger recollections of our Web-enhanced class. My fictional story actually became a research *tool*, as I learned more about our classroom from my students as they read and reflected about the story.
2. My university faculty colleagues in chemistry and biochemistry and other areas of science. I hope that university faculty would read this story and learn of alternative ways to conduct educational research, rather than the control and experimental groups that many often envision as the only appropriate model of educational research (because of its similarity to scientific experiments). I want my science colleagues to become aware of alternative ways of teaching, learning,

and assessment, besides the traditional lecture with students passively taking notes and then memorizing the material.

3. The science educator. I think that university and college science educators would be interested to experience fictional writing as a way to share qualitative data about science education research in a way that gets at the problematic issues that need to be addressed to improve science education. Using fiction is one method that allows emotions to surface, and emotions are powerful forces that can influence learning.
4. The general reader. Hopefully, this story interests other people by showing them not only the power of working within collaborative groups but also the problematic issues that can arise in human interactions. The chemist and the inventor of birth control pills, Carl Djerassi (2000), has turned to writing science-in-fiction and science-in-plays to bring science to a wider audience. Perhaps this same goal is possible with fictionalized stories about learning. As a writer, I have come to realize the power of writing, using fiction to draw people into the story and facilitate learning.

4.3.4.3 In What Form?

Burroway (1996) and Tierney (1997) explain many possible forms of fiction writing, including generalized story, reportage, confessional, interior monologue, stream of consciousness, monologue, oratory, journal, diary, etc. My own story is a generalized story with spoken words and a central narrator, Magnolia.

Burroway explains:

> Form is important to point of view because the form in which a story is told indicates the degree of self-consciousness on the part of the teller; this will in turn affect the language chosen, the intimacy of the relationship, and the honesty of the telling. (p. 213)

Often the form my fictionalized story took was spoken aloud, allowing more spontaneity than if I had written the story with the characters writing e-mails to each other, for instance.

4.3.4.4 At What Distance from the Action?

Burroway (1996) discusses authorial distance:

> Authorial distance, sometimes called psychic distance, is the degree to which we as readers feel on the one hand intimacy and identification with, or on the other hand detachment and alienation from, the characters in a story. (p. 229)

I use the present tense in my story in order to encourage the reader to enter the story and make the story more immediate.

The tone of a story is harder to define, as the author's tone filters through the characters to the reader. Each reader may interpret the tone differently, depending on the life experiences of the individual. As Burroway (1996) states, "...you as author manipulate intensity and value in your choice of language, sometimes matching meaning, sometimes contradicting, sometimes overstating, sometimes understating, to indicate your attitude to the reader" (p. 235).

I tried to set a tone for one character, Bristol, as a strong character, clear about his goals. He shows his strength through his actions and his words. For instance, in the beginning of the story, Bristol spoke and I described him:

> Bristol breaks the hushed tones, as he insists to his three group members from their Web-enhanced biochemistry class, "We haven't been effective in creating this group Web site because we haven't met to get our links together. So far only three of us have communicated by e-mail."
>
> Bristol, born in the Bahamas of African descent, lived in England for eight years before emigrating to Miami. Now he's an American citizen, currently attending Mabel Clark University. Bristol rubs his short cropped, black beard back and forth with his left hand, while tapping the forefinger of his right hand, waiting to see whom in his collaborative group responds.

I could feel Bristol's presence in the room with his group members, while he was feeling impatient with Heather, but trying to be patient, as he tapped his right forefinger and rubbed his beard with his other hand, waiting for his team to start to collaborate.

4.3.4.5 With What Limitations?

Burroway (1996) points out that the fiction writer develops characters with points of view to which we may identify and others which we may oppose. The reader learns of the teller of the tale through that character's point of view. Burroway provides examples of the unreliable narrator, "who has become one of the most popular characters in modern fiction" (p. 239). One example Burroway cites is Huck Finn's assessment of Tom Sawyer. Burroway points out readers may intellectually oppose Huck (because of his assessment of Tom) yet we may morally identify with him. In point of view, the author wants the readers to identify with the "attitudes, straightforward or ironic, of the authors and narrators who present us these characters" (p. 237). Giving us some other examples from fictional works, Burroway argues that, "we identify with Othello's morality but mistrust his logic, trust Faust's intellect but not his ethics, admire Barney Fife's heart of gold but not his courage" (p. 239). Burroway states, "the unreliable narrator always presents us with dramatic irony, because we always 'know' more than he or she does about the characters, the events, and the significance of both" (p. 239).

I first wrote this story from the point of view of Bristol. However, with the advice of my friend, Bonnie, I decided to rewrite the same story from the point of view of Magnolia. That process of rewriting made me realize the degree by which point of view modifies the story. I had to rewrite various sections, to portray Magnolia's point of view, as well as focus on the aspects of the scene that Magnolia notices and remove Bristol's perceptions. I believe that the second time I wrote the story from a different point of view that I learned more about the scene. Each person has a different point of view, based on people's prior experiences and present goals, thereby fitting with the principal ideas of constructivism. Had I rewritten the story from all four characters' points of view, I am certain I would have an even greater understanding.

Burroway closes the two chapters on point of view with the following advice:

> I'm conscious that this discussion of point of view contains more analysis than advice, and this is because very little can be said to be right or wrong about point of view as long as the reader ultimately identifies with the author; as long, that is, as you make it work (p. 242).

Readers may decide if you identify with me, the author, and if the story works for you as a way to address problematic areas of teaching, such as using alternative assessment through collaborative groups.

4.3.5 My Perspective

My perspective as the story's author was that providing collaborative learning groups for students could be a powerful way to enhance students' learning (Bruffee 1993). I have benefited personally in collaborative learning through five science education graduate classes that I took as a student (four were at FSU and one was through Curtin University of Technology) and the fiction workshop that I took at FSU. Collaborative learning is powerful because the process is social and students use language that helps them construct meaning. However, collaborative learning has problems too, resulting from social interactions when students' goals and ways of working do not mesh. If students resolve interpersonal differences, collaboration can greatly facilitate learning by providing a constant venue for students to use the discourse of the subject matter.

When I was in Australia in 1997, I met Judy MacCallum at Murdoch University and learned about her video with Jim Macbeth called *Collaborative Learning: Working Together in Small Groups* (MacCallum and Macbeth 1996). The MacCallum and Macbeth video depicts a four-stage model for collaborative learning: (i) finding common ground, (ii) roles and goals, (iii) getting the job done, and (iv) reflecting. Even though I understood the MacCallum and Macbeth model for collaborative group work, I decided not to take class time (23 min) to show the video, although I made the video available for groups to watch. One group that had early troubles with collaboration did watch the video during office hours, and afterwards had less trouble. Afterwards, I realized that collaborative groups might have had more success had I shown the video in class, as most biochemistry and science majors did not have much experience working with collaborative groups.

The video comes with a series of questionnaires that students in collaborative groups can use to reflect on their experiences. MacCallum and Macbeth granted me permission to adapt their four forms for groups or group members (provided that the reference and copyright are indicated). The four types of forms from MacCallum and Macbeth include the (i) Individual Reflection, (ii) Individual/Group Reflection, (iii) Meeting Record, and (iv) Final Group Evaluation. All four forms were available for my students to use. For the class, I only collected the Final Group Evaluation

Forms, one for each project for each group, three samples of which can be found at http://www.chem.fsu.edu/~gilmer/downloads.html. For the thesis and this book, I used the name Collaborative Learning Survey for the Final Group Evaluation form.

Each week I read the CLS forms that each of the ten groups submitted. Reading and reflecting on my students' comments gave me an indication of the problems that existed. The students completed the CLS forms in class on the day projects were due – in the heat of the moment – so students' emotions sometimes showed. I utilized these data in my fictionalized story (this chapter) and in my analysis of collaboration (Chapter 5) and technology (Chapter 6) in the classroom.

4.4 Receiving Feedback on Story from My Students

I was able to contact about one third of my students from our biochemistry class to ask them to read my story and provide me with feedback. I gave my developing story to one student, Suzanne, so her comments are in my worksheet, found earlier in this chapter. I have selected four additional students, representative of the responding students, to present you, the reader, with my students' reactions to the story.

4.4.1 Mary, an African American Future High School Science Teacher

Mary was an African American student from Florida with plans to become a high school biology and chemistry teacher. I was particularly interested in future teachers of science because, at the time, I was just becoming one of three co-principal investigators of a grant, called the Florida Collaborative for Excellence in Teacher Preparation, funded by the NSF, Division of Undergraduate Education (http://www.ehr.nsf.gov/due/).

Mary was in a collaborative group that needed attention at the beginning of the semester to make the group functional. I met with Mary and her group members for over an hour, helping the students learn to listen to each other and work together. Mary was the student I interviewed in depth at the end of the semester. I transcribed the tapes from her interview myself, and my doing so opened a doorway into Mary's point of view and her way of talking.

About a year later, Mary came to see me in my office, and I gave her a copy of the transcript of my interview with her. I asked her to look at the transcript and do a "member check" for me. I did not hear back from her until I sent her the fictional story and asked her for feedback. She had forgotten I had given her the transcript of the interview earlier, but then she found it. She commented both on the story and the transcript of the interview. In addition, she commented on the impact of the course and her changes in thinking about teaching and learning. I include here a few of Mary's sentences about the story:

> This short story about the technology-based biochemistry course was excellent. The scenario depicted any group of students that worked together for the duration of the course. There is commonly a levelheaded member who guides the group with confidence. One or two members of the group show strength in the course content and/ or the technology of computers and the Internet. Then, there is the student who is always "so busy" and lacks cooperation and commitment. As I read this short story, I tried to figure out who held these characteristics in my group and [other] members of my class.Details of the student's lifestyles and daily events give the reader(s) some insight into the student's environment. I liked the illustration of the atmosphere at Barnes & Noble. I know that I studied there from time to time when the Library got full during final exams week. Inserting the events of the tropical storm and its connection to hurricane Andrew was great. That particular part brought back memories of my own experience with Hurricane Andrew. Last but most important were the details of what the students planned to do over the weekend. The science majors at Mabel Clark University are very diverse in background and interests. Our university town provides an hour's access to the Gulf Coast, and a variety of activities around town. (E-mail, 27 June 2001)

I felt satisfied that Mary thought I accurately portrayed the dynamics of the class. I was particularly interested she could see the structure of the groups, with individuals in the group assuming certain roles. This connection between the structure that I provided in the classroom and the students' sense of agency corresponds to Sewell's ideas on the dialectic tension between structure and agency. Reading the story triggered Mary to think about the roles that characters assumed in the story, because she could see the parallel with the groups in our classroom. Mary identified with the scene in which the students met in Barnes & Noble because Mary sometimes studied there. Mary had told me about her own family's ordeal with Hurricane Andrew, so she appreciated that connection in the story as well.

Mary matured in the course. She began the semester feeling not very confident and a bit overwhelmed by all the tasks she had to do on her own or with her group. In her portfolio for the contribution to her first group Web site on adenosine-5'-triphosphate (ATP), Mary wrote the following two sentences:

> My contribution to the project consisted of looking for Web sites and putting them on our group Web site. In the presentation, I will present the part on two of the Web sites we found. (Electronic portfolio, 1st group Web site)

I wrote her back her grade of "Good" which is equivalent to a "C," with the following advice:

> Mary, please reflect on your learning, including all the criteria in the rubric. For instance, tell me something about the science that you learned, how does it relate to your prior learning, what sorts of links did you provide, and what were some questions that came to you after doing the research?

For the students' online individual portfolio entries and their collaborative Web sites, I had a rubric of the requirements for an "excellent" grade, to give students a guide for their responses. Science majors were not accustomed to writing or utilizing a rubric. I list the points of the rubric in Chapter 6.

Later in the semester, I assessed Mary's portfolio responses as "Excellent," equivalent to an A. Not only did she learn the type of responses that I sought, but also her responses suggested to me that she started to learn the biochemistry. Mary mentioned working with Dana helped her with the technology:

> I can safely say that I worked very hard on this week's Web site. Instead of just a couple of links and words, I made my own Web site off of Geocities. I was also able to help Dana with her contribution to the Web site. I believe that she has a better understanding for HTML and the difference between secondary structures and 3-dimensional structures of proteins.
>
> My site was a brief explanation of the α-helix. This structure is just one of the three possible secondary structures, which are the β-pleated sheet, the 3_{10}-helix and the p-helix. The α-helix [is the] structure commonly found, in comparison to the p-helix and the β-helix [she meant β-pleated sheet].
>
> There were two major points that I learned from this search about the α-helix. Two of the sites that I found talked about an ω-angle. It is found between the carbonyl carbon and a nitrogen molecule [sic]. It normally has an angle of 180°. I also learned that the helical structure could sometimes be distorted in a complex structure of more than one type of secondary structure. I also learned that the 3_{10}-helix could be found near the end of a α-helix of some proteins.
>
> My one and only question about the α-helix is what is it in the amino acids that make them choose the α-helix formation versus the β-pleated sheet? (Mary's contribution to her group's sixth Web site on proteins).

Mary showed some intellectual growth from her first portfolio entry to her third one on protein structure. However, I missed at least one mistake that Mary had made on her Web site. Mary had said that the ω-angle was between the carbonyl carbon and the nitrogen molecule (and she meant nitrogen atom). I think Mary was referring to the planarity of the peptide bond, with the ω-angle to which she referred as 180° being the angle within the peptide bond connecting the carbonyl C and the α–C and the bond connecting the N and the α–C. However, we generally define the angles, ψ and ϕ, for a peptide bond using Ramachandran plots. Mary did not mention the angles ψ and ϕ. I concluded that Mary had learned some biochemistry but did not clearly understand all the subject matter.

Mary's one question in her electronic portfolio on the three-dimensional structure of proteins (e.g. "My one and only question about the α-helix is, what is it in the amino acids that make them choose the α-helix formation versus the β-pleated sheet?") was interesting on the linking of certain amino acids together to form the α-helix rather than the other types of secondary structures, like β-pleated sheet. Physical biochemist Alan Fersht made portion of his research career from studying why certain amino acids help favor one type of protein secondary structure over another.

During the semester, I responded to Mary, as follows:

> This is excellent work, this time, Mary. I can tell you are starting to learn much more. Your hard work shows. Keep up the good work.Cheers! Penny (dated 10/4/98)

I found that the questions that the students asked were a good indicator of their thinking. Some of the other questions that Mary asked included the following:

> On DNA: My question on this subject is if there has been a policy set by the FDA as to lengths that scientists can go on the alterations to the genetic makeup of living things. (Mary's question on the Chapter 4/5 Web site)

> On hemoglobin: I wonder if the pesticides used today will help to minimize these mosquitoes, carrying malaria, from infecting the general population. [This question triggered Mary's interest because she is an African American. There is an incidence of sickle cell disease with African Americans due to a mutation in the DNA, which codes for the hemoglobin protein molecule. Those with sickle cell have an unexpected benefit of being resistant to malaria, but these same individuals are more likely to die because the sickle cells that contain the mutant hemoglobin tend to form a sickle shape and get stuck in the blood vessels when there is low oxygen pressure.] (Mary's question on the Chapter 7 Web site)

> On carbohydrates: My only question on this matter is if food is produced only in space, will it affect our digestive tract differently from food produced on Earth? (Mary's question on the Chapter 9 Web site)

> On vitamins as coenzymes: Are water-soluble vitamins better than oil-based vitamins? (Mary's question on the Chapter 11 Web site)

I noted that Mary's comments especially focused on practical applications to the world around her.

4.4.2 Franklin, an African American Premedical Student

I gave Franklin, an African American male undergraduate student from the biochemistry course, a copy of an earlier version of a paper that included the fictionalized story (Gilmer 2000a, b, c) after the *Fiction Workshop* concluded, and asked for his critical feedback. He said:

> I must say that it was interesting reading such an account after such a long period of time. Many of my feelings and even frustrations that I felt when I was actually in the class came rushing back. I guess that means that it was a realistic account of what occurred. (E-mail, 28 May 2000)

I felt encouraged that Franklin, like Mary, felt emotions while reading the fictionalized story and that the story elicited his remembering (about 18 months later) the frustrations that he felt when taking the course.

Franklin outlined two things that stood out for him about the biochemistry course.

> One was the frustration, which was involved in dealing with three other peers with different backgrounds and different levels of understanding, and the other was the benefit that came out of those differences interactions. (E-mail, 28 May 2000)

The key words that I noticed in Franklin's statement include *frustration, peers, backgrounds, understanding, benefit, differences* and *interactions*. Those seven words seem to sum up the experience of many students. Franklin commented further:

> I seem to remember that not only did I learn about various biochemical concepts, but also I learned about computers and science education and a heap of other subject matter than

> came about as a result of these collaborative groups. I also got a taste of public speaking and actually presenting scientific material in a manner that any science major or science education major might be expected to do in any graduate program. Working with graduate students now I have seen the lack of some of these things and their effects. It often makes understanding the material difficult. (E-mail, 28 May 2000)

In listening critically to Franklin's words, I could see the depth to which I had asked my students not only to learn biochemistry but also work in collaborative groups, present orally their understandings of complex biochemistry content, learn from fellow students' presentations and become skilled at using computers effectively.

An anonymous student in the LEQ made a suggestion that relates to Franklin's comment on the amount of learning needed and the academic credit received in the course. This student suggested offering the course as a 4-credit hour course (instead of 3-credit hours). In that way, we could couple a regular 3-credit hour class to a 1-credit hour computer laboratory (that would meet for 3 h of classroom, plus 3 h per week of computer laboratory). This would give students time to learn to use the computer in a setting with technical help, plus the 4-credit course would give students time to meet as a collaborative group. All students would have the same time and place to meet each week, and this set-up would have averted some of the frustration of finding a common time to meet to work on collaborative group projects like constructing their group Web site.

I am confident that learning in a postmodern way was tough for my students when their other three semester-hour science courses were basically lecture format. I thought having the class as the first of a two-semester sequence may have put my students at a disadvantage in the second semester, with most of their fellow students having had a traditional lecture course in the first semester. Franklin commented on this point:

> The downfalls that I see with this type of learning is that as with our case this type of learning was not used by any other professor, and unlike other lectures where you usually have the same professor for at least two consecutive semesters that leaves the student at a disadvantage. I do not think that this type of learning environment would be difficult if used for an introductory level class, i.e., Biochemistry etc. for non-majors. It would be excellent for someone unfamiliar with a subject to seek out what it really is about and make practical applications. (E-mail, 20 May 2000)

I think that Franklin was correct that students would not have had as hard a time in our class had the biochemistry course been just a one-semester course instead of part one of a two-semester sequence. Another biochemist would be teaching the second semester of the two-semester sequence, so students felt that they needed the foundational knowledge. Many of the students in my class were premedical students, including Franklin, and they were still assessed for medical school, mainly by traditional multiple-choice, MCAT tests. Franklin addressed this point as well:

> The thing that I found somewhat difficult as a premed student was making sure that I had covered the important foundational concepts that I would find on the MCAT or some other standardized test. Especially, since they are presented from an old standard methodology of teaching and not this new postmodernist view. (E-mail, 20 May 2000)

Related to Franklin's point on foundational knowledge, I want to mention that before starting to teach the biochemistry course, I had just finished reading a book on a postmodern perspective on collaborative learning (Bruffee 1993). I had confronted non-foundational knowledge once before when reading Guba and Lincoln's *Fourth Generation Evaluation* (1989). However, in reading Bruffee's book I needed to confront again non-foundational views of knowledge and the kinds of negotiation that occur in a non-foundational social construction of knowledge. Having been trained within science with a foundational view of knowledge, the transition was tough for me. Even so, I tried to bring many of these ideas into my classroom. However, in hindsight, I think I tried to change too much, too quickly, at least given the structure at my university.

Related to the foundational knowledge issue, my biochemistry colleagues expressed concerns early in the semester that the students in my class learn the foundational knowledge (to be ready for the next semester of biochemistry and for MCAT or GRE examinations). To help my students, I had them read the traditional textbook and answer about 25% of the questions at the end of each chapter. Each group answered all the questions, dividing them up among themselves. Collaborative group members could help each other, but probably did not have time to negotiate with each other on this, with all of the other assignments, many of them time-consuming. Franklin extended his critique further:

> So I found myself battling to not only learn this new concept of teaching but dealing with my own frustrations as well as those of my [collaborative group] members, not to mention the technology of making Web pages with my server ever so often crashing, but on top of all this doing the traditional reading the 50–60 pages of text and trying to do problems.
>
> Even though our institution is one of the most "wired" universities, all students did not have access to the computer resources on campus, especially in the evenings. Often students would meet with their group members, would socialize some and then get down to doing their assignment, all huddled over the one computer that was hooked to the Internet by a slow modem through a home telephone line. I realize it would help to offer the three semester-hour per week laboratory linked to the regular class time would obviate some of the technological problems and provide time for the collaborative group to work together on Web pages and end-of-chapter problems. (E-mail, 20 May 2000)

Even with these frustrations, I remembered many students feeling empowered by being able to put their ideas on the Internet. They were proud of their creative Web pages. I encouraged students to select the topic of their interest that would fit within the context of the chapter under study.

The idea was for students to have time to connect to their prior knowledge to current learning as well as provide them freedom to choose a topic of interests. Franklin summarized his learning:

> However, I did enjoy the class and continue use the knowledge that I gained from your class about the Internet to supplement my knowledge today. That was also helpful because like our own groups, the Internet puts you in connection with others across the world [that] have the opportunity to present the same material from their own point of view with their own examples. (E-mail, 20 May 2000)

I thought that my students became more literate using the Internet, which would aid them in learning for other courses or other aspects of their lives. The Internet made the students feel connected to other students and scientists around the world. Communities of scientists participate by sharing their understandings of biochemistry, and my students tapped into this knowledge plus contributed their own syntheses of ideas.

4.4.3 Manny and Rebeka, Two Graduate Students, Trying to Work and Learn in Their Collaborative Group

A male graduate student of Caucasian ancestry, Manny, wrote me about his reaction to the fictionalized story. His group had trouble, especially in the beginning, interacting as a group. Two factions existed within his group, two African American undergraduate women in one faction, and the other of two Caucasian graduate students. These divisions created communication problems, but the members still completed their work. Manny wrote:

> Reading your narrative story brought back memories (faces, places, things happened). I will try to describe the degree to which this story reflects what happened in our group. Here are some thoughts the way [they] are coming to my mind.
>
> As indicated in the story, indeed, there was a difference in the degree to which people were interested in participating and becoming committed to the group work. Some people were interested in biochemistry, some in learning how to develop Web pages, some in both, while others did not seem to be excited for either one. Since some of us were not familiar with the technology and how to develop Web pages, a lot of our first meetings were spent talking about how to use, for example, HTML code and not really discussing biochemistry. We had meetings at the beginning, which became rare after the middle of the semester, when we were meeting only just prior to the day of our class presentation. Most of the communication was performed using e-mail. In the story people are talking about their personal lives (e.g. what they did during the weekend). In our group at least, we were not so open to discuss things other than class. I recall that we used to spend much less time during our meetings, compared to what the group in the story was spending.
>
> The story is true regarding arguments among group members relative to their contribution to group work.
>
> Besides the few differences noted above, I believe that the story definitely represents what happened during that semester in our biochemistry class. (E-mail, 3 August 2000)

I can understand why Manny reflected as he did. I know that the other Caucasian graduate student in Manny's group, a woman, Rebeka, was very disappointed in the class, but she refused to write to me about her concerns. At the beginning of the course, Rebeka pleaded with me to add her to the Web-enhanced section. Right from the start, she was a leader in the technology in our classroom, and she even taught glycolysis using animations of the molecules one day for me when I had to miss class. She even showed the enzyme by which glycerol (made from the breakdown of fat) enters glycolysis in the liver via a phosphorylation event followed by a reduction to a glycolytic intermediate. In one of Rebeka's group presentations of a Web site on complex carbohydrates, she and one other group member asked the members of the class some questions during their presentation to engage them in learning. However, during the semester of the course, I could tell that she was not all that pleased.

About two years after the course was over, I met Rebeka while walking on campus. Basically, she told me that she believed the learning in our class was shallow.

She said something similar to, "Just reading off some words you wrote on the Web site when you present in class isn't learning." I believe some other students shared comparable feelings to Rebeka.

In the late summer of 2003, I ran into Rebeka near her office when I was visiting a faculty member in her department. Rebeka and I spoke again about the course. This time she said: "Oh, I remember the biochemistry course very well. There was too much technology without enough biochemical pathways. Oh, yes, they learned the technology, but that is not what they were supposed to learn in that course."

I was not able to encourage every student to become excited about learning as some of the students were. The course had many assignments, with many tasks to complete in the course, for instance, making the ten group Web sites, writing in the electronic portfolio, doing problem sets from the textbook, communicating and meeting with group members, and making three presentations on group Web sites in class, so I imagine some students might have felt overwhelmed. Also I was gathering information all the time from them, in the final group evaluation forms (one of the CLS), in assessment of group presentations, and a questionnaire at the end of the semester. I can see that some students became so focused on the tasks that they may not have focused on the learning of biochemistry.

4.5 Summarizing the Chapter

Utilizing fiction as one of several genres for writing about science education reform enhanced my learning. To develop *verisimilitude* and *coherence* within my story, I needed to think through my students' experiences as learners in this alternative environment. I had to put myself in their shoes in order to write the fictionalized story. I had expected students to work together in collaborative groups, to construct Web sites, and to present them orally in class. I had expected them to make connections to their prior learning. However, these goals were difficult because many of these students had never worked in collaborative groups on such open-ended projects in science classrooms.

I chose to bring emotion into the writing, with Bristol getting angry with Heather, and Magnolia having a hard time dealing with conflict. I address emotions because we tend to remember better when the amygdala in the brain is affected by emotional stimuli (Novitt-Moreno 1995). Writing the story provided me an avenue to get feedback and member checks from my students, opening the door to continued communication with my students and colleagues.

Will different professional communities, such as academic scientists and science educators, respond to the genres differently? Will any genre be more effective for any one group, especially for scientist scholars not ordinarily reading educational research or being aware of the current educational theory or reform issues? Will fictional writing influence the public's perception of issues concerning learning in university-level science classrooms? Will the fictional writing influence other educators considering methods by which to report science education research? Will these alternative genres influence science education reform by allowing scientists and science educators to get to deeper-seated issues, thereby "shaking the epistemological foundations of modernist grand narratives" (Kincheloe 1997, p. 57)?

Since finishing my study, Smist (2004) provides her view on the value of organizing small groups within a science classroom. She includes the rationale, the practicalities of forming groups, tasks for small groups and the teacher's learning from the feedback from the students in the classroom.

Chapter 5
Students Collaborating in the Classroom

5.1 Preview

I focus on the experience of collaborative learning in my biochemistry classroom. Using a theoretical perspective called cultural historical activity theory and the theory of structure | agency (Chapter 3), I examine the students' constructions of their experiences in terms of the tools, rules, communities, and division of labor as they move toward their objects and on to their outcomes in an activity theory diagram (see Fig. 3.2). The most informative data on collaborative learning include the weekly collaborative reports on the CLS and the final summative evaluation of the ten qualitative questions from the LEQ.

This chapter contains the analysis of the ethnographic data from my students in the biochemistry course. This chapter specifically focuses on students' collaborative work in our biochemistry classroom. Two of my four research questions outlined in Chapter 1 are addressed in this chapter. They are:

1. How does work in collaborative groups influence learning?
2. What can I learn about my teaching through doing action research in my classroom?

The data resources I employ for the analyses include the qualitative questions in the LEQ and the CLS and entries from Suzanne's electronic portfolio (on her collaboration with each of her group's Web sites) over the entire semester. I use the same data resources in Chapter 6 while focusing on the technology the students utilized.

Integral to my analysis of these data sources is the theoretical frame. I utilize CHAT[1] to identify and examine the patterns of coherence and contradictions as the *subjects* endeavor to attain their *objects* and move to their desired *outcomes*. The *subjects* are my biochemistry students, their *objects* consist of learning biochemistry through collaboration while using technology, and their *outcomes* include becoming professionals in the field of science, medicine, and engineering.

[1] Cultural historical activity theory (CHAT) examined in Chapter 3.

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Additionally, I use Sewell's theory of structure | agency (Chapter 3) in conjunction with CHAT to examine the interactions of the structure of the classroom, the learning environment, and students' sense of agency.

With these two theories as my framework, I focus on collaboration in this chapter and technology in Chapter 6. Besides focusing on my classroom's collaborative efforts, I include additional information on the literature used to frame my study. I highlight ideas I learned from my students and methods I have since used in my biochemistry classrooms.

5.2 Utilizing Collaborative Learning

My major dilemma in designing the biochemistry course was finding ways to encourage university students to actively engage in learning science. Within the positivistic paradigm (Kincheloe 1991), the teacher presents the knowledge in nicely organized lectures to passive students, who rely on note-taking, reading the textbook, and memorizing in order to learn. The teacher may connect to the students' prior learning, but often the teacher begins at the level she or he thinks the students *should* be at in their thinking. The problem, of course, is that the students start with their *current* understandings, which may be different than this expected level. Therefore, if the material presented does not connect to the students' prior learning, the students may resort to rote memorization without understanding. If the material is only memorized, the student promptly forgets, as the concept does not connect to prior learning.

The question for these mostly passive classrooms is: "Do the students really learn?" Without doubt, some students will learn no matter the way in which we teach them, but is there a way for us to more successfully engage more students in learning science (Tobias 1990)? And if so, how do we go about changing our pedagogy?

Recent research suggests that encouraging student–teacher and student–student interactions and co-participating in a discourse community are critical to learning (Tobin, 1997, 1998, 2000). A discourse community emphasizes the use of the language of the discipline (Lemke 1995), with students actively listening, speaking, and writing their constructions of science. Creating such communities within a classroom may help students learn in ways that are more meaningful and interconnected with interests and experiences outside the classroom.

The idea that students learn by using language is a critical part of my action research plan in my biochemistry classroom. I want to explore the implications of encouraging my students to utilize oral and written language through group conversations and to present their group Web sites, do problem sets, and write their individual portfolio entries because I believe these measures would enhance my students' learning of biochemistry.

The theoretical roots for advocates of group learning lie with Dewey (1920), Vygotsky (1962), and Piaget (1970). For example, Linn and Burbules (1993) outline the reasons for group participation fostering learning: "by fostering cognitive skills, by promoting social skills, and by imparting workplace skills" (p. 92).

Either cooperative learning or collaborative learning can structure group participation. Many use the terms collaborative learning (Bruffee 1993) and cooperative learning (Johnson et al. 1991) interchangeably, however, they are not identical. Linn and Burbules (1993) make the difference clear with their definitions, stating that "*[c]ooperative learning* involves dividing a task into parts and having each group member complete one of the parts" (p. 92). In contrast, they define collaborative learning thus: "In *collaborative learning*, two or more students jointly work out a single solution to a problem" (p. 92). Therefore, the difference between cooperative and collaborative learning is that in collaborative learning, the students work together on the tasks whereas in cooperative learning each one has a separate task, bringing the project to completion.

Two examples of the use of cooperative learning in higher education include:

1. The University of Virginia (2007) outlines the advantages of cooperative learning for students, originally developed by Johnson and Johnson (1991)thus: "positive interdependence, face-to-face promotive interaction, individual accountability, social skills and group process" (p. 1).
2. Wright (1996) uses cooperative strategies and open-ended laboratories with success to creative authentic learning environments in an introductory analytical chemistry class.

I was particularly interested in utilizing collaborative learning in my biochemistry classroom as such collaboration was a powerful force in my own science learning (Gilmer 2007), both as a biochemistry doctoral student at the University of California, Berkeley, and a postdoctoral fellow in biophysical chemistry at Stanford University. I wanted to encourage interdependence among my students, so that they could learn from each other, teach each other, and find new ways to learn from their peers, much as I had experienced earlier in my career.

I had collected my data in the fall semester of 1998, but two years later, studies on collaborative learning in college chemistry classrooms influenced my thinking as I analyzed my data (Glaser and Poole 1999; Shibley and Zimmaro 2002). Glaser and Poole's (1999) goal is to improve student learning in large sections of organic chemistry in higher education. Glaser and Poole's study focuses less on technology than my own. Their students work in collaborative groups while learning from the Internet, but they did need to post their assignments in the form of Web sites. Similar to my own study, Glaser and Poole's students in groups peer assess each other's group electronically. Shibley and Zimmaro (2002) approach collaborative learning differently in that they utilize the collaborative groups within the laboratory portion of the course, associated with the lecture. Shibley and Zimmaro report improved student interest in chemistry, and plan to bring collaborative groups to the lecture portion of an introductory chemistry course.

Thompson et al. (2003) examine collaboration among faculty and graduate students in designing and evaluating an undergraduate electrical engineering course. Their project is a collaborative effort involving faculty and graduate students in engineering and education, who negotiated while they "tried to understand the complexities of the curriculum" (p. 7). The use of a design research paradigm (Edelson 2002), a "strategy for developing and refining theories" (p. 105), may help in the communication and collaboration between the faculty and graduate students in both cultures.

Bruffee's (1993) book on collaborative learning was critical in my choice of using collaborative learning in my action research plan. Bruffee, a proponent of nonfoundational social construction of knowledge, focuses on negotiating at the boundaries among knowledge communities. From my experience, such negotiation between various communities is critical to my research. Those communities in my study include people like my students, my biochemistry colleagues, and other groups that my students may want to join (such as medical school, graduate school in the sciences or engineering, or teacher education for K-12 education).

On the role of the teacher, Bruffee (1993) states:

> The teacher's role is to design tasks that help people discover and take advantage of group heterogeneity and thus, by expanding the group's collective "zone of proximal development," to increase the potential learning power of every individual in the group. (p. 40)

Bruffee's reference to "zone of proximal development" refers to the pioneering research of Piaget (1970). By students working together collaboratively, my hope was to help each student learn from the others while teaching each other. I wanted my student groups to be heterogeneous, with respect to gender and ethnicity. Such students would enter the group with varying learning styles and cultural experiences, enhancing the repertoire available to all students within the group.

Bruffee (1993) cautions against hovering over students while they work in groups on group projects. If the teacher hovers over the group as they work, the teacher would destroy the "peer relations among students and encourage the tendency of well-schooled students to focus on the teacher's authority and interests" (p. 29) rather than their own. Bruffee also promotes heterogeneous grouping of students because "differences tend to encourage the mutual challenging and cancellation of unshared biases and presuppositions" (p. 32).

Brown (2002) shares some insights on possible reasons some people have trouble with collaborative learning. She says:

> Collaboration is a powerful process. It is bound to bring change, and change can be threatening. From a psychological standpoint, collaboration is difficult because each of us has fears that make us react in instinctive ways. These fears are particularly powerful when we are under pressure. One such fear is inadequacy; another is losing control. Unable to see the alternatives, we may project those fears onto others. A man who fears he can only count on himself, for example, will project that fear on others by refusing to accept their offers of assistance. The result? An inability to collaborate.
>
> But for each fear and projection … is a countervailing force that leads to collaboration. People who feel they must "go it alone" and who distrust others, for example, may ultimately realize that there are many reassuring ways of connecting to others – sometimes in places and forms that are very surprising. They then have the mindset needed for collaboration. (p. 2)

Through the research and insight of all of these researchers, I decided that collaborative learning would be an important element in my biochemistry classroom.

Glaser's research on teaching organic chemistry classrooms with students learning collaboratively and Bruffee's book on collaborative learning were guideposts for me. Brown's ideas on reasons that collaboration may not work for certain individuals helped me when I worked with students, especially those who were having trouble collaborating, whenever they were trying to learn to work with team members.

5.3 Deciding on Approaches to Teach My Students

While preparing my curriculum, syllabus, and ideas on approaches to teach the biochemistry course, I did not feel that my biochemistry colleagues were interested in hearing my plans to teach differently from the usual three lectures per week and assess my students with three or four hour examinations and a final exam. We seldom spoke with each other about teaching, especially undergraduate teaching, other than our teaching assignments and choice of textbook for the following year. Our discourse centered on biochemistry research and the students working with us in scientific research.

The number of undergraduate majors in our department grew considerably, especially when we added a major in biochemistry during the early 1980s. The number of majors had increased so we needed two parallel sections of the same biochemistry course during the semester I conducted my action research. One of my colleagues, Professor Timothy Logan, agreed to let his section have a larger enrollment so that I could keep my enrollment lower for this experimental course.

As I envisioned my class, I decided to focus on collaborative learning, use of technology, and the Internet to enhance learning and alternative forms of assessment. These forms of assessment would include students (1) working in collaborative groups to create their own Web sites on topics related to the textbook chapters we were to teach; (2) presenting three of the group's ten Web sites to the rest of the class; (3) recording their personal contributions to their group's Web sites in an electronic portfolio; (4) writing questions still in their minds at the conclusion of each Web project; and (5) answering questions at the end of each chapter in the textbook within their group. Compared to traditional assessments of the usual three or four exam examinations plus the final examination, therefore, most of the assessments I used in this experimental course were considered alternative.

5.3.1 Seeking Input from Biochemistry Colleagues

After writing the tentative syllabus I did seek input from one of my junior biochemistry colleagues, a tenure-track but still untenured woman, Nina (pseudonym). Nina used traditional hour and final examinations in her own classes, and she had tried some alternative forms of assessment in her teaching. However, she had not used electronic portfolios or group-generated Web sites in any of her courses. When she realized that I was planning to have neither the traditional hour examinations nor even a final examination, she disapproved of my plan.

However, by that point I already had decided that I was asking my students to demonstrate sufficiently their learning by utilizing the discourse of biochemistry in their writing (in both electronic portfolios and on their Web sites), in problem sets, and in class as they made oral presentations on their Web sites. I did not want to ask my students to do any more. Therefore, I made the decision to proceed as originally planned, but accepted the fact that my other colleagues may have felt similarly to Nina.

To broach the topic with the rest of my biochemistry colleagues, I took an opportunity to speak about my plans and actions in teaching the biochemistry class at our research program's retreat (Gilmer 1998). This retreat occurred at the end of the third week of classes (in a 15-week semester). Everyone at the retreat except me spoke about his or her research approach in science, methodologies, and data. I wanted to communicate with my colleagues about my approach to teaching biochemistry, in part because of Nina's reluctance to accept my plans to assess my students' learning. I wanted to share the shift in the teaching methodology early in the semester, while there was still time to change things, if necessary. I was aware that the approach a teacher uses to assess his or her students drives student learning, and I was curious to hear the input of my colleagues.

I purposefully showed my colleagues an overhead transparency on nonfoundational knowledge (with reference to Bruffee's book on *Collaborative Learning*). At this point in my learning, I was struggling through the difficult transition from a positivist (Kincheloe 1991) to more of a constructivist teacher (Tobin and Tippins 1993). Mentioning nonfoundational knowledge got my biochemistry colleagues' attention. I think my colleagues were earnest in their concern. Nonfoundational knowledge is a radical change from the standard scientific view that knowledge exists in the world, with the scientist as the one discovering this "Truth" and the teacher professing our constructions as "Truth" to our students.

My decision not to utilize hour or final examinations came back to haunt me as my full professor biochemistry colleagues balked at my methods of assessing students. We had a tense, hour-long meeting during the week after the retreat. I wrote the following e-mail to my two co-major professors, Kenneth Tobin and Peter Taylor, shortly after the heat of this confrontation:

> I had the conversation yesterday with my full professor biochemistry colleagues, and they are locked into traditional examinations, even though their averages [when teaching the same course] are generally in the 50–60 range [out of 100]. I'm trying to figure out how to work with them, to learn from their perspective, and to do a better job of evaluating what is happening in my class. I do have some money, which I could use to hire someone to interview these students (using pseudonyms), transcribe the data, and then see through their lenses. My colleagues want some form of a traditional exam.
>
> It was refreshing to be able to talk with my colleagues about biochemistry. I realize now, one day after the conversation that they don't realize that how we evaluate the students is

> a strong influence on what they learn. Do you have any suggestions on how I can work with them and do a better job of evaluating the students? I chose not to have examinations because I feel I will be evaluating the [students'] learning on the basis of the assignments and my method of evaluation. How I respond to this challenge is critical. (e-mail to Ken Tobin, 24 September 1998).

Since I did not convince the biochemists at that point in the semester of my students' learning, I decided to add two optional forms of evaluation to address my colleagues' concerns: an extra-credit midterm and an optional, extra-credit final.

One consequence of undertaking this alternative teaching is that for six years my biochemistry colleagues did not allow me to teach that identical course (or the second semester of the two-part biochemistry series) for science majors. Starting in Spring 2005, I began teaching this upper division course that our biochemistry and other science majors planning to go to medical school again.

One reason for the hostility, I believe, is that my biochemistry colleagues felt concerned that I did not share with them, in advance, my plans to teach our "main line" course in such a divergent manner. I do regret that I did not share my plans with them earlier. However, I was glad that my colleagues became engaged in my teaching and research and their reactions provided me with more insight on the challenges to overcome. Three colleagues did follow-up my invitation to come to visit my classroom near the end of the semester, and one of these same colleagues, Professor Robley Light, came to my class on one other time earlier in the semester. In Chapter 7, Dr. Light participated in writing the metalogue with me on the problematic issues of bringing reform to science teaching and learning in higher education.

My colleagues also believed I was being unfair to the students, since when the students enrolled for my section months beforehand I had not advertised the class as Web-enhanced class with alternative forms of assessment. I agreed with them on this point. However, in my defense, months ahead of time when the students did preregister, I was not sure of the approaches that I would use to teach the course.

One of the primary reasons that I decided to focus on using the Internet in the experimental biochemistry course described in this book was from my teaching *Science, Technology and Society* (STS) during the previous spring semester in 1998. On their own initiative, one pair of students in a collaborative group developed a Web site for one of their group projects. I was so impressed with the results of their effort that during the summer semester of 1998 in another STS course, I required students to develop collaboratively a Web site. These two experiences together gave me the power to act in developing and teaching the experimental biochemistry course, which is examined in detail in this book.

As I planned the semester, I decided to have just 24 students. I thought this plan was workable with the technology available and the methods I planned to assess my students. Many students in the other traditional section of the same course, however, pleaded with me to make my section larger so they could be in the Web-enhanced section. This brought my number of students up to 37. After the end of drop-add, three of my students asked to switch to the parallel section of biochemistry. Those three students wanted a more traditional class and did not want to be in the Web-enhanced class with collaborative learning. Therefore, in the end, my enrollment expanded from the originally planned 2 students to 34 students. This change in number of students significantly impacted the class, as I had many more student groups that needed to make presentations. Ultimately, I also had less time to teach.

Regardless, the class proceeded as I had originally planned, except for the fact that I had more students than I had wanted for the study. However, the new students I allowed into the class were very keen on technology and collaborative learning, and in turn, definitely contributed to the successes in the class. Also the added but optional traditional assessments that my biochemistry colleagues demanded contributed to my demonstration of students' learning, especially the optional final examination. Although I had to pay the "price" of not teaching biochemistry for six years, my colleagues are supportive now of me when I teach biochemistry and do not complain about alternative assessments and use of technology in my methodology.

5.3.2 Site of My Action Research

In the fall of 1998, I conducted this action research study in my upper division-level biochemistry undergraduate classroom. While my students were mainly undergraduates, four graduate students enrolled. The class was for junior- or senior-level students, and was a class required for a major in biochemistry and for biology majors planning to go to medical school. A few of my students were majoring in engineering, nutrition, or science education.

My Web-enhanced class met three times per week for 50-min class periods over a 15-week semester. Twice a week we met in the room that was technology-accessible for me and the students, and the other day we met in a traditional classroom generally utilized solely for lectures. The traditional classroom had a chalk blackboard and an overhead projector.

In my syllabus I stated my goals for this class:

1. Encourage the students to be active learners.
2. Connect to the students' prior learning.
3. Provide a learning environment in which the students gain an overall perspective of biochemistry.
4. Have the students teach and learn from each other in collaborative groups.
5. Have the students learn the power of using the Internet as a source for up-to-date information on biochemistry.
6. Have the students learn how to develop Web sites on topics that students selected to study in depth.
7. Encourage the students to reflect on their personal goals for the course and on their learning using an electronic portfolio.

I wanted to bring communicative action to my students in the form of collaborative groups through social interactions. I offered my students the freedom to explore their own interests by allowing them to develop Web sites that interested them within the topics included in the first semester of a *General Biochemistry I* class.

While not the perfect environment, I chose to conduct my action research in my own university-level, first semester of a two-semester sequence of biochemistry. I set out seven goals listed above for my students, so that they could see the important foci during this semester in an experimental offering. I was able to get sufficient access to technology in the classroom for two of the three meetings per week with my students.

In summary, I provided an environment in which higher education science majors needed to take initiative to learn not only the biochemistry but also technology and collaborative learning. I gave my students freedom to select the topics of their Web sites, within the constraints of the various chapters we were to learn for that semester. I encouraged the students to use language in writing their goals in their electronic portfolios and in their learning of biochemistry within their Web sites. At the time of the study in 1998, the technology was much more primitive than now, so my requiring groups to design Web sites pushed most of them beyond their prior learning of technology. In addition, my requirement that the students present three of their ten Web sites to the entire class encouraged them to use the language of science orally, not only within their collaborative groups as they planned for the Web site but also during their presentations in class. Having the experimental course also provided an avenue in which I could discuss aspects to teaching with my biochemistry colleagues.

5.4 Critiquing the Learning Environment

I distributed the LEQ to all my students to take anonymously during the last week of classes in order to obtain their perspectives on aspects that did and did not work in the course. I wanted to use this additional feedback to help me prepare for my future teaching. Using a constructivist type, LEQ, now called the HEES (available at http://www.chem.fsu.edu/~gilmer/downloads.html), I had access to both qualitative and quantitative data but analyzed in depth only the qualitative data.

For this chapter, I focused on the student responses to the LEQ (available at http://www.chem.fsu.edu/~gilmer/downloads.html) into three of the five main categories listed in Table 3.3: Technology/Web sites; Teaching; and Collaboration, because my foci developed into teaching biochemistry using technology and collaboration. Each category had several subcategories. I also included associated comments from the CLS collected from each group each week that a Web site was due (available at http://www.chem.fsu.edu/~gilmer/downloads.html). Since the students wrote their comments on the CLS in the "heat of the moment," the students indicated more problematic areas in the CLS than in the LEQ.

5.4.1 Teaching

I sorted 15% of the LEQ text files into the teaching category, which had five subcategories: learning through lectures, teacher attributes, peer teaching, structure, and textbook. I only included comments from the lecture subcategory and the teacher subcategory in my analysis.

5.4.1.1 Learning Through Lectures

Some students had strong views toward their wish to have more lectures while others had just as much passion toward having the small number of lectures that I did offer. Had I kept to the originally planned number of 24 students, I would have had more time for other types of learning. We would have had six to seven collaborative groups instead of ten. Had we had the smaller number of groups, we would have more time for learning to use the Web and/or for having more lectures. However, the students that I did add after the original 24 were strong additions, and they contributed considerably to our learning as a group and class dynamic.

I think most students had a hard time engaging in a new form of learning after years of learning through the lecture method. In the LEQ, one student said: “Exposure to new techniques is good, but relying too much on them can be overwhelming. Just a little bit more of a traditional feel might help students feel more comfortable.” I think that this is an important point. In teaching during later semesters, I have interspersed lecture with “active learning” exercises to encourage the students to be more active in the classroom.

Students did write in the LEQ that they enjoyed my lecturing: “I learn a lot from Dr. Gilmer’s lectures. The information was clear and organized.” Another said,

> I think that Dr. Gilmer was excellent!! I would have enjoyed two lectures a week from her and two a week from students. Also, the longer student presentations were the most beneficial. (Source: LEQ)

I think the above student wanted two groups to present during one class period rather than three groups, which sometimes did occur. I no longer have so many groups present over such a short period of time as 50 min.

Another student commented:

> I feel I learned a lot from the students’ presentations, so this is a good idea. However, my instructor is an excellent teacher – very organized and calm – so I think I could have learned a lot from her too – if she would have lectured twice a week – or lecture one day, second day for open questions and answers about homework problems, third day for group presentations. (Source: LEQ)

I conclude that my students were searching for more effective ways to learn biochemistry and they valued me, their teacher, as a resource to support their learning during class time more so than having their peers adopt teaching roles at the whole class level.

5.4.1.2 Teacher Attributes

I divided this section of teacher attributes into three subcategories: compassion, flexibility, and other traits.

5.4.1.3 Compassion

Two students wrote about compassion in the LEQ. One said: “[Dr. Gilmer] shows a lot of compassion for her students, which encourages us to learn.” The other said: “Dr. Gilmer is always willing to help and truly cares about the students.” These students openly sensed that I do care that my students learn.

One time I remember being gruff with a student in my classroom. This instance occurred in response to a student’s question on biochemistry in her reflections on contributions to the group’s Web site on DNA. Her assignment was to ask the question she had in her mind after conducting the research for the Web site. The student asked a very simple question about the base pairing in DNA, and I made some comment to her, equivalent to the following: “Can’t you think of a harder question?” The student wrote me back: “That’s where I am in my thinking, Dr. Gilmer.” Her response made me feel badly, and I have been more careful ever since. This experience made me more understanding of students who come to my classroom with weaker backgrounds in science, to ask a question that does not put students on the defensive but still encourages them to grow in their thinking.

5.4.1.4 Flexibility

On the flexibility issue, one student in the LEQ wrote: “[Dr. Gilmer] was also very flexible with all of us and always willing to help. She is an excellent instructor,” and another student said that “Dr. Gilmer encouraged us to have things on time, yet she offered us some flexibility.”

I remember being flexible in one instance when a student group was not ready for their presentation on the scheduled day. Unfortunately, the students in that group did not tell me that they could not present until right before the start of class. I was not ready to present a lecture since I had expected them to present, but I did so anyway. I remember that Robley Light, one of my biochemistry colleagues, visited our class on that day. I felt like I was not teaching up to my usual caliber.

I did learn from this experience and, since then, I have required students to send me their Web site or PowerPoint presentation by a set time beforehand. Then I can review and upload their presentation to the class Web site. In this way, the student group prepares ahead of time and can focus more on the presentation instead of the Web site creation and posting. We also save class time because the program is already on the Web site.

5.4.1.5 Other Traits

One student suggested that I could have addressed methods to solve the problems at the end of the biochemistry chapters during class time. Apparently, she or he had mentioned this to me before, but I must have forgotten or did not take the time during class to show students the logic of answering selected questions from the textbook. That student in the LEQ wrote:

> The book was informative, except it lacked examples for the problems that we were to answer. I brought this fact early on to the attention of our teacher, but she never remedied this by giving the class examples in lecture. This is a must for those who had problems answering the questions.

Similarly, another student said that "it would have helped to see the correct explanation in class, not just posted." I think these students had a valid point. By not helping students construct meaning using mathematical and written language, I ignored a real concern from these two students, and possibly more, to indicate these statements in the LEQ.

The way I could have addressed not helping my students with problem sets in my teaching is threefold: (1) to have time during class before the problem sets are due to answer student questions; (2) to post written answers to the problem sets (and optional midterm examination) afterwards; and (3) to ask additional questions that relate to discussions and presentations from class.

Another contradiction occurred because although I was teaching biochemistry, we spent considerable time on learning technology and making student presentations, so we had less time for biochemistry. Four students voiced this concern in the LEQ. One student said: "[We] should have placed more emphasis in class on biochem." In a similar vein, another student said: "Yes, I learn better from structured relay of information, students' presentations are incomplete and lack real understanding that is important for teaching a subject." A third said: "I believe that more traditional in depth lectures should be given in addition to the Web pages." Similarly, a fourth student said: "I believe the instructor should have done most of the presentations. Presentations by the students did not help understanding the topics, probably due to lack of teaching experience."

Heeding these comments, since teaching this class I have spent much more time teaching the science content. For example, in a lower-level biochemistry course, I have students in groups make presentations during the laboratory part of the course, so the technology we use in class relates to utilizing Blackboard. Since the laboratory is three h per week, students can present at a more leisurely pace. Additionally, this change provides time for students to give written feedback to presenters in electronic form shortly after the presentation. Students now have opportunities to learn to use more technology, including software programs to calculate and plot their laboratory data.

A number of students in my action research study wrote complimentary comments in the LEQ about various aspects of my teaching, such as my willingness to help them and being "extremely helpful and proactive to help the students learn the material." Another said:

> The instructor is responsible for the success of this experimental course. It requires a unique instructor who is able to make things happen, and there aren't many out there! Dr. Gilmer is one of a kind!

One student noted in the LEQ that I am "very professional yet friendly – She treats us students as colleagues with a lot of respect." Another mentioned my "availability," which is an attribute in which I take pride. I always try to be prompt to answer e-mails from my students and to address their concerns and questions.

Two students mentioned in the LEQ that they really liked the way I taught. One said: "I really liked the teaching style, allowing the students to research a topic and then present it to the class. I feel this is [the] optimal way to achieve understanding." The other commented: "I enjoyed the new way of teaching a course. I learned a great deal about computers, and she was helpful to us."

Therefore, on the three issues of teacher attributes, I learned to be more compassionate with my students. Most students thought I was flexible, but I learned to set limits, such as having students get their group assignments posted before a class presentation. On problem sets, I learned to take the time to go over typical problems in class and have answers to questions at the problem sets available.

5.4.1.6 Dealing with Other Issues

Two other issues emerged on the learning environment: number of credit hours for the class in the future and lack of any required hour examinations.

5.4.1.7 Credit Hours

One of the questions I asked the students on the LEQ was whether the course should be offered as a four-credit course with three credits for the lecture, and one credit for a three hour/week computer laboratory. Opinions varied.

> I think the "Web" part of the class should be a lab[oratory] hour that meets once a week, three hours like a usual lab[oratory]. Then still have three hours/week of lecture and the course can count for four [credit] hours rather than three. With a longer computer period, projects can be fully explained, and it will also give time to have tech[nology] help sessions. Also with three lecture times, there is still enough teacher/student information.

Another student had a similar suggestion, just a different allotment of the time:

> I would have liked twice a week classroom lecture by my teacher and just my teacher. … Then [we could have] a four-hour block of computer lab time to [listen/make] student presentations and work on [our] own computer work.

Others agreed that adding an additional credit to the course would allow more time for lectures, which students really seemed to want. Most students said that they found that learning both biochemistry and technology was difficult, especially for just a three-credit course. They felt that changing the class to a four-credit course would decrease the stress and "solidify the learning."

I think if the course were four-credit, students would have more time to work together within collaborative groups and would feel less pressured during their presentations. Having a four-credit class would allow the students to share technological methods that each group has utilized. During one group's presentation, one member from another group actually got up and shared his learning to set up a table on vitamins in HTML and link its contents to other Web sites.

Most of the students did learn to make a Web site. For instance, one student in the LEQ said: "It was a lot of info[rmation] all at once, but I got the hang of it pretty quickly. No, a [computer] lab is not necessary." Another student commented: "[By] about the third website we all had mastered website creating but the beginning was really rough!" A third student mentioned he focused more on the technology in the beginning and less on the biochemistry, but by "the second half of the semester I use[d] the HTML to my advantage to perfect my web reports. I made HTML a tool of learning to help build my knowledge of biochem." The students had many other similar comments.

However, some groups relied on only one group member to upload the electronic files for the entire group. In those cases, most members of that group did not really learn the technology, as I had hoped they would.

5.4.1.8 Lack of Examinations

I chose not to utilize regular hour examinations or a final examination, but I did offer examinations as extra credit opportunities (based on urgings from my full professor colleagues). I had originally decided that I could evaluate and grade students on the assignments I collected without resorting to examinations. One of my students made a statement, which surprised me about the lack of examinations:

> [Having] no tests [inhibits learning]. I think three to five tests would give us a little more inspiration to keep us with reading the text, even if they were short, fill in the blank, or short essay form tests.

Another made a similar comment: "We are never really forced to sit down and think about all that we've learned, i.e., tests or quizzes."

A third student stated:

> [Grades based on work/projects accomplished] worked for me, but I also felt that there is a negative side to no testing, as there is a lesser motivation for the general class.

A fourth student indicated that she or he needed the motivation to organize and learn the information: "[I didn't like the] lack of tests – didn't know what to do with information."

With these comments from the LEQ, I learned students' insights about the effects of not having tests in class. The lack of tests elicited a "carefree attitude," and thereby did not reward the studious students (other than their own feeling of self-accomplishment). One student even said: "Without tests very few people study (including myself), and some don't attend class on a regular basis."

Students in the LEQ did present me with various options for addressing the issue of utilizing examinations (or quizzes) to test their knowledge:

> If this Web-mediated instruction continues I would require less presentations and extra work. A formal lecture should take two or three days a week – and then tested at the end of each chapter. Perhaps it could be a ten-question quiz at the beginning of Friday's class, followed by two twenty-minute presentations on the following chapter.
>
> A few tests and a little less focus on computers and technology [would improve the course].
>
> The only change that should be made is another assessment mechanism (i.e., quizzes) to gauge the progress of the students' ability to understand the basic topic of biochemistry.
>
> There should be some form of quiz or test that allows the instructor to determine the students' education and for the students to self evaluate his or her own preparation for their future.

Ever since teaching the Biochemistry (BCH) 4053 class under study, I have always included hour tests and/or quizzes in my classes. I learned that some form of formal evaluation on science content is critical to engage students in learning. One student mentioned that hour tests or quizzes also help the students to self-assess their learning throughout the semester. Students seem happier with this sort of regular assessment.

5.4.2 Collaborating

Glasersfeld (1989) points out that "the most frequent source of perturbations for the developing cognitive subject is the interaction with others" (p. 136). This statement matches my own observations and feedback from the problems in collaborative groups. In this section I utilized the comments of my students on collaboration to understand and evaluate the environment to learn biochemistry.

Coding the students' comments from the LEQ showed that 18% of all comments fell into this category of collaboration, with six subcategories: group presentations; co-learners; accomplishments; real world; conflicts; and cooperation. I choose two subcategories to present here: group presentations and co-learners (because a considerable number of comments were in these two subcategories, and both were foci within the learning environment I was trying to achieve). After examining both subcategories, I examined the contradictions and coherences in the postings of one student named Suzanne throughout the semester.

5.4.2.1 Group Presentations

In the course of the semester each collaborative group had to present three of their Web sites to their peers and me. As a team, the students needed to figure out the topics they wanted to research, prepare the Web sites, upload them onto the Web, and present three of the ten Web sites in class. Typically, the co-learner teams could find relevance for their topics and could make the topics worth knowing for the other students.

One group that presented their Web site on carbohydrates chose to present on the topic of complex carbohydrates (similarly in the fictionalized story in Chapter 4). An African-American student in this group chose to talk about the complex carbohydrates in sweet potatoes, which are a part of her culture. She was also interested in the color of sweet potatoes, which she included in her segment of the presentation. This group commented on the CLS that they learned "through studying the book, exploring the topic on the Internet and productive discussions between members."

I learned each person's contributions to the development of the Web site through three types of postings: individual students' portfolios throughout the semester, the CLS used for each Web site by each group, and self- and peer-assessment form to group members at the end of the semester.

The first way was the student's writing about his or her own contribution to the group Web site in the individual's electronic portfolio. I could see directly the part each student did. I asked for this information because I could track each person's accountability for group projects. I would read each student's portfolio on three occasions during the semester and comment individually via the Web.

The second way of assessing accountability of students' involvement in developing the Web site involved use of the CLS. The students in their groups wrote their responses in class on the day that the Web sites were due (available at http://www.chem.fsu.edu/~gilmer/downloads.html). One crucial question I asked the group members was whether the credit should be given equally or unequally within their group. Near the beginning of the semester one group gave unequal credit to one group member – however, this never happened again because the original, delinquent student attended to her share of the work for the rest of the semester. One other group of two students fell apart midway during the semester; one student continued her assignments and indicated unequal credit each subsequent week after the dissolution.

Word got around that each group member had to do his or her share of the work. I am not saying that the Web site creation was always equal for each group member for every Web site. Sometimes group members worked out the process among each other that if one did more in one Web site, then another would do more for the next. They worked around each other's schedules and examinations in other courses. I had not wanted this to happen, but with the load of tasks my students had to accomplish, I was flexible on distribution of the workload, to a degree.

The third written method of keeping track of students' contributions within their group was a form that I distributed at the end of the semester. I asked the students to score each member of their group as a learner, as a teacher, and as "being there." Each student responded using a number code; however, students could also write comments about their reasons for giving a specific score. See Fig. 5.1 for an example from one group.

This specific group of students had trouble with each other while trying to collaborate on their group projects, especially between La Tonya and Alicia (see Fig. 5.1). The students scored each other and themselves using the criteria given. This group was interesting because everyone (except La Tonya) thought someone other than him/herself ranked higher. La Tonya co-ranked Roosevelt and herself as

Please fill in your name at the top of the table below, and the name of your group members below your own. Rate yourself and your fellow group members for how each of you worked within your collaborative group (both out of class as you worked on problem sets and/or toward your group presentations) in the three categories indicated on the table, using the following scale:

9-10	Excellent
7-8	Very good
5-6	Good
3-4	Fair
1-2	Poor

Add up the three scores for each person and write the number in the total column. The maximum a person's score could be would be 30, 10 from each of the 3 categories.

Below is an example of how each member (listed first as "self") of a four-member group responded to this form :

Name of group member	As a learner	As a teacher	Being there	Total
Terrie (self)	10	7	8	25
Alicia	10	7	8	25
La Tonya	10	7	10	27
Roosevelt	10	8	8	26

Name of group member	As a learner	As a teacher	Being there	Total
La Tonya (self)	8	8	10	26
Alicia	3	0	3	6
Roosevelt	8	8	10	26
Terrie	4	3	3	10

Name of group member	As a learner	As a teacher	Being there	Total
Alicia (self)	10	9	8	27
Roosevelt	10	8	8	26
La Tonya	0	4	5	9
Terrie	10	9	10	29

Name of group member	As a learner	As a teacher	Being there	Total
Roosevelt (self)	8	8	7	23
La Tonya	10	8	10	28
Alicia	7	5	5	17
Terrie	8	5	5	18

Fig. 5.1 Self- and peer-assessment form for contributions to collaborative group

the highest in their group. I could get a sense of group interactions from using this self and group assessment of group activity form. The CLS gave me a sense of the degree of collaboration within a group of students.

La Tonya wrote the following additional comments on her form for self- and peer- assessment of contributions to her collaborative group:

> Terrie and Alicia were the laziest members of the group. We started off excellently for our first project, but after that it went downhill. Terrie and Roosevelt are absent from class a lot, but Roosevelt will call me to find out what he missed and what he needs to do. Alicia never asks what's going on in the group. Terrie always has some excuse as to why she can't come to our meetings, but at least she informs Roosevelt or me. Alicia never informs anyone or posts it on the dialogue journal. At least Terrie does.
>
> Roosevelt and I work very hard together to get our Web sites done. We search for links and write text. Terrie and Alicia post one link without text and this affects our grade as a group. I try not to let my personal feelings toward Alicia interfere without work as a group, but I can't work with persons that don't cooperate. Take for instance our last presentation. Roosevelt and I were ready to present that Friday but Terrie and Alicia didn't start searching the Web until Sunday night, and that's why we had to postpone our presentation. Please take this into consideration when grading our group. Please grade accordingly. Thanks. La Tonya.

Alicia wrote the following text of additional comments:

> I enjoy working in this group, other than the fact that one of the group members at times made it very difficult for group cohesion.

As another measure of student-generated Web sites, I also had each group peer assess all 30-group presentations, including their own. I shared the pooled comments with the presenting group, in a way that students were unable to determine the source of the comments. In the appendix in Gilmer (2004), I provide an example of the evaluation of three presentations by one collaborative group over the course of the semester. Students learned from the feedback they received in order to improve their next presentation. In this class, I asked the group to assess itself as a group. I think that students also became more aware of presentational issues while listening and providing feedback for presentations by other groups.

For instance, on the CLS, one group said:

> We took the positive feedback from our group presentation and the group that presented the other day and tried to completely alter our Web page in an attempt to help others learn.

Therefore, I had three ways to learn the contributions of each group member to the group projects. In addition, I learned information about presentational issues from peers and the group presenting. This pooled information helped groups learn to improve their next presentations.

Additionally, some problems arose with the presentations of group Web sites. One reason was that many students were nervous. Through their writings, I learned that the students were not only concerned with their grade for the presentation but also with their responsibilities to each other and with learning to teach. Many of them had never taught previously. Sometimes the presentations were rushed, partly because they did not pace themselves so others could learn. However, if getting the Web site up and running in class took longer than expected, we could not do the two or three presentations planned for a single 50-min class. One student commented in the LEQ about this:

> I feel like the group presentations were always rushed, and there wasn't enough time to get the actual point across. I don't think I learn as well from my peers as I do from a teacher that has studied this for 20+ years.

Another student mentioned in the LEQ that groups "did a fine job researching information links and graphics to help us understand the subject." Two additional comments from other students in the LEQ included: "Doing presentations helps us learn in that we have to know enough about the subject to teach others about it," and "[m]aking presentations and Web pages really imprints the knowledge."

One student mentioned in the LEQ "the student presentations often went on too many tangents." Sometimes, however, some of the "tangents" made the material relevant for the others. For instance, in one presentation about metabolism of ethyl alcohol, pyruvate and lactate, the students presented on topics that concerned college students: the drinking of ethyl alcohol. That presentation did encourage students to examine their drinking habits. Students learned the biochemistry of human's metabolism of alcohol, and the chemical conversion of ethanol is relevant to a number of important biological functions. I had written the following on the group evaluation sheet for their presentation: "I learned that alcohol metabolism uses alcohol dehydrogenase in reverse direction, using up NAD^+ [nicotinamide adenine dinucleotide], so there is less energy through glycolysis (therefore the alcohol-imbibed person gets sleepy)." I had not realized that beforehand, so I learned from my students.

At the time of the study, I had not resolved the issue of giving individual grades instead of group grades. One student thought that I should have given individual grades for the group presentations rather than the group grades. The student said in the LEQ: "Grades for projects should be individual (This will make everyone involved more comfortable)." Another student said something similar in the LEQ: "I don't think [group work] should be totally based on your collaboration, but the computer technology aspect of the course is extremely effective." At the time I felt that a good group project involved collaboration, so giving individual grades is difficult because the work has been created jointly. I have resolved this issue since the biochemistry class under study in this book; I now give students a joint grade on the group project (a Web site or a PowerPoint) and individual grades on the oral presentation during class.

Some students felt that I should have given the students more time for group work to be completed. I realized during the course but especially afterwards that many students found the collaborative process to be taxing. Students had other obligations – other course, family, or part-time job commitments, so that they could not always find a time in which everyone in their group could get together, plan their project, put their Web site together, and plan their presentation. One student in the LEQ said:

> Cut down on the amount of homework problems and chapters that need to be covered. Focus more on chapters and allow groups more time for group work to be completed.

> I know this is college, however, it's difficult to read the chapter, do the homework, research and post information, and get a presentation ready every week.

I did expect my students to do a considerable amount of work, as each group had three presentations and ten Web sites to prepare within 15 weeks. However, the technology at that time in 1998 did not support as conducive a place on the Web for students to post information and files to each other, as we now have available for students working in collaborative groups. Now, by using Blackboard, I can put the students into collaborative groups, where they can use a discussion board just for their group members. Additionally, e-mail exchanges and file exchanges are possible, so students can post information and intermediate files while a group works on a final project. In retrospect, I could have reduced the number of presentations from three to two and the number of Web sites from ten to eight. This would have eased the burden and given the students the freedom of more time to learn and reflect.

When teaching *Introduction to Biochemistry* (a similar but less rigorous course), I now have students complete only one group project, and students can select to use PowerPoint or Web site presentation. I have also made a Web site filled with suggestions for working in collaborative groups (see Chapter 6).

5.4.2.2 Co-learners

I must reiterate the sentiment of Solomon's statement that I quoted in Chapter 3 on the importance of social influences in learning. Throughout the course, I watched some of my students thrive in the social interactions. Sometimes a fellow student can explain, in a few words, the idea that the teacher could not explain in an entire lecture. In part, since she or he has just learned the idea, she or he understands the learning process for comprehending that idea. Also, the students utilize similar styles of speaking, so they often can convey the meanings more easily between each other than between the teacher and the student with the question.

Students found working in collaborative groups to be a taxing endeavor. Three groups out of ten had so much trouble that I met with each group at least once, and sometimes several times in the semester. Because many of my students' traditional science classes were competitive, students had a hard time transitioning into a collaborative learning environment.

Also some students may have had fears that they were inadequate, so they may have projected those fears onto each other (Brown 2002). Retrospectively, I realize this sort of fear and projection may have been happening in the interactions between Alicia and LaTonya (Fig. 5.1 and associated text). One time when I met with their group, the two were literally yelling at each other in a small room during the meeting. Luckily, the two other group members and I convinced these two feuding students to calm down. However, I was surprised at this event because I had never seen students so forceful with each other.

Many students wrote at length about having to work with, and learn from, others. Passionate comments from both positive and negative experiences were much of my data.

I divided the comments into three subcategories: those by students highlighting the strong points; those by students writing about the “headaches” of working with peers; and general comments about working in collaborative groups.

5.4.2.3 Strong Points

More than half of the students felt positively about the value and strengths of working together in collaborative groups. Sometimes just two or three of the collaborative group members worked well together, but not necessarily everyone. For instance, a student commented in the LEQ:

> Our group consisted of four people. However, only [one other] and myself were ever present. But that member who was present taught me a great deal, and we often studied for this class and others. I was satisfied with my participation because I was probably the second highest to one other member.

Another student had a similar comment:

> I only learned from one of three [other] members of my group. I really only worked with that one student, such as studying and posting Web sites outside of the class a lot. This was helpful. I think that the other two members of my group did not participate like they should have.

Many other students were satisfied with their group members. However, students did not always study together. The *Connecting Communities of Learners* (CCL) Web site has a page called the “dialogue journal,” in which students within a collaborative group could post information, like Web sites or times to meet as a group. This journal facilitated communication among group members.

I asked the students their reactions on working with the members of their collaborative group and if they wished I had switched group members part way through the semester. Below are two typical comments from the LEQ:

1. I did learn from my group members, and I did teach. I did not study with my group although we communicated outside of class often. I was satisfied with (my) group and myself. I would not want to switch (group members) in the middle of the semester.
2. I like my group; most of the time we helped each other. I do not think I would have liked to switch group members. We mainly helped each other with technology problems. The research and Web site productions were all up to us as individuals. We never studied together.

Two students did leave different groups and paired together to form a new group. However, for the last five of the ten Web assignments one group member would not communicate with the other. The time was stressful on the student still participating in class. Despite this, the continuing student managed to do well in the class. In the LEQ, she or he said: “Well, I didn’t have good luck in my group – since we were only two and my other group member quit. But I could see other groups learning from each other and helping each other, and I envisioned a good outcome." She made her presentations by herself. I was impressed with her composure in such a situation.

Basically, my students shared with me the processes that worked and those that did not. The students learned each other's strengths and weaknesses, and most did not want to have to change midstream, as changing groups would change the "chemistry."

Students commented in the LEQ: working in a collaborative group "helped [me] to develop skills necessary to work with other people, e.g., understanding, respect for the other's opinions, learning how others learn." In other words they "pull from each other's experiences." One student summarized: "[The best policy in the course was] group learning even though it doesn't always work out." Similarly, another student said: "Working in groups is wonderful – not only does it help to prepare you for the real world, but if you are willing to listen to others, it can help you understand and confront your weaknesses." This last comment fits nicely within my action research. By listening to my own students I can better understand more about the environment I provided in the classroom. This insight helps me to confront my own weaknesses and areas in which I can improve as a teacher.

On the CLS, one group member divulged the following about the benefits of learning from her group member:

> Working independently on loading [the Web] site made me realize how nice it was to work side by side with [my group member]. I think that after splitting the Web sites we came together more effectively. We met each other on a more equal level of expectation and performance!!!

This student suggested that in the beginning, they just split the work cooperatively, and so did not work collaboratively. With time, however, they learned to work together collaboratively and to expect approximately equal quality of work from the other.

5.4.2.4 Headaches

Other students focused more on the contradictions within their collaborative groups. I entitled this subcategory as "Headaches," in part due to this student's comment from the LEQ:

> Group work made this class a headache. Cooperation and effort will always lack in groups of Western cultures. The diffusion of responsibility [in group work] perpetuates many members' laziness, while hurting those who give a damn.

For me, I felt disappointed that this student had yet to experience a beneficial collaborative effort with others in my class or any other. Others indicated on the LEQ, while they have had good experiences working in groups, they had negative experiences in our class.

> If you get someone in your group who is just determined to be unconstructive and negative, then it seems to lower the morale and definitely the whole purpose of the cooperative learning experience.

In the LEQ, one student had some suggestions to increase the probability that groups would work better:

> Since we were going to work in groups for the whole semester, in the first two weeks we should have been given the chance to get to meet our group members and see if we could work effectively as a group by seeing our own interests and schedules, so that in the case the group did not fit, we could have the opportunity to change to another group.

I think that this comment is valid. In a 15-semester week with as many group projects as I had the students do, it would have been harder had I let them have 2 weeks to decide if their group would work. However, I can see giving the students a week to decide if they think the group would work.

Another valid point that students mentioned concerned the interpersonal conflicts that students within a group had in their schedules. I would like to minimize nonproductive groups, such as one student mentioned in the LEQ: “The group work can also inhibit learning. Our group did not really get along well, which made it difficult to learn as much as we could have.” Another student had a similar perspective in the LEQ: “Group work is a “win or lose” situation. Sometimes you can get a really good group, and you get a lot out of it, or you can get a group that is really hard to work with and all you get out of it is frustration.”

Having fewer group projects would give groups more time to work together on each group project. In my more recent classes, I have active learning exercises in class, so that my students could talk with their neighbors during the exercise. This provides my students a sense of the group interactions before the group has a project due with a group grade and gives students a chance to reorganize groups, if needed.

One student suggested in the LEQ that I should “lessen the load” by requiring fewer Web sites. She or he continued: “Group sharing is a good idea, but maybe ease up on the requirements of groups doing work together. I think students should do their own work – then share with the group. That way each individual can meet his/her standards.” When groups worked well together, students did their own work and shared and interacted. Unfortunately, not all students are at the same place in terms of their developmental levels and are not ready to accept responsibility for their own learning. One suggestion with merit is for the students to do some work on his or her own.

One student suggested in the LEQ that if I provided “guidelines to promote studying with others [this] would be helpful in the future.” I headed this advice and have included a list of lessons learned on collaboration at the end of this chapter. I make this list available to my current students, and a few of them wrote me back that they appreciated my doing so for them.

Unfortunately, in the biochemistry class, I did not show the video, *Collaborative Learning: Working Together in Small Groups,* and *User’s Guide to the Video* by MacCallum and Macbeth (1996). During the previous semester I had shown this video to the class. The video was 23 min long, about half of a 50-min class, so I chose not to use class time in my experimental class. If I had taken the time to show the video near the beginning of the term to this biochemistry class under study, my students would probably have benefited. Since I am conducting action research in teaching the biochemistry course, I have used the video in other classes that require collaborative groups. In addition to the video, I now provide a Web site (On-line: http://www.chem.fsu.edu/~gilmer/courses.html) that helps students learn to work on collaborative projects. I set out the process of working in a collaborative group in steps. Additionally, the site includes resources hyperlinked to relevant sites. I think that use of this Web site and the video improves group interactions because students gain insights into effective ways of handling complex and difficult social interactions.

The positive and negative experiences of my students' experiences in our class informed me of ways I could improve the learning environment. Already some of these ideas I have implemented in my classes since teaching this experimental course. Also in my fictionalized story in Chapter 4, I confronted the problematic issue of working in collaborative groups. This method of fictionalization illustrates my understanding of the interactions in our experimental biochemistry class as if I were the student, Magnolia (the story was written from Magnolia's point of view as she deals with working in a collaborative group).

5.4.2.5 Suzanne's Portfolio on Collaboration

I also utilize the electronic portfolio of one student, Suzanne, in order to demonstrate the historical aspects within the time frame of the course. This dimension shows the writings of one student throughout the entire course here, on the environment for collaboration and the use of technology. I collate and tabulate Suzanne's words for each Web site, with one table focusing on collaboration (Table 5.1) and the other focusing on use of technology (Table 6.4). I focus on the contradictions and the coherences that she experienced, on which she reflected in her writing in the electronic portfolio.

Suzanne completed a member check of her entire portfolio after the end of the course. Looking at Suzanne's goals and her contributions to her group's ten Web sites provides a historical look at Suzanne feelings about her participation in this Web-enhanced class. I read her contributions to her Web sites carefully, examining her text and identifying the contradictions and coherences from her explanations of learning biochemistry.

Concerning her group's collaborative effort, Suzanne wrote that in the beginning, their group selected too many research topics to be able to focus in depth on the biochemistry subject matter (Table 5.1). Her group had trouble arranging times to meet in order to work on their projects. She found that everything took a lot of time, especially in the beginning while she struggled to learn the technology. On the fifth Web site, she wished that she could have learned more from her group members on the topic of mutated plasma membranes. As the semester progressed, her coherences of using collaboration (Table 5.1) increased while her contradictions decreased, as recorded in her electronic portfolio. Suzanne liked being able to learn from others in her collaborative group.

Table 5.1 Contradictions and coherences in collaboration: Suzanne's portfolio entries throughout the course

Web site #	Topic	Contradictions	Coherences
1	Hydrophobic/ hydrophilic Interactions	She chose too many research topics (three) so not enough depth	Wide range of knowledge, including practical aspects, like "cleaning agents, antibiotics, diseases and even margarine"; help group members learn by selecting areas to research that they had not.
2	Genes as a link to disease	"I wish we could arrange more group meeting times so that we can share our findings, relate them, and organize the page together"	"The ability to learn from each other is a special advantage of this class … I am up for the challenge—the results are worth it."
3	Globular proteins	"The research itself seems to be so time consuming that I don't have the time I would like to allot to researching computer technology"	"I always explore [my group members'] contributions, learn from them, and relate them to each other … I am glad that one of us always takes the initiative to select one practical application as a research topic"
4	Role of hemoglobin		"Another reason that I am glad we chose this topic is that it tied into our previous Web page on globular proteins"; fellow group member got Suzanne interested in blood substitutes; "my interest has been aroused in the blood stream and all of its components"
5	Plasma membrane and membrane transport	"Still, I would like to know [from my group members] of more detrimental effects of mutated plasma membranes"	"My group members' articles greatly facilitated the comprehension of my paper because they provided a framework"
6	Enzymes		"My coverage on allosteric effects was very easy to learn because of my [group's] previous report on hemoglobin"
7	Lipid metabolism		"Each of my group members studied a stage of the fundamental process: fatty acid and amino acid metabolism, glycolysis, gluconeogenesis, and, more generally, oxidative metabolism."
8	Otto Meyerhof and the history of metabolism		"I concentrated on Meyerhof's projects that I could integrate, namely his work concerning ATP and metabolism"
9	Chemiosmotic coupling		"My focus was on the relationship between the inherent structure and composition of the mitochondrion and its role in energy synthesis… the work of my group members was very interesting to follow because they covered information that I hadn't encountered in my research"
10	Photosynthesis		"[The photosystem] is the same chemiosmotic coupling that we learned about in animal cells" [then Suzanne highlights the differences].

Progressively, Suzanne's group gelled. They learned to work together as a team, with each member contributing and learning more deeply from each other. Their group presentations were good in the beginning but improved with time. Suzanne became much more comfortable and creative with the Web site production.

In Table 5.1, I select quotations from Suzanne's portfolio to highlight the coherences and contradictions in collaboration of Suzanne's learning while constructing each group Web site. I list the title for each of her group's Web site as well.

Suzanne's is just one example of one student's portfolio of learning. I have read and studied all of the portfolios and have a wealth of data. I selected Suzanne's for inclusion, as her evolution of comfort with technology and the learning environment are apparent and clear. This evolution of comfort was true with many students, so her text is representative.

5.4.2.6 Problem Sets

I assigned problem sets from the textbook for students to answer because much of chemistry is learning analytical problem solving. I did allow the students to work within their collaborative group to solve the problems.

I knew that the students needed to become competent at solving problems. If students worked together on their problem sets, they would use the spoken and written language (Lemke 1995) and the symbolic mathematical language. Even though students worked in groups, they had to post their own answers on the Web within their own electronic portfolio. The textbook had the answers in the back of the book, but did not show the method to arrive at the solutions. I gave the answer key to all the problems to the teaching assistant. This teaching assistant graded the problem sets based on the steps that students took to answer the problems. I generally did not take the time in class to go over much of the problem solving.

Of the sorted text units, 12% of them concerned problem sets. Most students said that answering the problems was worthwhile although some thought the questions I had chosen to make them answer could have been more relevant to their learning. Some student comments in the LEQ included: "Answering questions did help – it was the only thing that required the students [to] 'learn' the chapters," and "[a]lthough the questions were sometimes hard, they helped [me] learn." Another said: "Working problems and answering questions forced you to dig deep and draw conclusions … the questions within the chapters were excellent and made you pull from different areas in the chapter to answer them." I wanted the students to think critically, and I partially achieved this goal by having them answer the questions from the chapters.

One area for improvement would be to give examples of similar problems in class before the designated questions are due, or to review the answers to the problems in class after they were due. One student said: "The questions often times asked things that could not be found in the textbook, and we had to use other textbooks." Actually, I purposefully assigned problems that forced the student to integrate knowledge, hopefully, through the Web usage. One student in the LEQ had an interesting alternative:

> I wish we [had] presented the homework problems [in class] instead [of the Web sites], and maybe used our Web pages to take a test that the instructor has constructed from the Web pages. I think I would have learned the chemistry better that way.

I think this is a very interesting alternative. Presenting homework problems would have kept the students up to date, especially if they did not know if they would be called upon that day to answer questions. The other student's suggestion would encourage students to utilize and learn biochemistry from the Web sites created by the other students.

Students would definitely have preferred answering the problem sets on paper and turning them in rather than posting them in their electronic portfolios. Students stated in the LEQ: "Posting them on the Web was a pain," and "[p]osting homework on the Web was more time consuming than beneficial." The difficulty of answering the questions electronically did not initially occur to me. After a few students turned in their answers on paper, I realized that electronically posting the technical answers to the problems, containing Greek symbols, mathematical equations, and chemical structures, was a waste of time. Since teaching the experimental course, I have collected problem sets done on paper.

5.5 Collaborating More Effectively

One question I asked the groups on the CLS for each Web site was if they had suggestions for working more effectively in groups. Below, I have collected various quotes and put them in an order that a group might encounter as they learned to collaboratively teach and learn from each other. This is the list that I give to students in classes since the experimental study.

1. Coordinate and communicate within the group.
2. Try to be punctual to all meetings.
3. Listen to each other's thoughts and feelings.
4. Get more organized and start making meetings more efficient.
5. Assign in advance the tasks needed to complete on time.
6. Communicate and share (Web) sites/info that are helpful to each particular aspect.
7. Talk one on one.
8. Do (biochemistry) chapter problems together.
9. Meet outside of class more.
10. Keep in mind all of the information we have learned for future collaborative work.
11. Continue working closely and accept ideas from one another.

5.6 Summing up Collaboration

The research questions for this chapter are:

1. How does work in collaborative groups influence learning?
2. What can I learn about my teaching through doing action research in my classroom?

According to Sewell's theory of structure | agency (Sewell 1992, 1999), the three components to structure are *human*, *material*, and *symbolic*. For my first research question restated at the beginning of this chapter, the *human* component of structure is critical for collaboration. The two important components to human agency for this research are *access* (which include gender, underrepresented populations, and technology) and *appropriation of resources* (which include the knowledge that individuals know and can utilize from their culture and the use of resources needed to meet goals). Students' goals include relevance, interests and the "objects" from cultural historical activity theory. Both *access* and *appropriation of resources* pertain to my research question on collaboration.

For the research questions in this chapter on my action research, the *human* component of structure interacted with the *access* and the *appropriation of resources*. All of my students had their own goals and ways of learning. One goal should have been to learn biochemistry. By learning biochemistry, each one of my students moved toward his or her objects or goals in order to achieve the outcomes that each one wanted.

My goal was to empower my students to find their own agency, to become learners, and to find relevance and meaning in science. I wanted to encourage each student to reach beyond her or his original goals as she or he entered my classroom. I have chosen to pursue these aspirations using collaborative learning (while using the language of science) and technology as my primary tools.

This action research exposes my own personal strengths and weaknesses, but in the process, I learned more about encouraging students to work collaboratively on group projects and structure the curriculum to foster collaboration and learning. This personal look at my own experiences on teaching and learning may help other college-level faculty members as they plan and reflect on their own teaching. I outline through this chapter my learning through conducting action research.

The LEQ and the CLS provided a wealth of qualitative data. I utilized these data and focused on the functioning of the classroom and the learning that occurred within the collaborative groups. Suzanne's contributions to her Web site from her portfolio provides a brief glimpse into the historical flow through the semester.

I believe one major problem in my biochemistry course was that students did not really understand the difference between cooperative learning and collaborative learning. I knew the power of collaborative learning because I had experienced collaboration in my own career (Gilmer 2007), but some students felt that if they just did one segment of the presentation, this isolated segment was enough.

They did not realize that they needed to work together continuously in order to improve the learning for the project. This effort included getting together, either electronically or as a live group, and going over each one's contributions and integrating them, both in their minds and for the project. One group on the CLS said their group was particularly effective in "integrating our individual contributions and knowledge and bringing it together to an integrated but diversified subject matter [and] … relating to each other's part of the presentation." This group learned to work together by partaking in collaborative learning.

Students did not actually have to get together physically for collaborative learning because I created a dialogue room for each group on which they could share their preparation, lists of Web sites that they found, and approaches they were taking for their chosen topic. On CLS, one group said, they were particularly effective in "working as a group without actually ever being in contact with each other. We have mastered the technology well enough to use it for group projects while working independently." In my current teaching, I have a place for each group on *Blackboard* Web site, in which we have discussion boards, chat rooms, file exchanges, and e-mail sites. Group members can share presentations or other files they find on the Web, with one site for each group, encouraging them to work electronically and collaboratively.

Only after I taught the experimental biochemistry course did I fully understand and appreciate the differences between cooperative and collaborative learning. I had assigned a chapter to read on "Construction of Knowledge and Group Learning" by Linn and Burbules, for a graduate course I was teaching in *Technology in Chemistry Education*. Even though I had read this same chapter several years beforehand, I had not fully understood the differences between collaborative and cooperative learning until I reread the chapter after collecting all my experimental data.

Communication is a key ingredient in good collaboration, whether we communicate by getting together in class, after class during group meetings, or on the Web. I read the group responses from the CLS each week, and so I could touch base with a group that was having trouble. In my action research study, communication was a theme that many students mentioned in the CLS: one group was particularly effective, for example, in "communicating our concerns and providing ideas, which may aid in allowing things to run more smoothly." However, one group that did not communicate well shared in writing that they were particularly effective in "absolutely nothing – no group communication." A third group said we are "communicating our ideas [with] each other, effectively dividing up the work." When communication was good, students learned to trust each other. If communication was not good, groups cited that their need for the next project was communication.

One group summarized their skills/knowledge gained on the CLS:

> If we compared our present group to the group from the beginning of the term, you would be amazed. Everyone gets along and has an equal voice. Even though our schedules conflict, we have learned not only the basics of biochem but also how to work efficiently and effectively as a unit.

This is a pleasant remark on which to close the section on collaborative learning. I do think that many students gained insight about successful collaboration while they were learning biochemistry and technology. While some students focused more on one aspect than others, in the end, many students learned aspects that the other students in their group had learned. This lesson on collaboration is equally valuable to these students' professional lives as the biochemistry that they learned.

Chapter 6
Students Using Technology in the Classroom

6.1 Preview

I focus on the use of technology in developing Web sites for communicating with group members, preparing class assignments, and presenting group-constructed Web sites in the classroom. Students use technology to learn biochemistry, construct their group Web sites, write electronic portfolios of their learning, and give in-class presentations for three of their group's Web sites. Data include their Web sites, electronic portfolios, and responses to the qualitative questions in the LEQ and CLS, and student interviews. Again I employ social constructivism, cultural historical activity theory, and the theory of structure | agency to analyze both the coherences and contradictions in the students' learning of biochemistry while using technology.

In this chapter, first, I introduce the topic of students using technology in the classroom by providing the setting for my technology-rich institution, which values the use of technology in teaching, then I illustrate my practice of using technology in teaching. I also give a summary of the literature that examines the use of technology in college science classrooms, especially chemistry or biochemistry classrooms.

This introduction sets the stage for the qualitative ethnographic data from two primary sources: the LEQ, which I gave my students at the end of the semester, and the CLS, which I gave to each group throughout the semester on the day when each of the ten group Web sites was due. In addition, I utilize some portfolio entries from Suzanne, a student in my classroom, to give a chronological look of the study. Through these entries one can see Suzanne overcome her technology problems, as she was able to shift her focus from learning technology to learning biochemistry. I also examine the response of another student, Michael, to the "final question" on his learning about hydrophobic–hydrophilic interactions through using our students' generated Web sites.

Finally, through the lens of cultural historical activity theory and the theory of structure | agency, I examine the coherences and contradictions in achieving the goals that I set out at the beginning of the study, thereby helping me address two of my research questions:

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1. How do uses of technology and the Internet influence students' learning of, and interest in, biochemistry?
2. What can I learn about my teaching through doing action research in my classroom?

These two domains – my students' learning and interest as well as my own teaching – interact and influence each other.

6.2 Learning to Use Technology in Teaching

6.2.1 Relevant Experiences in Technology Before Start of Action Research

From 1993 to 1995, I was co-principal investigator with Angelo Collins of a Teacher Enhancement grant from the NSF. Our program, *Science for Early Adolescence Teachers* (Science FEAT), focused on practicing middle school teachers who taught in northern Florida and southern Georgia (Spiegel et al. 1995). Teachers could earn a master's or specialist degree through our program with three summers of classes and two academic years of applying learning from the past summer in their classrooms.

My first immersion in technology came in the first summer of this program, while working with 72 teachers, teaching them STS, with all assignments due electronically. Teachers had group projects and individual portfolios of their learning. For the second summer of Science FEAT, I led an experiential learning activity with all teachers engaged in scientific research with mainly non-academic scientists in the field over five weeks. Students posted their learning portfolios electronically in document files.

However, near the end of that second summer, I had major surgery for a fast growing cancer. As I recovered from surgery and chemotherapy over the next year, I found that separating my own diagnosis from the tumor biochemistry that I had studied in my laboratory for ~20 years was too difficult. I feared my original cancer would continue to grow or metastasize, or I could contract leukemia (due to increased incidence after chemotherapy). From my own scientific research in T-cell-mediated killing of leukemic cells, I knew in exquisite detail that leukemic cells divide quickly. Having just had cancer myself made performing biochemical research about leukemia, just too personal for me to continue.

Therefore, I needed to embark in a new research direction. In the fall of 1995, 23 years after finishing my first doctorate in Biochemistry from University of California, Berkeley, I started a new graduate work in Science Education at my home university, initially as a "special student." Part of my motivation to learn Science Education was that I felt if I were stimulated to learn, I could focus my energy and gather my strength to recover from cancer (which I did). Kenneth Tobin was my first science education professor. I took one class per semester for two years, while working full-time in my regular faculty position.

I realized that I needed some new research, something that challenged me differently, and would require to me work hard. I found quantitative research in my first doctorate to come easily, so I decided to try something new – qualitative research. By examining words, instead of analyzing numbers, as I did for my kinetics experiments in my first doctorate, I found myself in a new creative endeavor, conducting research on teaching and learning of undergraduate-level biochemistry.

While still recovering from chemotherapy and conducting my first action research project, I had a powerful dream that I could coalesce my teaching, research, and service at my "triple point," in which teaching, research, and service could all interconvert and become one (Gilmer 2002). This dream fueled my recovery from cancer and my newly found energy. Rejuvenated, I joined the graduate program at Curtin University of Technology in August 1997, and I proposed to conduct action research in my biochemistry classroom for my doctoral thesis.

I learned to teach using technology using a Web site called CCL (Tobin 1998, 2002) over three summers. During this time interval, as FSU faculty, I taught a science education graduate cohort of about 150 graduate students (for M.S. or specialist degrees) in Miami, Florida. I was one of the "content" people, teaching *Physical Science* and *Science, Technology, and Society*. Since we taught these graduate students partly by distance learning as well as on site in Miami, I needed to learn to use our program's Web site and learn the power of teaching using technology. During this period of time, over meals with Nancy Davis and Ken Tobin, I began to confront some of my positivist ideas on teaching.

In the summer, just before I taught the experimental Web-enhanced *General Biochemistry I* course, which is the subject of this book, I received an award from my university for my ideas on using the Web for this upcoming course for science majors. My university paid for a portion of my summer salary so that I could learn to use the Web-MC, which was new at my university, and other technologies for teaching (i.e., using PowerPoint, etc.). I was in the first cohort of faculty to enroll in such technology workshops at my university (Manner 2003).

My university, the site of my action research, cited itself as "consistently ranked as one of the most 'wired' universities in the country." In 2003, FSU's Web site stated (FSU 2003):

> The core network infrastructure is robust and substantial. Virtually every office on campus has computers that connect to Local Area Networks for file and printer sharing, the intranet, and the WWW. Many programs and departments maintain their own networks that operate within the framework of the larger network.
>
> Every residence hall room has an Ethernet connection for each resident. This high-speed connection provides for a fast and 'always on' connection to the campus network and the WWW.
>
> For faculty and students, great strides have been made to increase and improve our technology-enhanced classrooms. These classrooms enhance the learning and teaching experience by providing a multi-media environment. This includes network and Internet connections, video, and LCD large screen projectors. (¶ 1).

Regardless when I went to teach the course for the action research study reported in this book, at FSU I had neither an Internet connection nor an LCD projector in my regular science classroom. Our FSU Business School kindly provided me with one of their technology-rich classrooms twice a week. For the third class period each week, I met in my standard science classroom with a chalk blackboard and an overhead projector.

6.2.2 Using Technology in Teaching Science

Jonassen et al. (2000) and Jonassen (2000) examine the use of constructivism and cultural historical activity theory for determining the "potentialities of technologies to promote meaningful learning" (Jonassen et al. 2000, p. 103). Jonassen (2000) argues that to get beyond the transmission role of technology, "it is necessary to adopt a transformative view of technologies as resources for transforming existing practice by providing new ways of thinking, knowing, and acting in education" (p. 23). Using technology in a transformative way can empower our younger generation to become independent, self-realized, and life-long learners.

Empowering our younger generation was part of my goal in my classroom, so these papers by Jonassen et al. (2000), Jonassen (2000), and another by Linn (1998) were important references for me. My hope was that technology would be a catalyst for my students' transformation, much as technology had been for me. I wanted to "capture the process of social construction of knowledge in instructional programs" (Linn 1998, p. 273). Linn makes the point that autonomous learners could critique each other's ideas while advancing all students' (and the teacher's) understanding of science. Success in this situation depends upon "carefully critiquing the ideas of others, as well as on soliciting alternative ideas, sorting out conflicting information and responding to other learners" (Linn 1998, p. 274). Utilizing a constructivist process in conjunction with technology enhances the effectiveness of technology as part of the learning medium.

6.2.3 Utilizing Technology in My Action Research

Basically, for my biochemistry class, I had two course Web sites, both password protected. One was called Web-MC, which the university developed, and I uploaded a course homepage, syllabus, class schedule, specific resources for the class, assignments, rubric for assessments, communication links, and help resources for use of the Web. The second Web site, CCL (Tobin 2002), provided a site in which each student posted answers to end-of-the-chapter questions and reflected within an electronic portfolio on his or her goals and contributions to the group Web sites. Students and I could easily communicate by e-mail, via the two course Web sites, and I interconnected both sites electronically. One advantage of the CCL site is that I could comment privately to the student on the student's stated goals or learning. Students in all ten collaborative groups could utilize a group electronic dialog journal, which became a private meeting place on the Web where group members, for example, could post Web sites of interest to other members of their collaborative group, or times that they could get together to meet in person.

In the beginning of the course, we took time to learn the technology, since most students did not know how to use the Web as a search engine, and all but one graduate student had never developed a Web site.

Our class met three times a week, for 50 min each time. In a typical week, I lectured typically for one and a half class periods; collaborative groups generally had about 10 min during each class period for planning and showing other members in the group their ideas and efforts to date; collaborative groups presented their Web sites for the rest of the time (at least one class period per week). In my lectures, I tried to outline the key concepts from our textbook to give the "big picture" ideas and provide ideas for the students to select their topic for their next Web site. During class, I did not take time to show students methods to answer assigned problems, but I did post my written answers on a bulletin board, after the problems were due.

By the middle of the semester, many of the students developed an expertise in technology, often with the help of other students in their collaborative group. Students working in collaborative groups developed specialized Web sites by using information they gathered from the Web and our biochemistry textbook (Matthews and van Holde 1996). Ten collaborative groups (with two or four students each) made group presentations for three of their ten group Web sites. Table 6.1 gives the titles of all 30 Web sites presented during class by collaborative groups of students. These titles show the diversity and complexity of topics chosen by my students. The Web sites correspond to biochemistry content in Chapters 1–4, 6–7, 9–13, 15, and part of 17 in our textbook, *Biochemistry*.

The teaching assistant for the course developed a table with hyperlinks to the 100 Web sites (ten for each of ten collaborative groups) that my students had created. Since most of these Web sites are no longer available on the WWW, I do not provide the URL addresses to any of the student Web sites.

For each presentation, students peer assessed each other's Web site presentations and also self-assessed their own presentations. Within a week of the presentation, I collated the results, including my own comments, in typed format and distributed them to each member of the presenting group (examples available at http://www.chem.fsu.edu/~gilmer/downloads.html). Students felt that this feedback helped them to improve their presentations. By peer assessing other group's presentation, students became more aware of features that made a presentation better because they had to think about the criteria for assessment. The questions to which each group responded on the group evaluation of all group presentations were as follows:

1. What was your interest in the material presented?
2. How did the presenters encourage you (and others) to get involved in the presentation?
3. What new information did you learn that you could integrate into other material learned in the course?

Table 6.1 Titles of group presentations on Web sites generated by student collaborative groups

First set of Web sites
Structure of proteins and their importance in life
Different forms of protein secondary structure
Gene cloning and recombinant DNA technology
Elastin, the elastic polymer
How buffers act metabolically
Cell membranes – amphipathic molecules
ATP – the charged energy molecule
Collagen – its structure and how it is used in the body
Genetic diseases and the human genome project
Acid–base balance in the body
Second set of Web sites
Quaternary structures of proteins
Antibodies and human disease
Carbohydrate structure and blood types
Allosteric effectors and regulation of biological activity
Membrane protein channels
Complex carbohydrates and polysaccharides
Coenzymes and vitamins
Vitamins and trace metals
Neurotransmitters and the brain
Carbohydrate metabolism
Third set of Web sites
Inhibitors of the electron transport chain
Creatine phosphate and muscles
Metabolism of disaccharides and non-glucose monosaccharides
Aldolase and the glycolytic pathway
Metabolism of alcohol, pyruvate and lactose
Photophosphorylation and photosynthesis
Hormones – controls of the body
Light absorbing pigments
Different fates of pyruvate
Photosynthesis – Calvin cycle and C4

4. What resource information (i.e., Web site links, other resources) was shared with the class?
5. What is your overall evaluation of this group's presentation?
6. Additional comments?

Learning the criteria that make for a good presentation helped each group in the next presentation. Table 6.1 shows the diversity and practicality of the presentation topics.

My *General Biochemistry I* class completed the same number of chapters as the parallel, all-lecture section of biochemistry, taught by a different faculty member. Both classes used the same textbook during the same semester. My colleague, Professor Timothy Logan, allowed his section to be larger so that I could maintain a smaller size for my experimental classroom.

Table 6.2 Compiled student grades from experimental class and comparison group of general biochemistry (for majors in sciences)

Biochemistry classes	First semester		Second semester	
	Average grade	Percentage of advance [b]	Average grade	Δ grade [a] (Second to first semester)
Gilmer's students	3.5 ± 1.1	47	2.3 ± 1.3	−1.2 ± 1.2 [c]
Comparison group of students	2.4 ± 1.2	60	2.7 ± 1.2	0.3 ± 0.8

[a] Δ grade is the difference between the grades the students (only those proceeding to take the second semester course in the sequence) received in the first semester course minus the grade in the second semester course.
[b] Percentage of advance indicates percentage of the students in each section that took the second semester course.
[c] Out of the 15 students from my section taking the two-semester sequence, I granted extra credit to ten of them for doing either the extra-credit mid-term or the extra credit final question, or both. This came to an average additional 0.3 grade point per student.

The final grades that my students received in the first semester tended to be higher (3.5 ± 1.0) (on a grading scale of 4.0 being an A) than those in Logan's parallel section (2.4 ± 1.2) (Table 6.2). Part of the reason for this was because I needed to award extra credit for the optional mid-term and final question, which raised my students' average grade by 0.3 points (see footnote c in Table 6.2).

Out of my 32 students finishing the course, 15 took the second semester course in the sequence. A comparison of the grades of my students versus those of the Logan's first semester biochemistry students taking the second semester course showed no statistical difference (2.3 versus 2.7 ± 1.2) between the two groups partly because the standard deviation was so large for the small group of students (Table 6.2).

6.2.4 Rubric: Web Site Construction and Portfolios

I developed a set of five criteria for grading the written work, which we used to assess students' individual electronic portfolios and the group-generated Web sites (Table 6.3).

6.3 Examining Coherence and Contradictions Using Technology

In this section, I cite data from several sources: (1) the LEQ and the CLS that my students wrote on their experiences as they used technology in our classroom; (2) Suzanne's portfolio on her entries related to technology during the course of the semester; and (3) Michael's response to the "final question."

Table 6.3 Rubric for *General Biochemistry I*

Criteria for evaluation of written work:
1. Accurate relating of current understanding of the science content, using the language of the biochemistry discipline
2. Reflecting in relation to your prior learning and/or experiences
3. Writing in good form, without spelling or grammatical errors. Using a spell check and a grammar check on your word processor first. Using HTML code, to emphasize your points, and making your text easier for others to read and learn
4. Providing links to your learning. Providing active electronic links
5. Asking good questions that result from your research of the science content

6.3.1 Students Constructing Web Sites

Within the main category of Technology/Web Sites in the data (Table 3.3) from the LEQ, the four main subcategories included: Group Web Sites, CCL Web site, Class Web-MC Web site, and Web Learning. These comprised 25% of the all text units.

Statements on technology from CLS (total of 619 text units) fell into two major categories: (a) academic/task achievement (22.7% of total), and (b) process achievement (70.1% of the total). In academic/task achievement only 2% of all the statements related to technology, while in the process achievement, 14% of all the statements related to technology. Most of the CLS statements dealt with collaboration (47%) in the process category and the content of biochemistry (17%) in the academic/task achievement category. The total percentage of categories was only 93% because some statements were only a word or two and were not sorted, but they counted as text units.

6.3.1.1 Computer Skills

Most of my students felt amazed at the extent of information available on the Web. This class took place in 1998, still relatively early in the Internet's development. The students were astonished that the information was more up-to-date than our textbook. For example, our textbook stated that predicting a protein's three-dimensional structure, using the amino acid sequence, even for small proteins, was only "in its infancy" (Matthews and van Holde 1996, p. 196). However, my students found a Web site that could predict a number of three-dimensional structures for proteins from amino acid sequences. I do not think that most students were attuned to the fact that our knowledge of biochemistry advances all the time. Students came to realize that through the Web, they could search and find information that supplemented and expanded on information in their textbook.

Many of my students had never made a Web site, though most had used e-mail. Many had not learned to use search engines on the Web. Most students did not know that this class would be Web-enhanced when they signed up for the course, but still most stayed with the course and learned the technology. For instance, one student said in the LEQ:

> There were a lot of Web sites, but I enjoyed them. They were time consuming. As for me, I came into the class computer illiterate and am learning with competency. The beginning was rough; I had to learn the computer as well as the [biochemistry] concepts. Maybe provide a recitation period for computer skills to be taught.

Students had to select a topic for their Web site as a group and then "figuring out how to divide up the information doing individual research on our subtopic, put[ting] [it] on the Web, and then review[ing] each other's work to provide total coverage of the topic" (Source: CLS). The students in each collaborative group had to decide on their topic and organize each person's part of the research. They had to learn to work together to bring the Web site all together. After doing the research, they had to collect and organize the information and select the most appropriate information for their Web site. For instance, in order to connect each other's pages in an effective way, they would meet in the evenings and develop, for example, a "better understanding of the ATP molecule through discussion" (Source: CLS).

Some students mentioned that they thought that the requirement of ten Web sites per group was just about right. I chose ten as I felt that the students needed to demonstrate learning in almost every chapter of the book (from a total of 13 chapters). On occasion, I allowed students to develop one Web site from material in one of two chapters. Another student said in the LEQ that we should devote more time to learning HTML in the beginning, but "maybe delete two Web sites so we'd have more time to make them better."

A few students suggested that I supply a tutorial or have a Web tutorial session on making a Web site, including information about uploading documents, saving pictures, etc. I did actually have extra sessions in a computer laboratory outside of class time. However, since students did not typically come (although many may have had a conflict with classes or other obligations), I discontinued the technology help sessions, midway through the semester.

However, the idea of a Web-based tutorial was a good idea that I did not use at that time. Had I made Web-based tutorial, all students could have accessed the resource, perhaps more conveniently than attending extra help sessions I offered in the computer laboratory. Since then, as I mentioned in Chapter 5, I have developed a Web site (http://www.chem.fsu.edu/~gilmer/courses.html) to help students use technology and work in collaborative groups. To date, I have utilized the tutorial in four offerings of the *Introduction to Biochemistry* course. The tutorial greatly facilitated students' use of the Web and provided an approach to working together in their collaborative groups to get their project completed on time and in good form.

For the study described in this book, I used the CCL system for the students to maintain electronic portfolios. CCL was excellent in its organization (e.g., students could have portfolios separated into various folders; all the students could look at everyone's portfolio; and I could respond privately or publicly to each student's posting in each section of the student portfolio). However, CCL had some odd features, for instance, the uploading of pictures was confusing. Also CCL was cumbersome in allowing students to set up folders within their portfolios, but still CCL was worth the effort of learning.

Students in their electronic portfolio had a place to post their goals at the beginning, in the middle, and at the end of the course. Reading my students' goals was critical in making the class more relevant and meaningful to my students. Knowing my students' goals allowed me to connect to my students, even early in the semester. Also by requiring students to examine their originally stated goals twice more during the semester forced them to examine educational goals they had yet to accomplish and allowed them to recognize goals already achieved. Some students realized that they developed new goals during the semester, ones that they had not conceived at the beginning, like learning technology. I have continued to encourage my students to formulate their goals ever since conducting the action research described here.

Many students indicated that using technology facilitated their learning. For instance, one said: "We will be using technology in our jobs so why not use it in our learning also" (Source: LEQ). Many saw the power in integrating knowledge from more than one domain, such as chemistry and biology. Technology also taught students to be "patient and to envision a good result at the end" (Source: LEQ). With the "projects that related to the learning [in the classroom], they really reinforced the concepts that we were studying" (Source: LEQ).

Students also saw that the Web sites they had created had the potential to be "functional learning devices," (Source: CLS) as they integrated the group members' contributions to the topic on their Web site. The students learned to use graphics (e.g., one student during his group's presentation taught the others to make a data table on vitamins), frames, and text dividers, and even developed in-class quizzes to get their peers more active learners, during their presentation. Students and I felt charged during a presentation as one group linked to a Web site that another collaborative group had created earlier in the semester – we were constructing our own web of knowledge by collaborating and connecting to prior information that we learned earlier in the semester.

The students became familiar with the material, generally first through the textbook, working on problem sets, and then "looking for Web sites to integrate and expand our knowledge – building text for [our] Web page" (Source: CLS). Basically, not only did my students have to learn the information, they had to organize, phrase in their own words, and add graphics and other visuals to enhance the learning and keep their fellow students' interest.

Many students really enjoyed having others visit their Web site and sign into their guest book. Students felt empowered by the activities offered in this experimental course. One student mentioned in the CLS that they were "getting better at organization of thought and working together." My students had to learn the biochemistry content to be able to interconnect the ideas. One group wrote in the CLS a statement about each member's contributions:

> Brady has been of good technical help. I think he has more time to spend learning the different ins and outs of html. Samuel has also gone above and beyond in his Web pages. Suzy has learned more about the larger implications of biochemistry of molecules we have studied. Brendan is very thorough and knowledgeable in his subjects.

The "Suzy" mentioned here is the same student Suzanne whose writing you read in Table 5.1 on the contradictions and coherences in her work with collaborative groups over the generation of ten group Web sites. Her writings about technology come later in this Chapter 6. Suzanne's group worked well together, with all four of them learning from each other, and enhancing each other's topics within the group presentation. Through successful collaboration, students created their own knowledge and expanded the limits of others. The students enjoyed the process of knowledge generation and felt challenged.

As mentioned in Chapter 5, however, conflicts and clashes occurred in some groups. One group of two students had trouble with procrastination. They would do an all-nighter before their presentation. Once they lost their work because the computer froze (they forgot to save the file as they went along), and another time one of them was so exhausted, she overslept and missed class on the day of the presentation. The fact that the group was not ready for its presentation disrupted class; in these instances, I had to present a lecture, for which I was not totally prepared. Instead of letting groups that missed their normal presentation time present in the next class period, I should have put my foot down and indicate that they lost their chance to present. I learned that I needed to give a deadline for the groups to have the Web site available a few days in advance. That way I had time to be familiar with their topic and provide a critical review of their Web site, so the group would be ready for its class presentation.

One complaint I heard was that students thought they were learning more about computers than biochemistry, especially at the beginning. Had they not needed to spend so much time to learn to use the computer, they would have been able to integrate the biochemistry. Had I provided more help to my students for the technology with a Web-based tutorial, I think the learning environment would have been better for learning biochemistry. Now with much better software programs to make Web sites, creating Web sites would cause less of a problem for the groups, if the class were taking place now.

6.3.1.2 Web Learning

When I started teaching this biochemistry class, I had just learned to make my own class Web site, using the Web-MC, so I too was still very much a learner on the Web. I had a Science Education graduate student, Elizabeth Mayo, helping my students and me with some technical questions about making Web pages for a few class sessions near the beginning of the term.

At least one student was bothered by my being a "co-learner," saying in the LEQ: "I think the instructor needed to have a firmer grasp on the usage and capabilities of Web learning, we needed a leader, not a co-learner. The Web is a useful tool, but learning it should be part of other classes." To be honest, this student's concern is valid. I was not nearly as adept at technology as I am now.

In the Web learning category one of the most telling quotes cited in the LEQ had to do with the amount of information the students had learned: "I feel I learned a lot about the topics covered, but little about ones I did not [cover]. There may be too many Web sites [for us to have to make in the 15-week semester]." I think this student felt that she or he learned some depth of understanding biochemistry, but she or he also felt gaps in his learning. In part, she or he also was saying that the group members were so busy creating Web sites that they did not have sufficient time to learn the big picture of biochemistry.

Another student said we could do a group Web site every other week (instead of almost one per week). This suggestion would provide students more time to review the Web sites created by the other groups and to reflect on their learning. The disadvantage of decreasing the number of Web sites was that, at least with the system I used to assess my students, some students may not have read and studied entire chapters. I would need to adapt a way in which I could assess whether the students did study the other chapters.

Since teaching the experimental class, I started to use Rainer Glaser's *Chemistry Is in the News* Web site: http://ciitn.missouri.edu/ (Glaser and Poole 1999; Glaser and Carson 2005). At this site, students work in collaborative groups to report on a recent newspaper article that relates to the subject material in the course. Glaser's students report on organic chemistry, and mine on biochemistry. One nice feature of this site is that I can set up the site so that students peer-review each other's work, thereby getting the feedback to improve their post. In addition, as students review other group projects, they learn to improve their own projects. After receiving the group's reviews, the group has an opportunity to improve the project, and get reviews a second time. This reviewing teaches students not only to give and receive peer-review but also to utilize the Web for learning and improving one's own group project. I learned to have only one graded group project per semester. Glaser gives workshops at various professional meetings on using this resource, so now he has chemistry teachers from a number of institutions and a number of levels, including international locations.

Concerning the depth of learning in my experimental class, students varied in their responses on the LEQ. One student said: "I did learn in depth on many things via the Web page. I am acquainted with the information of other Web sites but will never say I learned [the Web sites from the other groups]." Another student commented: "these projects allow us to get into something that interests us, and really go beyond what the book covers." Similarly, a different student said: "The incorporation of Web searches along with the textbook gave us A LOT more information and research to pull from." Another student summarized:

> Procedures that worked well: We had to read the chapter so that we came to class prepared to listen to Dr. Gilmer's lecture. Then we had to answer chapter problems, [and] then reinforce our learning by looking in the Web and developing Web site projects.

I wished that all students would take this approach to learning.

Some students commented in the LEQ on the differences between textbook learning and learning on the Web. Students differed on whether they thought the textbook was useful: "We learn a lot from the Web sites and the lectures. It's just that the book isn't that useful." Another said that learning from the Web was an "opportunity to get beyond book learning and get into Web learning." Learning from the Web brought "a greater view of applications of what was learned in class."

Students did mention that trying to learn both technology and biochemistry was hard, especially in the beginning of experimental class. However, as one said in the LEQ: "I eventually figured it out." Since the experimental course, I have resolved this problem in courses that I now teach, by having them use technology earlier in the semester and by giving them more time to prepare for their group presentation. Also I only have them do one graded group project, so that they focus on one topic and one group experience.

What the students learned in this class often helped them in other ways in their lives. For instance, one student in the LEQ said about creating Web sites: "It was awesome. I really felt comfortable and confident in the use of the Web for doing research, something that can be seen in every project I do now – even not related to this class." Many students told me that they created Web sites for other classes and organizations to which they belonged. Some shared their own personal Web site that they had created either during the class or later. The knowledge that my students learned has been useful in both their academic and personal lives.

One student, Suzanne, did a member check with me on her entire electronic portfolio after the semester concluded. Suzanne's electronic portfolio entries on her contributions to her group's ten Web sites provide an historical look at her perceptions on use of technology during the entire semester (Table 6.4). I have studied Suzanne's written entries and identified her contradictions and coherences on her contributions to the group Web site. Basically, in the beginning, she mainly discussed her problems learning the technology (Table 6.4), but as the semester progressed, she focused more on her learning of biochemistry (Table 5.1). In Table 6.4, you can see that her learning of technology advanced. She wrote the process she used for developing each Web site and of her learning throughout the semester. I could not identify any contradictions in Suzanne's use of technology for Web sites #6 through #10. As the semester progressed, she mentioned new advanced Web site construction (Table 6.4). See Chapter 5 for Suzanne's contradictions and coherences in her perceptions of working in a collaborative group (Table 5.1).

In the written criteria for the rubric I used for students' writing (Table 6.3), I made it a requirement for each student to write the research question that was in his or her mind at the end of each project. In this way, I could assess each student's learning. I have chosen one of Suzanne's questions with the paragraph leading up to her question, so that the reader can get insights into her thinking (Fig. 6.1).

Reading a student's questions, such as Suzanne's in Fig. 6.1 gave me a window into his or her conceptions and his or her immediate and long-term goals for learning. Suzanne's question involved a basic structure–function relationship that researchers would ask about the linkage between the structure of a biochemical molecule and its function in a cellular environment, for example, the hydrogen ion pump working within a gastrointestinal cell. Some questions of this type I could address in class. In the metalogue in Chapter 7; Dr. Light and I discuss Suzanne's responses for her extensive content coverage.

Table 6.4 Contradictions and coherences in use of technology: Suzanne's electronic portfolio entries throughout the course

Web site #	Topic	Contradictions	Coherences
1	Hydrophobic–hydrophilic interactions	Took eight h and energy just to learn how to construct the Web site	Search on Web for definitions, examples and relevant research projects; "facilitation of learning;" "I learned another language: html."
2	Genes as a link to disease	Spent so much time on computer that I "hope to get back on the path of biochemistry next time"; "When things didn't work, it was very frustrating"	"I must admit that utilizing the computer to this higher capacity was very exciting when things worked."
3	Globular proteins	"still cannot load pictures directly onto my site … the Internet provides a never-ending source of knowledge on the slightest subject"	"pictures and animations are extremely effective teaching tools"
4	Role of hemoglobin	"I can only pursue my topic for so long before I am forced to give in to the subject that apparently dominates the broader category of my topic … Many times, I have had to alter my paper because of the scarcity of sites related to my specific topic"	Added pictures that were "very unambiguous... I learned very easily from the pictures and information because of their clarity and organization"
5	Plasma membrane and membrane transport	"Unfortunately, I was not able to find the osmosis animation during my oral presentation"	"The simulations and illustrations made the processes much easier to grasp"
6	Enzymes		"I created a 'Picture Page,' which is basically a collection of illustrations accompanied by relevant text"
7	Lipid metabolism		"I am satisfied with the coherence of our Web site: the different divisions discuss a distinct aspect of the grand scheme of metabolism"

(continued)

Table 6.4 (continued)

Web site #	Topic	Contradictions	Coherences
8	Otto Meyerhof in the history of metabolism		"My summary describes the muscle preparation and the facts learned from it that led to the identification of the 'muscle machine' and the assumption for Meyerhof's experiment."
9	Chemiosmotic coupling		"I am very appreciative of the Web project because it has well prepared me for chapter 17 on photosynthesis. The chemiosmotic process applies to plants as well, only it occurs in the chloroplasts."
10	Photosynthesis		"I did learn a new trick in Web design that was easier than I anticipated, targets within a page."

In both Chapters 5 and 6, you have read from Suzanne's portfolio of her coherences and contradictions in both collaborative learning and technology, respectively. However, in the end, upon reading Suzanne's final goals statement in her electronic portfolio, Suzanne stated that although she had to work harder in the biochemistry course with me than earlier biology classes, she felt more motivated as an independent learner in my class:

> No biology class has ever been able to get my dedication as this one has. Every time I *tried* to motivate myself (back then), the tedious reading assignments of the textbook just didn't nourish my interest. And though we are required to do work in this course, I don't feel the force that I used to feel when reluctantly studying for an exam. It is more like something that I *want* to participate in, even though it requires more work than studying for, or taking, an exam. I think that this is because I am given a challenge and am encouraged to be an independent thinker by having to construct my own Web page, which illustrates my learning in a way that I would have it taught. (emphases in italics were hers)

I knew the students had to work harder in my class, but learning does require active participation and struggles to overcome obstacles. Suzanne displayed these activities to me. Also Suzanne asked a good biochemistry question (Fig. 6.1), related to her research on plasma membranes. She realized that she could learn deeply and share her learning with her collaborative group members, and although she tended to be shy, she could share well her understanding of biochemistry with the whole class during presentations. The biochemistry course challenged Suzanne like no other science class she had taken as an undergraduate. Suzanne is finishing her doctorate at a major Research I university in Molecular and Cellular Pathology. In a recent e-mail when I asked her for an update on her life, she wrote, "you have had an amazing career and have had such an impact – definitely on my life and career!" (e-mail, 4 August 2009).

Still, I would like to know of more detrimental effects of mutated plasma membranes. Those that I have come across thus far are obesity, cystic fibrosis, and high cholesterol. I discovered a theory that links obesity to the malfunctioning of the sodium pump, and linked cystic fibrosis to a defective channel protein. Then, probably the most known effect of an unhealthy plasma membrane, and very common, is high cholesterol. When too much cholesterol is taken in, the plasma membrane rigidifies. When made rigid, the lateral mobility of the membrane is restricted, thus its functions are inhibited. In order to meet the needs of the cell, transport must occur. Yet decreasing the mobility and fluidity of the plasma membrane makes transport more difficult. This is why people need to monitor their diets and limit their cholesterol intake.

I am curious to know other situations in which the plasma membrane has mutations and plays a role in the cause of disease and illness. *For instance, is the malfunction of the hydrogen pu mp what accounts fo r gastrointestinal problems ?*

Fig. 6.1 Student questions about portfolio and Web sites. One example of Suzanne's questions (and associated preceding paragraph) from one section of her portfolio on contributions to her Web sites

6.3.2 Web Writing

The typical university biochemistry classroom does not emphasize writing. Instead, typical biochemistry professors emphasize the ability for the students to solve analytical problems, memorize various metabolic schemes and structures of molecules, and apply some theories. Since I believe that learning requires the use of language (Lemke 1995; Kovac and Sherwood 2001), I encouraged my students to use language, both in oral presentations and in writing their portfolios and Web sites. I wanted my students to construct meaning through the use of words, as they learned biochemistry from reading our textbook, attending class, lectures and other student group presentations, working in their collaborative groups, and utilizing the Web. If students reflected on their learning through writing, I believed that students would form stronger connections, which would, in turn allow them more time to learn more deeply. Therefore, my students had to construct meanings in biochemistry through the words that they discussed in their groups, wrote on their group Web sites and individual electronic portfolios, and spoke during their presentations in class. Suzanne showed some evidence of growth in her efforts to construct meaning in her writing (Table 6.4 and Fig. 6.1).

I assessed my students' learning through their writing. The students posted three types of writing assignments on the Web: (1) writing for their Web sites; (2) writing goals and examining progress toward reaching these goals (for three times over the course of the semester); and (3) writing about their own learning while preparing each of the ten group Web sites, including the question that she or he still had in mind at the end of the project.

In addition to the above, I offered two "extra credit" opportunities: (1) optional midterm, and (2) a "final question." For the extra credit "final question" the students could write about a reoccurring biochemistry theme that they saw in at least ten (out of 100 available) group Web sites. Figure 6.2a shows the guidelines for writing the "final question," Fig. 6.2b highlights a portion of Michael's (pseudonym) response to the "final question" on hydrophobic/hydrophilic interactions in biochemistry, and Fig. 6.2c has my response to Michael at the end of the semester.

In this example, I only chose five of the ten Web sites that Michael quoted in his extra credit "final question." Two of the five Web sites were from his own group's pages and the other three were from other group's pages. Michael wrote about the general principles of intramolecular and intermolecular interactions of protein folding, membrane formation, glycoproteins becoming embedded in the plasma membrane, and other matters that involve hydrophobic–hydrophilic interactions. I removed the links that were still active. I included his final reflections on the course and my responses to Michael's work and comments (Fig. 6.2c). I felt as satisfied to read his response then as I do now.

Michael demonstrated his learning of hydrophobic/hydrophilic properties of molecules from throughout the entire course (Fig. 6.2b). Michael felt empowered to learn biochemistry by the technology that he had learned to use in our experimental class.

Michael was one who had come to my office at the start of the semester, introducing himself to me and asking me to add him to this Web-enhanced offering of the course. He started out not very confident of himself, saying he was a "farm boy," from rural Florida. However, he developed considerably in his self-esteem and in his learning during the course of the semester. Within a few weeks of the start of class, I realized that he "went exponential" in his learning. He demonstrated this to me in his writing – he developed a detailed knowledge of hydrophobic–hydrophilic interactions, for instance. His first group presentation

a

This assignment is worth up to 5 extra credit points, out of 100 points total for the course.

Write up to two pages of text that demonstrates that you see connections on a topic that has come up repeatedly in the course. For instance, you can select a topic like one of the following:

1. energetics, or
2. coenzymes, or
3. oxidation-reduction, or
4. hydrophobic/hydrophilic interactions, or
5. catalysts, or
6. thermodynamics, or
7. another topic of your own choosing

Then go to our table that teaching assistant has set up, and then follow your theme, checking out some of the 100 Web sites that both your group and the other groups have developed in our course. http://home.earthlink.net/~wfa98/SummaryPage.html [note: this page is no longer active]

Then clearly identify your topic, and write text that is coherent that links at least three of your Web sites and up to seven other class Web sites. Use active links, so they can be easily followed.

This is due to be posted no later than Wednesday 5 pm, December 9, 1998. If for some reason you cannot post it (due to some problem with your portfolio), then send it to me by e-mail to gilmer@sb.fsu.edu [this was my e-mail at the time that I taught the course].

I hope by doing this assignment that it will help you strengthen your connections in learning biochemistry. You should do this assignment individually.

Fig. 6.2 (**a**) Criteria for the final question in *General Biochemistry I*. (**b**) Portion of the text of Michael's response to the "final question." All hyperlinks were removed (but the words that had been hyperlinked are underlined). (**c**) Gilmer's response to Michael's "final question"

b

A topic that I have seen come up repeatedly in our course is hydrophobic/ hydrophilic interactions. Just for a brief review, hydrophobic is the molecular property of being unable to engage in attractive interactions with water molecules. Hydrophobic substances are nonionic and nonpolar. They are nonwettable and don't readily dissolve in water. Hydrophilic refers to the ability of an atom or a molecule to engage in attractive interactions with water molecules. Substances that are ionic or can engage in hydrogen bonding are hydrophilic. Hydrophilic substances are either soluble in water or, at least wettable. These rather elementary concepts govern so many reactions, structures, and functions of biochemistry. I looked through the summary page and tried to gather a link from most of the groups. The concept is so vital to biochemistry that I had no problem finding ten links. The problem was picking the ten Web sites that best illustrated the concept of hydrophobic/hydrophilic interactions. I will start with my own links and then proceed down the summary page starting at the top.

My first link can be found be going to our page and the clicking, Globular Proteins. If you will look at any of the four links I think you will find that the major theme behind globular proteins is their structure and how it allows their structure.

Let's look at my link, Globular Proteins' Nature and Structures.

Here we see this kind of hydrophobic and hydrophilic structure in a globular protein. The tertiary structure of globular proteins reflects their interaction with their aqueous solvent. At a simple level, a globular protein may be considered to consist of a hydrophobic core surrounded by a hydrophilic external surface, which interacts with water. The tertiary fold of the polypeptide is such that those residues with apolar side chains are buried in the center, while the polar residues remain exposed. This principle is held by many to be the dominant driving force behind the folding of the polypeptide chain into the compact globular form: the aggregation and burial of the hydrophobic surface reduces the number of unfavorable interactions of these groups with water; thus the hydrophobic effect.

My last link from my own pages comes from Lipid Metabolism.

This is under the link, Metabolic Pathways. Dietary fat definitely relates to our theme. Dietary fat is non polar and requires a hydrophilic protein escort to circulate in the bloodstream. The protein molecules provide a polar coat for the lipid thus enabling transportation in the bloodstream.

Now for the links of my colleagues. You can link to The Summary Page. And here we come upon our friends at Group 4.Their link of Cell Surface Carbohydrates provides us with excellent relevant information.

Proteins or lipids in the cell membrane having hydrophobic properties may be covalently linked to polar hydrophilic carbohydrate chains (polysaccharides or oligosaccharides). These carbohydrates can play an important role on cell surfaces. They are important in cell recognition and in the extracellular matrix that binds cells to each other. As you can see they have an excellent figure illustrating this at the top of their page.

From the wacky members of Group 8, we have a great link to G-Protein-Linked Receptors.

One thing that every G-protein has in common is that they all have a single peptide chain that strings through the lipid membrane seven times. In order to do this, the G-protein must have hydrophobic amino acids in the membrane or exposed to the membrane and hydrophilic molecules in the extracellular space and cytosol.

And my last but certainly not least link comes from a second visit to Group 8.

This time our link is to Membranes. They have information on the cell membrane such as: Proteins in the cell membrane are hydrophobic on the outside of the parts that embed in the phospholipid bilayer.

The parts of proteins in the cell membrane that extend out from the membrane are usually hydrophilic, and sometimes the parts embedded in the membrane are hydrophilic on the inside.

The phospholipid bilayer does not allow large molecules, or charged molecules to pass through, as they cannot pass through the hydrophobic core.

The cell membrane is a fluid; it is not a solid.

Proteins in the cell membrane regulate the passage of large molecules, ions and many polar molecules through the cell membrane.

Michael's Final Reflection:

This concludes my final Web question. I am sorry if my page is too long but there is just so much information. I am actually sad this class is over. It has made studying for other classes seem very boring. On the up side I can leave this class knowing I have a solid biochemical background, and I am no longer afraid of computers. They are now truly my friend and not the feared enemy.

I do have some remaining questions about the future of this course.

1. Will there be more biochemistry courses on the Web? I think there should be.
2. Will it be changed to a 3-hour class and a 1-hour lab? Not a bad idea.
3. Will more teachers get involved with computer-enhanced courses?

Fig. 6.2 (continued)

c

Comments from Penny to Michael: (Michael received a grade of "excellent").

Reading your summary makes me realize that the potential of our students is so much greater than we ever imagined. We just need to believe in them and give them the tools to use their minds. My own studies of how people learn (in working toward my second doctorate in science education) have enhanced my teaching. I too have so much more to learn, and then think of what more we can do. It is like we will be in an explosion of intellectual growth. We are just seeing the tip of the iceberg of what we can do. You give me a vision of what we can be. Thank you. I'm so glad that you stopped by my office that first week of classes and decided to be in my class. We are pioneers!

Cheers!

Penny (Dated 12/11/98)

Fig. 6.2 (continued)

was on high-density and low-density lipoproteins (that carry cholesterol in the blood). Michael was particularly adept in thinking and writing, but he tended to be shy and not as convincing in his oral presentations. However, Michael was very clear on the biochemical principles and the facts in biochemistry, especially when he and I would speak on biochemistry in my office one-on-one. Since taking my course, Michael has graduated from medical school and is now in a radiology fellow.

Most students liked at least one form of written assessment but not necessarily all the same ones. Some students enjoyed writing their goal statements but thought writing the contributions to the Web site was a waste of time. Meanwhile, other students felt just the opposite. One student wrote in the LEQ about using multiple forms of assessment:

> [The best policy in this course is the] use of the WWW to research biochemical topics, stating goals, doing homework, [and] evaluating each other helps you see your own need for improvement.

One student wrote in the LEQ that writing the goals and Web site contributions did not "enhance my learning at all." Students' reactions such as these are contradictions to my stated goals in the course. These students felt that spending their time writing and reflecting was not effective for them. I wonder if these students were just not developmentally ready in their worldviews to be able to think holistically and reflect on their goals and contributions (Wilber 2000). Perhaps, if they spent more time writing, they might begin to appreciate and profit personally from the process. Alternatively, such writing exercises might just not have worked well for them, or they did not see the meaning and purpose in reflecting and writing.

For me, reading about my students' learning, their individual goals, and their frustrations gave me formative feedback so I could change actions throughout the semester. Although the task of reading and commenting on all the students' goals and learning was time-consuming, I found the process worthwhile. I felt I had my finger on the pulse of my students in my biochemistry classroom. Through reading their comments, I could change some defining aspects during the class, but others I could not change (because I had already stated in the syllabus my requirements and methods of assessment). I tried my best to change aspects so that I could to address the students' needs.

Depending on each student's needs and learning style, one form of assessment may have been more accurate than another. One student in the LEQ summarized the value of writing: "Writing papers really shows that a student is learning. It encouraged them to ask questions and do their own thinking while getting a firmer grasp on the material at hand." This and other such comments from the LEQ support my belief that writing helps, at least some, students learn. Here is another student's comment:

> Often times I wrote my contribution without looking at my research, which means that I really must have learned the info[rmation]. Not only that, but my contributions were sometimes better than the Web site in terms of fluidity of ideas and concepts.

This student's statement resonated with me because I find that writing helps me develop my ideas and also encourages me to think critically. I hoped those exercises had a similar effect for my students as well. Once a student has developed the self-confidence, like Suzanne and Michael did, you cannot stop them from learning.

One student's comment was similar in the LEQ; however, she or he emphasized the importance of using the words in conversation:

> I wish we [in my collaborative group] would have sat down more often and talked more in depth about our subjects. The discussions we had were usually to help us link ideas between Web sites. Having people to talk to did help though. Just using the words we read in books in a conversation helped me to summarize my ideas. Staying with the same group, if everyone works equally, is better [than switching group members part way through the course] because you get to know one another and discern how each learns.

I wanted my students to use the discourse of science orally, as they planned for their Web sites, for their group presentations, and in other class work. This student mentioned that working closely with others helped her or him learn because she or he needed to listen critically to others in her group and to put her own thinking into words. I think this is one of the important advantages of working in a collaborative group. Talking out ideas with other people helps one to connect prior notions with new ones, thereby constructing new, generally more complex, meanings.

Another student in the LEQ pointed out, "multiple types of assignments were good. Maybe the key is finding a balance about reinforcement and what is too much." She or he suggested I could use such assignments in other courses. A possible resolution for finding a balance is to give students a choice between writing goal statements (and about progress toward achieving those goals) or writing about the knowledge learned while creating a Web site within a collaborative group. Giving students fewer assignments would also allow students more time to focus on the "big picture," rather than on the individual subjects.

Another said in the LEQ that writing the goal statement did not really help him or her but thought that writing "maybe a group goal statement would help bring the group together faster." I feel this insight is important. If each student within the collaborative group provides input into the joint goal statement, each would have ownership of the group's goals and of their work as a group.

Another suggestion in the LEQ was to "make students think about the quality of their work and contributions, not just quantity." This student made me aware that some students did not understand that I was interested in the quality of their work. I try to be more explicit about this now.

Another student mentioned that she or he personally did not need to write the goals since "I, for one, kept my goals in the forefront of my thoughts and knew what I contributed." This student added in the LEQ another important insight: "However, I believe that [writing goals] were instrumental in helping the teacher gain a better understanding of how she could present things in a better format." I concluded that many students need the motivation to write their own goal statements, but some students, including this one, do so on their own. I know that this student is correct; my knowing the students' abilities, knowledge, and goals helped me formatively to organize the presentation of various topics and to increase the students' opportunities for learning.

6.3.3 What Worked, What Did Not?

For Sewell's theory (Sewell 1992), refer to Fig. 3.1, containing a diagrammatic sketch of the features of the structure | agency dialectic. One of the components of structure is *material*, and two primary materials in my course were technology and the Internet. With these materials, I molded the *structure* of the classroom to interact, hopefully positively, with my students' *agency*.

A second component of structure is *human* aspects, such as social networks (including not only their own collaborative group as they used the language of science but also that on the Web with scientists sharing their constructions of biochemistry) and division of labor (both within their collaborative group and between the students and me as their teacher).

The third component of structure is *symbolic*, involving status and cultural constraints, which I encouraged by their participation in collaborative groups, with students of all backgrounds, regardless of gender, ethnicity, sexual orientation, etc. in my class. Students could select topics for their Web sites that interested them, so that they could include their cultural background, like Mary studying the color of sweet potatoes in her group's presentation on complex carbohydrates.

The dialectic in Sewell's theory is between structure and agency. The first of agency's components is *appropriation of resources*, in which I identified a technology-enhanced classroom for us to access the Web as a learning resource and the *human* aspect of structure (Fig. 3.1). Using technology allowed the students to find their interests and to seek relevance in science through use of the Internet. Also I provided two class Web sites (Web-MC and CCL), which had different features to enhance learning. Students became involved in selecting the topic to choose for their Web sites, the resources they would use from the WWW and elsewhere, and the creation of their own characteristic signature for Web sites they constructed.

The second of agency's components is *access*. I opened this experimental class to 34 majors in the sciences, mainly undergraduates but also four graduate students. Through the interaction of access and appropriation of resources I wanted to encourage students to develop their sense of agency, or the power to act, so that my students could attain their goals. The students' sense of agency is enhanced through the dialectic with the structure provided.

For my students to achieve their *objects* and move to their *outcomes* (using the CHAT, Fig. 3.2), they needed to utilize the resources available to them, including the *tools*, *rules* or *schemas*, *communities,* and *division of labor*. Similar to Sewell's dialectic between structure and agency, another dialectic exists between CHAT and Sewell's theory, in which one informs the other. CHAT's *community* component (Fig. 3.2) relates to Sewell's *human* component of structure and to the *access* component of agency. The two theoretical perspectives support each other. Researchers utilizing CHAT would consider the collaboration of students in my classroom to be a powerful system of social interactions. Students had many common goals, some of which included getting the Web site completed by the next deadline, learning the biochemistry, seeing the relevance in their learning as related to the real world, and making their mark of understanding on the WWW. To do this successfully, students needed to access the language of science in their social setting within their collaborative group and during class. The *tools* in CHAT relate to the *material* component of Sewell's structure. CHAT's *rules* or *schemas* may hold individuals back from achieving their objects and outcomes. The usual practice of teaching in my university involves mainly lecturing to science students, which encourages passive learning. I tried to change those university teaching practices (or *rules* in CHAT), because one of my goals was to empower my students to act. I already mentioned CHAT's *division of labor* when discussing the fair and appropriate *human* component to structure. The *tools*, *division of labor*, *communities,* and *rules/schemas* from CHAT (Fig. 3.2) interact, thereby influencing if the *subjects* can move to their *objects* and on to their desired *outcomes*.

Several teaching methods resonated well with my students, as evidenced in responses to the CLS and LEQ and in their individual electronic portfolio entries. A number of students learned more in-depth knowledge in some areas than if they had been in the traditional all-lecture course. The students engaged in the discourse of biochemistry in their Web sites, portfolio writings, and oral presentations. They selected topics that interested them and that related to their career goals and interests. They learned to search and find relevant information on topics that they chose to study. As a team, they worked together to integrate the information on the biochemical topic. They learned the technology well enough to make the information useful to others. They learned to present the information in class for their presentations of three Web sites to their peers and me. They learned to set goals and reflect on their own learning.

While many of my students gained an in-depth understanding of some areas in biochemistry, my students did not learn all the areas as well as they might have in a traditional lecture course. For instance, I did not require students to memorize the structures of amino acids and nucleic acids. I was more interested in engaging them to learn the secondary, tertiary, and quaternary structures and the regulation of biological macromolecules than the individual structures of each component of the polymers. However, in the second semester biochemistry course, students needed to know individual structural information, so my students from the first semester course may well have been behind students from a traditional, lecture-only course, in that respect. However, one of my students, Ann, said that the students from my *General Biochemistry I* class were ahead of many of the other students in *General Biochemistry II* class, in terms of practical knowledge and scientific application.

Another frustrating problem that students encountered was trying to learn simultaneously both biochemistry and technology for using the Web. I felt a conflict in not having enough time to teach the students an overview of biochemistry and giving them enough time to learn to use the Web and create Web sites. Near the beginning of the semester, to help with the technology, I did offer one optional laboratory session per week that some students attended. By the middle of the semester, students were more comfortable using the Web and developing Web sites, so I discontinued the computer help sessions.

Through the action research, I learned to improve both my students' and my use of technology. To facilitate my students' learning to use the Web, I realized that I needed to provide *structure* for them to get started, so that they could develop the confidence that they can use technology to answer questions and demonstrate their learning in assignments.

I did not offer as much *structure* within the classroom during my action research in this experimental study as I currently do. Since that time I have added two different forms of *structure* to enable my students to use technology and develop their power to act:

1. *Chemistry Is In The News*: http://www.ciitn.missouri.edu/[1]
2. Group Learning Projects (GLP) Web site[2]: http://www.chem.fsu.edu/~gilmer/courses.html.

This realization that I needed to add more *structure* shows the relevance of Sewell's theory of structure | agency to my study. By providing more *structure* in later classes than I did in the experimental study, I can facilitate my students developing a stronger sense of *agency*, so that they feel empowered to act in ways that help them move along the continuum from *subjects* to *objects* to *outcomes* in CHAT.

[1] To see the student projects, look at the URL listed above and click on the link to "Student Projects" and look for courses in *General Biochemistry I*, *General Biochemistry II*, and *Introduction to Biochemistry* classes with Gilmer as the instructor, and finally click on "View Student Group Projects." Student groups had a choice to post beyond just the class to the world through the WWW. You can see those groups who made that choice to post worldwide. Starting in 2006, you can see some of the projects that my biochemistry students did in collaborative groups, with one graded project per semester.

[2] I offered this structured learning opportunity for four years when I taught the *Introduction to Biochemistry* course, mainly for nutrition, chemical science, and exercise science majors.

I have also greatly reduced the number of collaborative group projects, to one final one (with one trial project with *Chemistry Is in the News*, to help them find group members with whom they work well). Through my action research I continue to improve teaching as well as my learning while using technology, in order to address the contradictions and coherences in my classroom.

I have utilized technology in every science class I have taught since my action research study described in this book. Besides *General Biochemistry I* where I conducted my action research, other undergraduate classes in which I have utilized extensive technology include *Introduction to Biochemistry* (mainly for nutrition and exercise physiology majors): (a) *General Chemistry I*; (b) *STS*; (c) *Honors General Chemistry I*; and (d) *General Biochemistry II*.

I have also taught graduate classes using technology: (a) *Technology in Chemistry Education* and *Technology in Biochemistry Education*, both designed for Tallahassee-based graduate students in Science Education; and (b) *Nature of Scientific Inquiry* and *Scientific Research Experiences*, both designed for practicing rural teachers enrolled in a distance graduate program called *Science Collaboration: Immersion, Inquiry, Innovation* (Calvin and Gilmer 2008).

Finally, I want to emphasize the power of using theory in educational research. When I started this venture to earn a second doctorate in science education, I did not know the power of using educational theories. I knew the power of using scientific theories but only learned the power of educational theories when I was trying to make sense of the data from my classroom. Therefore, by using both CHAT and Sewell's theory of structure | agency, I felt empowered to think of my classroom experiences and interactions with my students with these theories in mind. The dialectic between these two theories informs my thinking and actions.

Chapter 7
Addressing the Problematic Issues of Bringing Reform in Science Teaching to Higher Education: Metaloguing with a Biochemistry Colleague

7.1 Preview

This chapter contains a metalogue with one of my biochemistry colleagues, Professor Emeritus Robley J. Light (referred to in this chapter and metalogue as RJL). In this metalogue, RJL had the opportunity to read my draft doctoral thesis and then ask me questions about my teaching, my classroom, and other issues related to teaching and learning. I responded in writing.

The metalogue is in two sections; RJL and I started the initial metalogue in 1999, one year after completing the action research. I was delayed in my writing and analysis as my father, Peter Gilmer, died early in 2000, and for two years I cared for my mother, Barbara Gilmer, due to her failing health. After she died early in 2002, I readdressed the initial metalogue with RFL, later in 2002, and wrote the final metalogue late in 2003, after RJL had read the first six chapters of my doctoral thesis and asked me questions, to which I responded. This chapter is a compilation of RJL's questions and my responses.

I share this metalogue with you because I think this conversation between RJL and me illuminates the milieu in which I teach and the *rules or schemas* (refer to CHAT diagram in Fig. 3.2) and the structure | agency dialectic (Fig. 3.1), within the Department of Chemistry and Biochemistry, in which I am embedded. The metalogue provides an illustration of two professional biochemists talking with each other about teaching.

One of my external examiners on the doctoral thesis wrote in her review that she thought that this chapter was the most interesting of my entire doctoral thesis because it gave her a clear idea of the culture of biochemistry. This metalogue is significant to my research for two reasons: (1) the metalogue illustrates the environment in which I worked while trying to implement change in the teaching of biochemistry at the university level, and (2) I learned my colleague's perspective.

P.J. Gilmer, *Transforming University Biochemistry Teaching Using Collaborative Learning and Technology: Ready, Set, Action Research!*, DOI 10.1007/978-1-4020-4981-1_7,

7.2 What Is a Metalogue?

The purpose of a metalogue is to provide a chance for formal reflection on some experience, such as the action research in which I was engaged. The reflection is not only on my part but also on that of my biochemistry colleague. A metalogue provides an avenue for readers to hear the language that the biochemists use with each other and from that language to understand better the culture within a science department, such as my own, in higher education in the USA.

Bateson (1972) introduces and defines the concept of metalogue:

> A *metalogue* is a conversation about some problematic subject. This conversation should be such that not only do the participants discuss the problem but [also] the structure of the conversation as a whole is also relevant to the same subject.
>
> Notably, the history of evolutionary theory is inevitably a metalogue between man and nature, in which the creation and interaction of ideas must necessarily exemplify evolutionary process. (p. 1)

Bateson (1972) also says a metalogue should address not only the problem but also the "structure of the conversation as a whole [should] also be relevant to the same subject" (p. 1). I think the nature of the conversation between RJL and me is particularly apropos to the problem of bringing reform to science teaching because typically academic scientists do not address the problems of teaching and learning. However, having conversation such as this metalogue, we begin to address the problematic issues.

Also through the conversation, a reader can infer the culture of university teaching of biochemistry. The structure within an academic science department such as my own, in which scientific research is foremost, relegates teaching and research on teaching to a lower status, so low that most scientists do not bother to discuss, except once or twice a year when we need to talk about curricular issues. The fact that RJL and I had the conversation and that the discussion was interesting does highlight the need for academic scientists to discuss teaching.

This particular metalogue addresses issues that RJL observed in my classroom or issues that the full professor faculty discussed as they learned of my reform in teaching our *General Biochemistry I* course for majors in our department and other sciences. The university in which I am embedded is a "Carnegie Foundation I category [the Foundation's], highest category for a graduate-research university. FSU is one of 88 American universities to earn this designation" (Florida State University 2007, available at http://registrar.fsu.edu/webtest/ugr024.htm).

7.3 Initial Metalogue with Professor Robley J. Light (1999–2002)

This metalogue started with RJL sending me a file with his questions, and I responded, returning the file to him. My responses triggered new questions from RJL, to which I responded again. This proceeded in the different time frames indicated. Here is a compilation of the various questions and answers.

PJG: RJL, thank you for agreeing to have this metalogue with me, as I feel that it will help me through the process of understanding what happened in my biochemistry course and how I can learn from the study.

RJL: Let me begin my comments with a positive observation. During the two class sessions I visited, I was impressed with the active involvement of the students in the class. The students seemed interested in what they were doing, perhaps even having some fun in the process.

PJG: I remember the two days you came to my class. On the first day, which was about half way through the semester, I had been expecting a collaborative group of students to be presenting, but their group had asked me that morning just before class, if they could postpone their presentation until a later class. I remember I did not feel prepared. I also remember that the overhead projector would not focus properly that day. Several students spoke to me afterwards that they were embarrassed that a number of the other students were typing at their computers while I spoke.

On the second day you came to my class was the last day of the semester. I had invited a number of our biochemistry colleagues to class that day. I chose that day to invite you and the others because three of the collaborative groups were presenting the last of their group sites.

I remember that you got to experience the process I call "synergy" or "resonance" with our learning community. The synergy happened at a few points during that class. One of the presenting students was having trouble with the technology, and another student, without hesitating, went up to help him. I felt that most of the students were paying attention to the concepts that the students in the presenting groups were saying.

I remember too that one of the presenters had an error in his presentation. I asked him a question to try to clarify the issue, but he became only more flustered. I almost wished I had not asked, but also knew I needed to ask, so other students would realize that he had made an error.

One of the hard issues for me was correcting students during their presentations. At times students would present knowledge that was so new that I did not know the information myself, as much was new from the Web. Sometimes they chose to present more practical information that would not have been in a traditional class. For instance, students once presented on buffers that are used in cattle feed, and I was unaware of that. Therefore, sometimes I did not know if all that they were saying were correct or not. However, if the science did not make sense, then I would ask something, at least to see if the student could respond logically to my question.

Some collaborative groups presented their Web site almost like a movie, going fast-forward, with no "pause" button, with the individual students' presentations coming very quickly, one after the other. I generally tried to look at their Web sites the night before the presentation, but they did not always have them finished before I went to bed.

One thing I did for the first three years after teaching the experimental biochemistry class under study was to require students to have their collaborative group's Web sites (or PowerPoint presentations) posted at least 12 hours in advance, for me to preview. However, I did not have time to provide feedback to them to improve their presentation, but only time for me to think about their overall plans for the presentation.

In the last two years, I have expanded the time for me to provide feedback. I have a GLP page, with an eight-step procedure delineated at http://www.chem.fsu.edu/~gilmer/courses.html. If you follow the link at the bottom of that page to "Detailed Information on GLPs," you will see the eight-step procedure. Now the students need first to present a proposal with their research questions posted and include their primary references, including at least two Web sites and one book reference. I checked their proposed references, to be sure that they are credible and provide feedback before the students need to post their draft group presentation. Once I have read the draft group presentation three days in advance of the date for the group's presentation, I have time to review in detail their plans, provide suggestions for improvement, and teach them, if needed, a process to organize their group project (or whatever else they need to know). Also I provide prior year's presentations (either Web sites or PowerPoint presentations) for current students to see the project and to learn some more biochemistry. On the main page for the GLP (cited above) are links to the students' biochemistry projects for four years.

RJL: However, I still have some reservations about the course, and colleagues in the Biochemistry Program have also stated some of these reservations. Let me start with one related to assessment of the student's mastery of the biochemical topics in the course. Traditionally, students are tested on their knowledge of biochemistry during and at the end of a course. One can argue that such tests are imperfect measures of actual learning or of the ability to apply knowledge, and that things "learned" for the test are soon forgotten. But something "learned" once is more easily recalled the second time in later review. A student cannot begin to "construct" his or her own version of this body of knowledge without confronting the facts of the body [of knowledge] that have been accumulated over the years.

PJG: I do think that many of the questions that we ask our biochemistry students in regular hour examinations or final examinations are questions based more on rote learning than on critical thinking. I have learned through my science education study that getting students to connect to their prior knowledge and to think critically on the subject matter are important. I think if you just memorize something for the "test," then you have not really learned the material. You cannot pull back the concepts later because the knowledge is not part of your network of understanding.

RJL: Agreed. But to answer "thought" or "application" questions, one must know some basic information. It gets frustrating when students cannot even reply with the basics.

PJG: Instead of teaching the "facts" of science, I present science as our current understanding of the topic. For instance, as a college freshman I was taught that the noble gases were nonreactive as a fact of science, I closed off my thinking about experiments to test if that were indeed true, because I thought noble gases did not react was a fact. Of course, a year later the heavier noble gases, especially neon, were found to react, opening a whole new field of chemistry.

I decided to do the Web-enhanced biochemistry course because I think of learning as connecting different ideas together, like I do if I am searching for information on the WWW. I can cross-link many forms of prior learning while I connect to new learning. I want to provide many opportunities for my students to utilize the WWW, to learn this valuable source of information, and to contribute to knowledge through their own lens[es] on learning.

Therefore, I thought that even though students did not actually study all topics, they might find and read other information while searching the Web. Also they had opportunities to learn from other groups' presentations.

I co-developed a theory that people learn by cross-linking their learning, [by] making several points of attachment (Gilmer and Engel 1996). This theory is analogous to [the] binding of a bivalent (or multivalent) antibody to a multivalent antigen. Once you get one point connected, you are more likely to get the other point(s) connected. Once at least two points are connected, you are unlikely to get dissociation (thereby, one would remember the learning).

Also the binding goes beyond just points of attachment. The [overall] strength of attachment can be stronger with more overlap. In the study reported in this book, I utilize students' writing about their learning of the science content, helping them to form stronger connections or overlap.

RJL: One can also argue about what information is important to retain and to be tested, i.e., what will be needed for subsequent study of the topic and for application in the student's ultimate career. For potential medical students, at least one hurdle is known, that of national boards in the subject area. I will not pretend that national boards are necessarily the best measure of what understanding is "needed" in the profession of medicine, but they do represent a requirement for entry into the profession.

PJG: I analyzed information such as the students' majors at the beginning of the semester. In addition, I analyzed the students' goals, as the students wrote in their electronic portfolios, mid-way and at the end of the course. Many of my students' goals included going to medical school. Medical students do not take the national board examination until the end of their second year of medical school, after they have finished taking their course work in medical school. Therefore, if the students actually attend medical school, they would not take their national board examination for at least two years. Many of the students do not plan to attend medical school, and some of the others will not be accepted. Therefore, I am only preparing some of my students for national boards in medicine.

RJL: I will admit that the tests we normally develop for such courses are often inadequate in many respects in measuring what we are hoping to measure. Part of the problem may be that seldom have we clearly formulated in our own minds the course objectives, and taken care to design tests around these objectives. I do not think the solution to that problem lies in just removing tests and letting students learn only what interests them. Even poorly designed tests will motivate students to study and to attempt to construct the information in their own terms.

PJG: I agree with you, RJL. I think that many times, we as faculty have not carefully thought through our course objectives and if those objectives fit the examination. I also have concluded from my study that some testing of students is necessary. In fact, every chemistry or biochemistry course that I have taught since then has had either quizzes or hour examinations and a final examination. Some students from the biochemistry class have told me that they needed that impetus to study and synthesize their learning.

I think you will be interested to read my students' comments about the class (available at http://www.chem.fsu.edu/~gilmer/downloads.html), and my learning from analyzing those data. The data are both quantitative and qualitative with a mixed method design. However, I only include the qualitative data since the focus of the rest of the thesis utilizes a qualitative methodology.

RJL: Yes, I would be interested in seeing the results of your questionnaire.

PJG: I have provided some of their comments within the chapters on collaboration and technology, but also in the dissertation (available at http://www.chem.fsu.edu/~gilmer/downloads.html), I have a full report of all of my students' qualitative comments from the questionnaire.

I have received more feedback since the course ended, by asking my former students to respond to the fictionalized story that I wrote from a student's perspective about working in a collaborative group. Their responses provide me more feedback on these students' experiences in biochemistry.

RJL: What were your learning objectives for the students, and without testing how can you know that those objectives were achieved? I do not believe just asking the students how much they learned really tells you anything.

PJG: My learning objectives or the five stated goals for my students in the biochemistry course as extracted from text within the syllabus and put in numbered form here, included the following:

1. To develop the tools to learn biological functions in chemical terms – the physical, chemical, and biological principles by which each biomolecule, chemical reaction, or pathway operates
2. To learn to use the WWW as a way to learn biochemistry
3. To work in a collaborative group to do Web searches, learn, use the language of science, and problem solve

RJL: This could be an objective for almost any course, not specific to biochemistry. We are going through a transition now with students as more and more come to the university with experience (as years ago new students transitioned from getting an e-mail addresses for the first time to becoming comfortable using e-mail).

4. To share learning with others in the class during your presentations of your group sites

RJL: Worthy objective, but how practical is it where the number of "lectures" or class contacts is limited?

PJG: Here, RJL, I meant for the students to share learning with each other, for them to learn that they can learn, and that learning can be exciting and interesting. I wanted them to feel the thrill of learning. I still provided some framework for the structure of the content in the one lecture I gave each week.

5. To become proficient in the scientific discourse of biochemistry, as well as with calculations involving pH, enzyme kinetics, free energy changes, etc., that is relevant to the structure–function relationships of biological systems

RJL: This is the one that is often hard to assess.

PJG: I looked at each of these five goals and sorted them according to the following categories:

Goals #1 and #5 involve science content.
Goals #2, 3 and 4 involve technology.
Goals #3 and #4 involve collaborative learning.
Goals #4 and #5 involve using the discourse of biochemistry.
Goals #3 and #5 involve problem solving.

My rationale for choosing these goals is that I wanted my students to utilize the language of science, in speech and in writing. I wanted to provide multiple opportunities for my students to do that.

Now you also asked the method I used to assess whether my students learned the biochemistry. Below I have included the evaluation process I had stated in the syllabus:

Grading/Evaluation

For your evaluation, you will be graded both on your individual work and your group work. Initially, your group assignments will revolve around teaching and learning biochemistry, using the WWW to find information about biochemistry and to integrate that information into what you already know. It will involve:

1. Teaching each other what you know, and
2. Learning from others what they have learned.

Everyone is responsible for reading the assigned chapters in our textbook and to work on selected problems. You need to know what topics are included in each chapter before we have our days with "Web-search and learning," so you know what topics to research on the WWW. After some preliminary net search, your group will decide on what area to focus for each of your group projects (generally done on Mondays).

Initially, you will find interesting sites and record these site addresses with some covering text into your group's dialogue journal. For instance, in the second chapter on "The Matrix of Life: Weak Interactions in an Aqueous Environment," some possible topics your group might investigate include: noncovalent interactions; dipole interactions; ionic interactions; H-bonding; pH; buffers; titration of weak acids; or ionic strength.

I would like you to find connections to your own world when you learn. For instance, how do buffers interact with your world? Why are they important to life? Initially, Libby Mayo [a graduate student in Chemistry who is facile with technology] or Penny Gilmer will provide the framework that links your sites to our common course site. In class, members of each group will share their learning with the other students, by showing sites for their topic and explaining the link[age]s between the ideas (generally done on Fridays).

As we progress, Libby Mayo and Penny Gilmer will teach you how to make your own group sites, with links to other sites. You will need to provide text to show your learning. You can import figures, tables, questions/answers, whatever you figure will help you and your classmates learn. We want to use the discourse of biochemistry and build a community of learners.

You will have 10 group assignments, on days listed as "groups sharing learning." Your group will have three presentations of group sites. When your group does not make a presentation in class, Bill Marion [TA assigned to the course] or Penny Gilmer will evaluate your learning as posted on our site. All group members will add text that relates to their own contribution to the collaborative learning for the group site.

Evaluation for your grade:

You will earn points toward your final grade. For example, for each presentation, each person can earn 4 points, so for three presentations you can earn 12 points (or 12% of your final grade). For posting chapter problems, you will earn 2 points per chapter or 28 points (or 28% of your final grade).

RJL: Is there a criterion of quality here, or just get the presentations done and the problems posted?

PJG: We did have quality criteria for the Web sites. In addition, a graduate student graded the problem sets, with points assigned accordingly. Students received grades for their Web presentations based on feedback from peers, self, and me, as their teacher. Table 6.3 shows the rubric for written work.

I found the best way for me to assess their learning while examining their Web sites was to read the questions (related to rubric point #5 above) that resulted from their research on biochemistry.

The way the students received their points towards their grade was as follows:

Own group's presentation on Web site (three presentations during class)	12%
Posting own goal statements and two updates in portfolio	6%
Posting chapter problems in critical reviews (14)	28%
Posting own group's Web sites (10)	20%
Posting in portfolio own learning from group site project (10)	30%
Attendance and participation	4%

RJL: Concerning the groups' Web sites, what checks were there for accuracy? Plagiarism of other sites? Sophistication of discussion?

PJG: I did some checks for my knowledge of each topic. I did not have time to do checks for plagiarism of other sites, however. We had just too many Web sites (100 in the semester) to do that as well. The sophistication of the discussion was important, and looking for their own questions (in their portfolios) on the projects gave me the clearest idea of where they were in their learning.

RJL: Concerning the chapter problems, were these worked-out problems from the book? (I have seen relatively few books with good sets of problems).

PJG: These were problems from our textbook from the end of the chapters. Sometimes the final answer was in the back of the book, but the process of getting to the final answer was not there. Students needed to provide the pathways that they used to get to the answers.

RJL: How much does accuracy of content count versus technological competence in getting the site up and looking good? Will there be a tendency to reward more heavily the more graphically skilled designers?

PJG: Sometimes I did point out problems in the accuracy of the information presented, like I did in class that second time you came to class. I would say that both accuracy and use of technology counted about equal in the students' grades. For other students to learn from one group's presentation, they needed not only accurate content but to present in such a way that was amenable to learning.

RJL: What would a portfolio of own learning contain?

PJG: The portfolio contained at least the students' goal statements (a total of three for the semester) and the student's reflections of his or her learning through each of ten Web sites generated by that student's group during the semester (where the writing should reflect the criteria on the rubric, stated above). I do provide portions of Suzanne's portfolio in Chapters 5 and 6. I also have a paper I presented (but have not published yet) on the goals of the four students planning to become secondary science teachers (Gilmer 1999c).

After my senior colleagues talked with me about their concerns on my methods of evaluating my students' learning, I added two other methods of summative evaluation. Since the syllabus was already set at that point, I added them as extra-credit opportunities. One was an optional midterm examination, and the second was an optional opportunity for students to demonstrate integrative learning, called the "final question" (Fig. 6.2b).

I had multiple opportunities to interact with my students, both in class and by reading the students' writing and assessing their sites. During class time, students made presentations of their learning (with opportunities for me and the other students to ask them questions), and they answered questions from end-of-chapter problems from the textbook by Matthews and van Holde.

RJL: I wonder if now, several years later, it would be possible to do some sort of retrospective questionnaire of your students for their evaluation of the learning in the class and how it helped or did not help them in subsequent courses. It would be particularly interesting to find out what kinds of things stuck with them and did not require extensive review, because I suspect our "conventional" methods of teaching do indeed force students to learn facts and other materials "for the test," but retention is probably not good. Only reinforcement with further continued exposure to the topic causes it to "sink in." If you could identify things that "sink in" and stay that way, it would be a tremendous step forward.

PJG: Unfortunately, it is hard to stay in touch with former students, even with e-mail. I am still in touch with about five of them. Therefore, I think at this point I would have a hard time getting any significant fraction of my former students responding to a questionnaire. Suzanne came to my office to get copies of the two chapters of my doctoral thesis that related to her contributions to my data. While she was here, I asked her, in general, whether her undergraduate science courses prepared her for graduate school in the biomedical sciences. She had no question in her mind after her first semester in graduate school that she had been prepared well in biochemistry and did not need to take their biochemistry course.

7.4 Resumption of the Metalogue in December 2003

RJL: We began this metalogue in May of 1999, with some additions made in July and August of 2002. It is now December of 2003, five years after the completion of your course. My memory of the classes I attended is now a bit fuzzy, but I have just completed reading your doctoral thesis, and that has stimulated some additional thoughts about your course. Let me elaborate on some of them below, in no particular order of importance.

7.4.1 Impressions on the Fictional Story

RJL: Your story does come across as realistic. You do begin to flesh the characters out, and your descriptions of scenes do help one visualize the action. As to the relevance of the story for your research, the main message that came through to me was the difficulty students had in finding times to meet and in getting all group members to participate. You did have a short description of the interactive discussions concerning biochemistry when the students were coming up with the common theme for their sites.

It would have been neat to show a student with a misconception or some confusion on a topic, how another person in the collaborative group explained the concept in a way different from the teacher's, but in a way that the confused student understood the concept correctly. (It seems to me that would be one of the important hoped-for outcomes of the collaborative group interactions).

PJG: RJL, your idea of my having had a scene in the fictional story with a student explaining some biochemistry concept in a way different than the teacher's, to help another student learn would have been good. I did see that happen in groups but did not think about putting that type of interaction in the story.

RJL: Thinking about the problem of finding meeting times for a group leads me to suggest that a major hurdle with this method of teaching is the *curriculum structure* we have set up for our courses. We are partially constricted by the educational model we work under – three h of class time a week available for a course with little congruence between the overall schedules of any two students, much less three or four students. Medical schools have had a good deal of success with "problem-based learning" in a group interaction setting, but there the students' schedules are built to make it possible.

PJG: I think you are right about the locked-in structure under which we operate tying our hands with options we cannot do but might be able to do, if the system were different. I think one way would be to offer a four-credit combined lecture-laboratory class in biochemistry, in which the "laboratory" would be in a computer laboratory and would be an opportunity for all the students in the group to be able to work together. I remember a student in my class suggested this possibility to me. Students could also work on their biochemistry problems together during this time, like the medical students do with problem-based learning. We could meet for two h, three times per week, with one h each day for "lecture" and the other hour having time for the computer learning and group work. Alternately, we could meet for three usual hours of "lecture" per week with a three h laboratory to work on the computers and with group members, solving problems, communicating and organizing group projects.

White (2002), a biochemist at the University of Delaware, uses problem-based learning with his biochemistry students. He has the students work on more historical problems in biochemistry that have been solved, much as James Conant (see later in this metalogue) proposed more generally. His students have to use discourse as they research and discuss the topics for their report that they share with other groups. Groups read different papers on the same overall topic. This process prepares them for the biochemistry course.

RJL: A corollary problem is the factor of time commitment. I recall a comment from someone years ago that "you can learn by doing, but you don't learn very fast." The lecture model is "efficient" in terms of the professor's time, and a good lecture should be able to at least lay the framework of "construction" for the students, getting them started on organizing their own thoughts, and helping them focus on important issues. But it lacks the feature of interaction – back and forth discussion that helps anchor the thoughts in a student's brain.

PJG: The lecture may be efficient for learners like you and me, but the lecture does not work well for many students. I have found that I can add some time for interaction within a lecture that may help more of the students learn better. I have been trying this in the last two offerings of *Introduction to Biochemistry,* using periods of "active learning" in the midst of otherwise lecture sections.

7.4.2 Value of Collaborative Learning

RJL: I do not need convincing of the value of collaborative learning. I have made several attempts to encourage group interactions in my classes over the past 10 years or so. I have yet to find really effective ways to do so (perhaps my own lack of imagination or experience), but I did find on some occasions the efforts were worthwhile (though I did nothing to document it). My recent experience with the Computer-Assisted Personal Approach (CAPA) homework system in general chemistry seems to be a step in the right direction. CAPA [On-line: http://capa4.lite.msu.edu/homepage/] generates individualized homework sets for each student, so each student has a set of questions similar but not identical to those of other students. I would encourage the students to get together to "solve" their problems – helping each other – because the concern that one would just "copy" the answers from another was removed. Some students worked alone. Some worked together. Each seemed to adapt to the method that suited his or her learning style. The trick is to figure out clever, but efficient, ways to get the students engaged with each other.

PJG: I like the idea that every student has a different set of problems to answer yet they are similar to other students' problems. I can see this would encourage students to work together, to use the discourse of science. I understand that CAPA has now merged with Learning Online Network (LON) to form Learning Online Network-Computer-Assisted Personal Approach (LON-CAPA) [On-line: http://www.lon-capa.org] so that it is Web-based and can handle more types of problems than just multiple-choice questions. Also the large data bank of questions that scientists have entered into the database is available to others. I understand that you will be using LON-CAPA in your next teaching of *General Chemistry I*. I will investigate these online questions for use in my chemistry or biochemistry classes.

7.4.3 The Grading Issue Revisited

RJL: You cover in some detail the concern that some of our colleagues and I had about not giving tests in the course. It seems from some of your student comments in the doctoral thesis that many of the students also had the same concern. Even a test, which turns out to be poorly designed, at least motivates the student to study (I hope). Earlier in the metalogue I spoke to this issue, and I now assume you have come to realize some form of assessment is necessary.

You indicated above (and in the doctoral thesis) some of the alternative forms of assessment you used. My major concern about them is how critical you can bring yourself to be. Earlier in the metalogue in discussing my visit to your class you state:

> I remember too that one of the presenters had an error in his presentation. I asked him a question to try to clarify the issue, but he became only more flustered. I almost wished I hadn't asked

Then in the doctoral thesis, under "Compassion" (available at http://www.chem.fsu.edu/~gilmer/downloads.html) you expressed remorse about being "gruff" with a student, and you commented to the student:

> Can't you think of a harder question? (p. 12)

Even in a traditional classroom I find myself conflicted over the desire to provide positive reinforcement versus the need to be judgmental of a student's performance. I often wish I was not the one giving the tests, but could simply act as a "coach" to help students master a test presented by someone else.

PJG: I did take the time to correct students during their presentations. I think it is harder for the student to learn from my comments while they are standing in front of their peers. It is easier to learn from written comments from the teacher on a test, but I am not sure if students actually look at the comments on returned tests either.

One of our colleagues, Professor Nancy Greenbaum, explained to me, at least in her smaller classrooms, that she allows her students to make corrections on a returned examination, as long as the answers along with the original test are returned by the next class period. That encourages students to pay attention to problems they missed on the test and gives them an opportunity to learn and use the discourse in responding with the correct answer, while they can still get some points back. Dr. Greenbaum would allow students to earn back half of the points that they had originally lost. I have done this with students in *Honors General Chemistry*, but the task is time-consuming, with my looking at each question, seeing the problems they had wrong, reading their correction, and calculating out the number of extra points they earned. Students like the regrading with extra points, however, and I think this process does encourage students to stay on top of the issue and learn from their mistakes.

RJL: Let us take, for example, two of the students' statements you present in the doctoral thesis that are partially correct, but still contain errors:

> I learned that alcohol metabolism uses alcohol dehydrogenase in reverse direction, using up NAD^+ [nicotinamide adenine dinucleotide], so there is less energy through glycolysis (therefore the alcohol-imbibed person gets sleepy). (Chapter 5)

How did you grade this? The "reverse" direction of alcohol dehydrogenase actually produces alcohol from acetaldehyde and forms NAD^+. Why does "less energy through glycolysis" result in sleepiness? You still have energy from the alcohol (i.e., via the NADH produced). This level of understanding is, to me, rather superficial (he gets the enzyme and cofactor right), but he completely misses any of the complexity of the interaction of metabolic pathways.

PJG: I was the one writing the statement that you quoted above in the group evaluation form. The students had called the reaction between ethanol and NAD^+ as the reverse direction (as the reverse reaction of the third step in the set of reactions shown below), because we had studied the formation of ethanol in yeast already, starting with glucose:

$$\text{Glucose} + 2\text{ADP} + 2\text{P}_i + 2\text{NAD}^+ \rightarrow 2\text{ pyruvate} + 2\text{ATP} + 2\text{ H}_2\text{O} + 2\text{ H}^+ + 2\text{NADH}$$

$$\text{Pyruvate} \rightarrow \text{acetaldehyde} + \text{CO}_2$$

$$\text{Acetaldehyde} + \text{NADH} + \text{H}^+ \rightarrow \text{ethanol} + \text{NAD}^+$$

For a person imbibing alcohol, the reaction would be as follows (the reverse of the third step immediately above):

$$\text{Ethanol} + \text{NAD}^+ \rightarrow \text{Acetaldehyde} + \text{NADH} + \text{H}^+$$

I wrote "less energy through glycolysis" would be available because in the presence of excess alcohol, NADH is produced from the oxidation of alcohol instead of being made along with ATP from the oxidation of glucose. Indeed, some ATP is generated from the NADH created as alcohol is oxidized, but more ATP and NADH would be generated if the individual were metabolizing only glucose instead of the alcohol. Therefore, an alcohol-imbibed person would feel sleepy. Also, the acetaldehyde product in the oxidation of ethanol would interfere with proper thinking by reacting with free amino groups, thereby contributing to the hangover from too much alcohol.

RJL: Here is the second example in which the student made an error. How did you respond to this one?

> Chapter 6, Figure 6.1 from Suzanne's Questions (Gilmer 2004): Then, probably the most known effect of an unhealthy plasma membrane, and very common, is high cholesterol. When too much cholesterol is taken in, the plasma membrane rigidifies. When made rigid,

> the lateral mobility of the membrane is restricted, thus its functions are inhibited. In order to meet the needs of the cell, transport must occur. Yet decreasing the mobility and fluidity of the plasma membrane makes transport more difficult. This is why people need to monitor their diets and limit their cholesterol intake.

Certainly, some grains of truth exist in this observation. Cholesterol affects membrane fluidity, but its interaction in the membrane is fairly complex, involving isolated lipid "rafts," and I am not sure any evidence exists that elevated blood cholesterol affects membrane properties of cells to the extent that the effect is pathological. Cells probably have an internal mechanism of regulating the amount of cholesterol remaining in the membrane and how much is esterified or otherwise compartmentalized. She seems to have missed the main problem of too much cholesterol, accumulation of LDL by cells behind the lining of the blood vessel endothelium, leading to plaque formation that can obstruct arteries or can rupture leading to clot formation.

Should one give the student good marks for getting things partly right, or take the effort to clarify where they are a bit off the mark?

PJG: Five years ago when the student wrote the comment in my class, I do not think lipid rafts were discussed in the literature. If so, I was unaware of the concept. I knew about lateral phase separations in the plane of the membrane, and that cholesterol has complex interactions with other lipid constituents in the membrane. I thought she did a reasonable job of summarizing a complex set of ideas in the literature that she learned from reading Web sites and interacting with her collaborative group members. One student in Suzanne's group, Michael, had done a very thorough job of studying LDL and HDL levels in blood in their group's first Web site presentation on hydrophobic/hydrophilic interactions, so she did not go over that again in the fifth presentation on plasma membranes, cited above. Suzanne also stated in her electronic portfolio:

> My group members' articles greatly facilitated the comprehension of my paper because they provided a framework. By discussing the nature of the membrane components, my paper was more readily placed in context and understood. The activity performed by the membrane was justified by the previous knowledge obtained on the qualities of the membrane components.

RJL: I am not sure the student's assessments of self and each other are of much help. I found the self- and peer-assessment data on one of the groups (Fig. 5.1) interesting in that respect. Alicia and Tonya give each other poor evaluations, not matching the evaluations from the other two members of the group.

PJG: The students needed to self-assess and peer-assess each other so that students would have an opportunity to tell me the nature of peer interactions within their group. I learned from reading all sets of interactions within my classroom. Also students know that they will be doing this at the end of the semester (as found in the syllabus), so I felt that this might help keep students in line, doing their share of the group work.

In the case of Alicia and Tonya, they were in a group that did not work well because the two of them would "butt heads." Both would dig in and criticize the other.

I chose this set of self- and peer-assessments so that others could see students' statements within a group of things that *did not* work well. The students did not see each other's comments. I had the students do these individually on the last day of class.

I wanted to comment further on the student's peer- and self-assessment. The part that I included in their grade was on each group's three presentations of Web sites (available at http://www.chem.fsu.edu/~gilmer/downloads.html, for examples of anonymous peer assessment) (with no names listed after each comment) and self-assessment (with "self" written after the comments). I indicate my own comments with my name in parentheses after the comments. I do think that students learned from the comments from their peers. They also learned the process of making a good presentation by reflecting on the process while assessing each other's presentations. My students tended to improve in their oral presentations, going from their first to their final presentations, utilizing the feedback from their peers, themselves, and me.

7.4.4 Depth of Learning

RJL: Some of the students commented they felt the learning would be "deeper" coming from regular lectures, rather than what they were able to provide for each other. Building a Web page, no matter how nice, is no guarantee that the students understood, or even read, everything on the page. A particular instance sticks in my mind in one of the student presentations I attended in your class. One student was describing a metabolic pathway (I forget its name), but he referred to the metabolic intermediate in question as "an enzyme." Maybe it was just stage fright, but that made me wonder if he had grasped even the basic idea of the connection between enzymes, metabolic intermediates, and metabolic pathways. There did not seem to be an easy way in your class organization to catch such an error and set him straight. Students would be reluctant to criticize each other, and there was no consequence to such an error that would lead him to be more careful and thorough next time.

PJG: You may be right that some things did slip past me as uncorrected. Student presentations are at such a pace, that if you have not had a chance to review the material first (as I generally did not), then so much is happening, that sometimes you want to say multiple things, and you do not have time to do everything. So I had to make choices. However, in this particular case, I did notice that particular error you mentioned, and I commented to Lawrence (available at http://www.chem.fsu.edu/~gilmer/downloads.html). I gave him the written feedback: "You did get mixed up on the metabolic scheme you presented, with what was the 'enzyme' and what was the 'substrate.'"

I conduct the process now much better as I have the students only prepare one group project per semester. I work with each group in the proposal stage and in the draft project stage. I have time to write them e-mail, look at Web sites that they reference, etc. That is one of the important things that I learned through my action research.

7.4.5 Science as "Truth"

RJL: In your Preface to the original doctoral thesis, you said: "Traditional teaching of science presents science as the 'truth,' a set of objectified facts to be learned, rather than as an interesting area of inquiry."

I disagree. Some science courses are taught that way, but need not be. The perception comes in part from the need to develop the vocabulary of the subject (which often consists of learning "facts") before one can introduce the subtleties and uncertainties. When Conant et al. (1948a, b) sought to develop a course for non-science majors, they resorted to focusing on early experiments in science (e.g., Boyle, Lavoisier, etc.) because there the students did not need so much background to be able to appreciate the way models rose from experimental findings, in turn suggesting further experiments. In biochemistry, one cannot begin to discuss the subtleties of the way structures affect function (or different ideas of what a structural effect might be), for example, if the student does not have a fundamental grasp of the structures one is talking about. Often one gets bogged down in presenting the "vocabulary" which makes it appear that one is only presenting "Truths."

PJG: I still think that most courses present biochemistry as a set of facts. Of course, we could change the way we present science. I think scientists would like to think of science as certain, and as a bedrock of information, on which they can build. However, I have been in science long enough to see paradigm shifts. One big one in the past 20 years was that ribonucleic acid (RNA) molecules could have catalytic activity like enzymes made of protein (the first macromolecules identified as having catalytic activity). Scientists held onto proteins as the only enzymes until the data showing catalytic activity with only RNA present could no longer be ignored.

RJL: By the way, I do not think discovery of compounds of the noble gases qualifies as a "paradigm shift" as I understand the term. Discovery that combustion is combination with oxygen and not loss of phlogiston would be a paradigm shift.

PJG: Finding out that noble gases can be reactive was a paradigm shift for me. This was the first time I had seen scientists changing their minds on chemical reactivity. I remember I felt like the rug was pulled out from under me. Now I know that paradigm shifts can happen, and, in fact, now I find such shifts rather comforting that through the process of science we change the way we think of the world.

7.4.6 Does Not Constructivism Apply to Educational Theory as Well?

RJL: You argue that one must construct knowledge for oneself. I think I begin to understand what this means, though perhaps not all the subtleties. A problem I had throughout [reading] much of the doctoral thesis was the introduction of new and strange vocabulary (e.g., domain theory, design framework, design methodology, cultural historical activity theory, agency, hermeneutic circle, habitus, non-foundational knowledge, etc.). Though you do define most of these terms as you go along, they do not become part of my own "constructed knowledge" easily – at least on one reading. Is this not going to be a hurdle for you in trying to "convert" your colleagues to alternative teaching strategies? Can you translate into their vocabulary?

PJG: I will help my colleagues "translate into their vocabulary," but the process is tough to do. I remember just starting in education, feeling that people were using words one way but differently than my use of the word. You may feel similarly. Having just recently been through the process of learning the social science side of teaching, hopefully, I will be able to help in the translation. I think knowing the culture and discourse of both the scientific and education communities helps me. I am adding a good index so that readers can refer back to earlier pages in which I defined the terms.

Thank you for reminding me of the difficulties of learning the language. I think our students have the same trouble learning biochemistry. I have read that students learn more words in a science lesson than in a lesson of a foreign language course. Griffiths (2002) addresses the problem of language in a biology classroom at the university level. Griffiths opens her chapter as follows:

> Language is the knot that ties us together. It is the common bond that allows people to form communities, to work toward the common good of humankind. Indeed, when one thinks of a social system, one very important aspect of that system is the language used to express ideas. One might also say that without the ability to share a common language there would be no civilized social communities. (p. 69)

We are trying to teach our students [to use] science vocabulary while we are trying to teach complex concepts, like structure–function relationships of macromolecules. No wonder they have trouble learning!

For our science colleagues, much as we expect our students to learn the discourse of biochemistry, they will need to learn the discourse of education and the reform movement, if they are to learn, much like you have started by reading and commenting critically in this doctoral thesis.

7.4.7 Different Levels and Aspects of a Subject

RJL: You seem to lump all science learning and knowledge into one category (i.e., Did the students learn some "biochemistry" or not?). As I try to think about this, it occurs to me that there are not only many different "levels" of understanding of something (as in Bloom's taxonomies), there are also different "aspects" of a subject to be understood. Let me illustrate what I am trying to get at here through considering a simple chemical subject: hydrogen.

How do we "understand" hydrogen? What do we "know" about it?

First of all there is the structural theory. For hydrogen, it is composed of diatomic molecules; [hydrogen] atoms are composed of one proton and one electron; protons are composed of quarks; quarks composed of strings; electrons composed of? etc. These can be stated as "facts" (Truths) or can be developed as ideas stemming from experiments. Some are easy to grasp, some very difficult, some perhaps controversial.

Then there is the energetics (i.e., Bohr theory, quantum theory – by the way, are Heisenberg and Schrödinger two *fits* to quantum theory, or *matches* to quantum theory? re: the distinction you make from George Bodner's analogy). That, of course, leads us into the dualistic nature of both matter and light, again ideas that can be presented in a relatively simplistic, or highly complicated, way. (I still do not quite "get" Feynman's idea of rotating arrows to describe light in quantum chromodynamics, and I probably never will, unless I was willing to learn the mathematics involved).

Then there are physical properties: Gases have very low boiling point; many gases can become superfluids at very low temperatures or have metallic properties at very high pressure, etc.

Then there are the chemical properties: Hydrogen reacts with oxygen to form water, forms metal hydrides, bonds to non-metals, forms relatively nonreactive bonds with C, is a good reducing agent, can be oxidized to form a positive ion, but can be reduced to form a negative ion; hydrogen ion in water is hydrated and involved in acid-base chemistry, etc.

Then there are industrial properties: Hydrogen is viable as a fuel source or as a rocket propellant, etc.

Then there is hydrogen's role in the evolution of the universe.

Etc.

Besides the different Bloom taxonomies as to the level of one's learning, it seems to me there are also different ways one can approach a subject. Learning to speak a foreign language is a bit different from learning to read or write using the language. Composition in English is different depending on whether you are writing a scientific paper or a short story (as you "learned" in your fiction class). Learning to recognize and appreciate classical music is different from learning to play it, which is different from learning to compose it, etc.

PJG: I agree about many different levels of learning biochemistry. I tried to tap into some of them while insisting that students write, speak, and calculate using language (both English and mathematical). You are right that science has many aspects, and if we can teach our students the process of learning and that learning is fascinating and challenging, then we have done our job as teachers.

7.4.8 Positive Reactions

RJL: Let me close by reinforcing the first comment I made in this metalogue. I found many positive things illustrated in your experience. When I attended your classes the students seemed excited about what they were doing. In spite of their misgivings, their comments in the doctoral thesis were always favorable about you and your concern for their welfare. Requiring them to write and to "use the language of biochemistry" is something we all ought to do, but seldom find the time. By reading their goals, submissions, etc., you could get to know the students well, as individuals, something I am seldom able to do in my classes.

Developing the skill to use the Internet was a positive side benefit (though a consumer of time) for this group, though in the future we may find that students will come to the course already with the required speed in this skill. (The next stage will be to teach them to be skeptical of everything on the Internet and to develop criteria of credibility).

I have always felt that, in the end, the best thing a teacher can do is to show students how to teach themselves, and you seem to have done that with this group.

This is my final response that I sent to RJL:

PJG: Since you read my draft doctoral thesis, I have completed the Appendices (available at http://www.chem.fsu.edu/~gilmer/downloads.html). I think you will be interested to read all my students' comments from the 11 qualitative questions in the LEQ (available at http://www.chem.fsu.edu/~gilmer/downloads.html). You can read both positive and negative comments. It is from the contradictions that I learned the most about improving the learning environment in my classroom. Here are the qualitative questions I asked my students in the final week of the semester:

1. What do you like most about this course? Why?
2. What do you like least about this course? Why?
3. What are the best policies, procedures, and activities for enhancing learning that currently exist in this course?
4. What policies, procedures, and activities currently exist in this course that you feel inhibit learning?
5. How should this course be changed so that it improves learning and better meets the needs of students?
6. Would you learn more chemistry if the instructor did more traditional lectures instead of students presenting their Web sites? If so, how would more lectures help you learn? Did you study with your learning group (or other students in our class) outside of class time? If so, what this helpful?
7. Did your writing of your "goal" statements and "contributions to your Web site" in your electronic portfolio help you with your learning, or was it only an exercise to do? If you did learn, what did you learn about yourself as you did it? Would you recommend Dr. Gilmer to continue the electronic portfolios in future classes? How could this assignment be improved?
8. Was it helpful to focus on particular aspects of biochemistry as you developed Web sites to help you learn biochemistry in depth? What could have improved your learning? Should we have dedicated more days to learning the Web and our Curriculum and Instruction Web site at the start? Were there too many Web sites to create?
9. Did you learn from members of your collaborative group? Did you teach others in your group what you knew that helped their learning? Were you satisfied with your own participation and that of your group members in the group work (both the creation of Web sites and in the presentations in class)? Do you think it would be good to switch group members, part way through the class? If so, how do you think it would help?
10. Did answering some of the chapter's problems and posting them on the Web site (or turning in your answers on paper) help you learn biochemistry? Did you

tend to work individually on this, or did you work as a group, helping each other when one got stumped? If the instructor had made up her own questions rather than using the questions from the back of each chapter, would that have helped you learn? Would it help if the instructor had posted the correct answers on the Web, after the assignments were done?

11. How was it for you to try to learn the technology of using the Web as a search engine, using our Web-MC Web site, or our Curriculum and Instruction Web site, and learning how to develop your own group's Web pages, while trying to learn biochemistry simultaneously? How could this process have been improved, to enhance your learning? At what point in the course did the technology part of the process become more straightforward? Should we have spent more time in class near the beginning of the course to learn this? One possibility is offering this course as four credits, with a three h laboratory as the fourth credit hour of what is usually a three credit hour class. What do you think of this idea?

Robley, let me thank you for reading my doctoral thesis so carefully and for participating in this metalogue on the problematic issues of bringing reform to higher education. One of my major professors, Peter Taylor, commented to me (e-mail, 2 February 2004) that you asked all the right questions, that we were both spirited in our metalogue, and that we "debated strongly." Taylor felt that "we are witnessing a *viva voce* (oral examination) of your thesis, given that he quotes from it." Taylor also stated: "It also gives fascinating insights into the culture of your department, especially the systemic restraints to radical pedagogical reform (or transformation)."

Peter also liked your explanation of the hydrogen example, and reading it made him "think about the need to explicate multiple learning outcome statements with multiple levels embedded within them … it's happening throughout Australia, including universities, and is making teaching a much more transparent process for students (and parents helping [their children] with homework)" (e-mail, 2 February 2004).

Robley, I think that our engaging in this metalogue follows the process that Bateson had in his definition of metalogue. We not only engaged in the conversation on the problematic issue of bringing reform in the teaching of science to higher education, but our "conversation as a whole [was] also relevant to the same subject" (Bateson 1972, p. 1). I think that Bateson, were he alive, would be interested to read our metalogue. He would have kept the metalogue going, as Taylor has done. Hopefully, our colleagues in higher education will read this metalogue and the rest of the doctoral thesis, and doing so will cause them to reflect on the students' learning in their own classrooms.

7.5 Closing Thoughts on the Metalogue

In conclusion, I feel that this chapter helps the reader understand the context in which I implemented reform and transformed my teaching of biochemistry. The reader can hear my colleague and me speaking and can get a feel for the culture in which I live and work in higher education in a physical science department in a College of Arts and Sciences. My students provided valuable feedback on the learning environment in our classroom, because they could see that I wanted their feedback to improve my teaching for future students. I was especially surprised that RJL in this metalogue said, "I do not believe just asking the students how much they learned really tells you anything." Of the 34 students, 32 responded to most of the 11 qualitative questions in the LEQ. All groups responded to all ten of their CLS forms. However, my students' comments were critical about the learning environment in our classroom, both in the LEQ and the CLS. I provide evidence for my learning in Chapters 5 and 6 with changes I have made in my teaching since the experimental study.

RJL's metalogue with me made visible the culture in which I teach, which constrains a teacher's quest for transformation. Wright et al. (2004) highlight the problem in higher education:

> Change is difficult in higher education because the organization of the institution, its expectations, and its social responsibilities inhibit risk taking, ambiguity, and the inquiry required for change to occur (p. 5)

Still with determination and persistence, I was able to change my teaching and learn from the study. However, I paid a price because my senior colleagues did not allow me to teach the biochemistry course for science majors for six years. However, since Spring 2005, I have been teaching one or two biochemistry classes for majors per academic year.

I do think that I learned from the written conversation I had with RJL. I can understand better the culture in which I have been embedded. I appreciate the time and effort he spent reading my doctoral thesis and sending me questions and responding to my points. This book initiates a start in changing the culture so that scientific research and educational research are both valuable to our community.

Chapter 8
Reflecting on My Learning Through Action Research

8.1 Preview

In this concluding chapter, I address the methods of my students using technology and working in collaborative groups to enhance their learning and interest in biochemistry. Because "[w]riting these stories reminds us of the continual co-creation of the self and social science" (Richardson 2000, p. 943), I am able to look back and examine the quality criteria in the various genres of writing.

Additionally, I address my sources of transformation, which I enacted in the curriculum. These sources help me reach deep inside myself and enable me to change my way of teaching (for over 20 years), think of knowledge as nonfoundational, and reflect on the process of growth and change.

I highlight the culture in which I work within a Biochemistry Program in the Department of Chemistry and Biochemistry. This culture is similar to that of the departments in which I earned my first doctorate in biochemistry at the University of California, Berkeley, in 1972, and at Stanford University where I did four years of postdoctoral research in biophysical chemistry and immunochemistry from 1973 to 1977. I have seen little change in the culture of science teaching in departments over the years of my career.

8.2 Changing Ideas on Biochemistry Research

Recently, however, in my biochemistry colleagues' vision statement for our program in biochemistry, I am starting to see seeds of change in the focus of the biochemistry research from a reductionist approach of determining structures of individual macromolecules to one which examines (a) the interactions among macromolecules (or "communities" of molecules that function together) more, and (b) the small molecules that add coherence (i.e., activate) or contradict (i.e., inhibit) the biological functioning of macromolecules:

P.J. Gilmer, *Transforming University Biochemistry Teaching Using Collaborative Learning and Technology: Ready, Set, Action Research!*, DOI 10.1007/978-1-4020-4981-1_8,

> Much of biochemistry today focuses on the structure and function of isolated macromolecules; our interests now are shifting in this post-reductionist era in two quite different but complementary directions. One is toward macromolecular complexes, networks and assemblies, especially those that occur in membranes responsible for such biological activities as cell signaling, signal transduction, transport, receptors, and drug resistance. A second direction focuses on the numerous small molecules that modulate, stimulate, impede, or mimic macromolecular function. These two avenues of scientific investigation present unique and timely challenges for organic, physical, inorganic and analytical chemistry. (Biochemistry Program 2008, p. 1)

I realize that I could use CHAT to explain the expansion of research approaches and questions from this recent vision statement of the Biochemistry Program. The "subject" using the CHAT (Fig. 3.2) framework, in this case, is the macromolecule of focus, with its structure (i.e., the object) being influenced by "communities" of interacting small regulatory molecules and other macromolecules, being energized by the "division of labor" within the mitochondria of a cell, and influenced by the available tools (i.e., the pH, the ionic or membrane milieu, the electrical potential), with the "rules" being evolution and the laws of physics. The "outcomes" would be the regulated biological functioning of macromolecules within the cell.

Here is an example of applying CHAT to a biological macromolecule: For instance, I studied the major histocompatibility complex (MHC) class I antigen, a cell-surface glycoprotein, which was the "subject" of my study. The "community" with which this antigen associates for its biological function is one of many possible viral peptides. The T-cell receptor on the cell surface of an immune cell recognizes the complex of the viral peptide and the MHC class I antigen, allowing the immune cell to recognize the virally infected cell for destruction. Therefore, the T-cell receptor is part of the "community" of the MHC class I antigen. There are other molecules as well involved in this recognition event. The plasma membrane is the two-dimensional "tool" which embeds the MHC class I antigen so that it can move in the plane of the membrane for the immune T cell's receptor to recognize and kill the virally infected cell. The "division of labor" comes from other components of the cell, which, for example, allow for the synthesis of the glycoproteins and for the regulation of metabolism, which energizes the cell. The "rules or schemas" control the genetic expression of the antigen and its physicochemical association with the T-cell receptor and other events in the killing of the virally infected cell. Biochemists now are tackling more holistic system, so that they can go beyond determining the structure (the "object") and now determine the interactions between molecules in appropriate settings to see the functioning system or the "outcomes."

I see CHAT as a reasonable model for these processes, and this theory may be potentially applicable in this case. Hopefully, my work with others in this burgeoning field will provide the avenue upon which a new direction in science departments can be forged.

8.3 In Closing …

I close this book with my conclusions on my learning from my action research study, with ideas for future studies on the problematic issues of encouraging reform in the teaching of science at higher education institutions.

In this chapter I answer the last research question:

What are the sources of the transformation in the enacted curriculum?

To figure that out, I also ask myself, what was my motivation to seek out changing my teaching, when I was already a full professor of chemistry and biochemistry? Using CHAT and Sewell's theory of structure | agency, I address the sources of transformation of the enacted curriculum.

How can my learning help other faculty in the sciences in higher education bring transformation to their teaching? What more can I do to continue my transformation, as I gain new insights through action research?

8.3.1 Reflecting on My Educational Autobiography

My educational autobiography does not appear in this book, but was a part of the submitted doctoral thesis (Gilmer 2004) and is a chapter in a recent book (Gilmer 2007). Regardless, I believe my reflections on my personal educational path are an important component of my journey, so I will mention a few important components here.

My own interest in chemistry stemmed from the era in which I grew up. The Russians launched Sputnik when I was 15 years old, between my sophomore and junior years in high school. America needed scientists at that time. By choosing science, I felt I was contributing to our national cause of self-preservation.

I could not fully comprehend the Cold War and the civil strife of the 1950s and 1960s, but at least through chemistry, I felt a part of the world became predictable and understandable. I felt drawn to that stability. At that point in my life, understanding the social sciences seemed out of my range of talent and even undesirable for me. However, now, at a different point in my life, I seek to understand social interactions (students in classrooms that I teach) rather than studying single macromolecules (like I did for my doctorate) or the interactions of macromolecules on different membranes (like I started in my postdoctoral position and continued until I had cancer, 20 years later). Now in my life I am better able to concentrate on people and the process of learning in order to create an environment more conducive to students.

I realize now that I survived in science because I could learn by listening to lectures and by working on my own to construct my own knowledge. I love that science is a part of the world that basically makes sense. I think others with like-minds feel a similar satisfaction. However, if we teach students *only* by lecture, we tend to encourage only those students who think like we do. Therefore, I decided to break the mold and take a radical step to incorporate all I could in order to improve teaching and learning, since I continued to push the "envelope," to find elements that work and others that do not.

In hindsight, I realize that the changes in my classroom, making the students learn in collaborative groups, using the Web, and writing reflectively in an electronic portfolio, were too radical. Lectures were the norm in the classes for science majors, but still many students felt attracted to try some radical approaches to learning science. A good number of the students grew "exponentially" in their learning of biochemistry through their realization of the power of learning by using the Internet and working collaboratively in groups. Therefore, I think research offers much insight to the realm of science education.

Through my reflections and writings for the doctoral thesis and this resulting book, I realized the underlying reason behind my decision to do educational research instead of continuing my previous biochemistry research on immune T cell recognition of tumor cells. Fifteen years ago, I found out I had a malignant cancer. After this discovery, I tried but was emotionally unable to continue my biochemical research of 20+ years. Continuing the biochemical study of cancer became too close to me, and I could no longer concentrate on my research. I needed to look for another avenue of study or else I would "die on the vine" of academia. I did not want to be "dead wood" in terms of my research. Research was too important to me.

I chose to expand my expertise and to learn science education from the "ground up." At that point in 1995, I had become involved in science education for three years. At that point in time, I knew only the current educational research and not the historical research, methodologies, and theories that led to the current views. Therefore, instead of studying details of interactions of macromolecules, I chose to study human interactions in the classroom. I had to immerse myself in coursework in science education and learn the theories and methodologies that would be most suitable for my research questions.

Thus, I decided to take graduate classes in Science Education at my university because I needed to find a way to maintain my intellectual curiosity and growth. As my health continued to improve, I decided in 1997 to start the work for a second doctoral degree at Curtin University of Technology (2009), which I finished in 2004. I feel that immersing myself in a field that was both compelling and difficult kept me motivated and focused. I believe that focusing on learning science education helped me survive cancer and the debilitating effects of chemotherapy. Fortunately, my cancer is still in remission, since 15 years. I am a survivor!

My colleagues within science are surprised to hear that conducting action research and writing this book (which first appeared as my doctoral thesis) were much more difficult than doing my first dissertation in Biochemistry. But for the first doctorate, I was "greased" to do the mathematical study of the kinetics of binding a vitamin B6 analog to a transaminase enzyme (Gilmer Kury 1972; Gilmer and Kirsch 1977). Mathematics and analytical thinking came naturally to me and I enjoyed it, as I had worked all my life at that point to be able to do such a biophysical study.

In contrast, however, at the start of my educational research, I lacked the background and natural talent to do qualitative research. I needed to learn to use a qualitative methodology (which was radically different than the extremely quantitative one I used in my biochemistry dissertation) and understand the quality criteria for such a qualitative study. I feel my understandings of science and education are analogous to the yin and the yang, the quantitative and the qualitative, and a bringing together of both in my mind.

For the second doctorate in Science Education, I read many more articles and books than I had for the first doctorate in Biochemistry. For instance, while I co-editing a book on college science teaching with my two co-major professors (Taylor et al. 2002), I read every article that I could find to which the other authors referred in their chapters. In my first doctoral dissertation in biochemistry, I had just 49 references, and each one was an article in a journal or book chapter. In my doctoral thesis in Science Education, I had 192 references, many of which were books that I had read in their entirety. This is an indication of all the learning I needed to do for this doctorate in Science Education.

I hope that I continue to remain in good health, now that I finished this degree, so that I have time to implement these ideas, publish the results, and work with other college faculty members, toward improving the teaching and learning of science in higher education. This research contributes toward the improvement of science education, and has truly become a crucial and passionate effort in my life.

8.3.2 Summarizing My Learning Through Action Research

I am pleased and excited to present a summary of my learning while conducting action research in a biochemistry classroom at the college/university level.

8.3.2.1 Reflecting on the Class

During the first few weeks of class, I vividly recall my students struggling to learn, particularly the technology. I even used class time to help students learn to create Web sites and worked with them on other technological aspects. I knew I needed to finish the same number of biochemistry chapters as the parallel section of the same course, because at least some of my students would merge with the students from the other lecture section to take the second semester of the course in the biochemistry sequence. The pressure to prepare my students for the next course while conducting my action research heightened my thoughts and actions throughout the course.

I had a vision of the strands of *General Biochemistry I* that I wanted the students to learn. I had delineated and explained the primary strands to the students (Fig. 1.1), near the beginning of the semester, as mentioned in Chapter 2; I had dreamt of my students learning the different-colored strands of biochemistry and weaving them together, to form a braid. The braid not only had color, but also was rich in texture; I could feel the different materials. I wanted my students to understand the vision I had in my mind for this class and their learning. The strands that made up the braid were the strands of biochemistry. I wanted my students to weave their own “braid” from their own constructions and growing interest in biochemistry.

After the semester was over, one of my students, Ann (pseudonym), a quilter, gave me a quilt that she had made, especially for me. The design on the quilt was a heart (Fig. 8.1), which she constructed from pieces of material to make the whole, much as she learned by constructing her ideas of biochemistry, fitting them into her knowledge structure. Ann’s gift of the quilt meant so much to me, especially her

Fig. 8.1 Gift of quilt. Ann (pseudonym), a student in this class, gave me this quilt that she sewed after the end of the biochemistry class. I treasure this quilt, which I have hung in my house

thoughtfulness and effort. I think she made the connection between my dream of the braid and her construction of the quilt from various pieces to make the whole beautiful. This quilt embodies the love Ann could see I had both for biochemistry and my students.

Ann enrolled in three other classes with me after the biochemistry course: STS, and two semesters of a *Directed Individual Study* project focusing on her interest in colon cancer and developing a Web site (which is no longer available) that was accessed more than 47,000 times in 2001. Throughout the biochemistry course, as well as the later courses, Ann demonstrated that she could construct her own knowledge of biochemistry and the interrelationships between various fields of science and medicine. She built her ideas by looking for patterns in life experiences and in scientific data. Since Ann graduated from FSU, she has finished medical school, completed a master's degree in public health, and is in her final, fourth year of residency in surgery.

Reflecting on my biochemistry colleagues' reaction to my course, probably none would have ever shared with students a vision for learning from a dream, such as this dream of mine. I know women's ways of knowing can be different from that of men (Belenky et al. 1986). As women legitimize alternative ways of knowing, we get power and contribute to knowledge. We may ask different research questions and value other forms of evidence than men. Lederman and Bartsch (2001) provide convincing evidence that women have not been well represented in the history of humankind. We as women need to step forward, be heard, and share our perceptions with the world, particularly in education.

I prefaced this book with a quote that a student from my class sent me by e-mail about a butterfly struggling to emerge from its cocoon, which is analogous to the way students need to struggle in order to develop as learners. If the teacher did not encourage the students to learn on their own, to construct ideas in their own minds, then they might never be able to construct ideas on their own. I wanted my students to "fly," to stretch their wings and try, so they would know that they could learn on their own.

An educational autobiography (Martin 2005) of another woman science educator, who received her doctorate about a year after I did from Curtin University of Technology, reminds me of the lesson of Ann's quilt. Martin writes: "Like the memory quilts, pieces of my history alone do not seem very meaningful, yet tied all together, they present a powerful story of the person that I have become" (p. 241). Ann's quilt did bring different pieces of material together to show her appreciation and form a heart. Similarly, my bringing together the various aspects of this research to make the whole (i.e., this book) is more than the sum of its parts.

8.3.2.2 Reflecting on My Students' Responses to Fictionalized Story

In this book, I have provided the fictional story that I wrote from the point-of-view of a student, as one component of my educational journey. I have presented papers on the fictional story at international conferences, in which I asked four members in the audience, each to come forward and read the text of one student's voice in the story and to enact the portions of the story (Gilmer, 2000a, c). Writing the story is one method I use to rework my teaching experiences into a variety of perspectives, to legitimize research texts (Mulholland and Wallace 2000; Kincheloe 1997). Authors utilize various terms for legitimization, including credibility (Guba and Lincoln 1989; Kincheloe 1991), trustworthiness (Glesne and Peshkin 1992), and use of "multiple tellings" (Mulholland and Wallace 2000, p. 1).

I found that my former students' assessment of my fictionalized story provided an avenue for me to explore the feelings and incidents that were not fully visible to me during the semester in which I taught the biochemistry course. I utilized my students' responses to my story to flesh out deeper understandings of the experiences of my students in an alternative learning format. This process helped me reflect on improving my own teaching and learning.

Writing the fictional story became a powerful research tool, both in allowing me to think from my students' perspective, and in giving me a way to get feedback from my students a year after the course ended.

For instance, Ann (the quilter) responded by e-mail, to my queries about the fictionalized story about our classroom, as follows:

1. Do you think the story reflects what happened in our classroom? Since it is a fictionalized story, it did not actually happen, but could it have?

Yes, this could have happened. At first I felt the story was a bit idealized, with your group having a diverse mix of majors, ethnic backgrounds, and personalities, and they were all really motivated too about learning. Then I reflected that most groups in our classes had some level of diversity, primarily in personalities. I think that the level that the students discussed the material was accurate, too. The problems that your group encountered were typical for any class where group projects occur.

2. As you look back at the course, what did you learn? And what do you wish you had learned? How could the experience have been better in terms of learning? What can you tell me that will help me learn from my research of our classroom?

I think my feelings toward your class are influenced by my status as a pre-medical student. As addressed in your paper, I was preparing for the MCAT when we took this class. While biochemistry is not required for MCAT, it is regarded as a good preparatory class. In your class, I developed a good understanding of the basics of biochemistry, which was extremely useful during the test.

As a student, I was at a disadvantage in *General Biochemistry II*, and other advanced coursework. In other sections, students memorized data that we did not, such as amino acid structure, and spent less time on technology and more time doing problems. In *General Biochemistry II*, I did not have items memorized that others did, and I had to put in extra time to catch up.

I was advantaged in some classes after *General Biochemistry I*. I had a greater understanding of topics I had studied, such as sickle cell [disease] and AIDS, than other students [did] in later classes.

Reading and reflecting about the experience in our biochemistry classroom has helped me learn from the experience. For instance, since my action research, I now have my students memorize the 20 amino acid structures because I know they will need them in the next semester's sequence in the course. Listening to my students, like Ann, on the positives and negatives of their experiences in my class allows me to continually change and improve my classroom.

In the long term, I believe that learning the technology enabled my students to learn more holistically than linearly. Students could start to see the connections between different aspects of a problem. For example, sickle cell disease depends on the genetics for the DNA that code for the sickle cell hemoglobin. However, the pain that sickle cell patients feel is due to the sickle shape to the cells trying to go through tiny capillaries. The shape of the cell depends not only on the hemoglobin protein packed into the cells but also on factors (including membrane-associated proteins) that control the normal biconcave disk shape of the human red blood cell. Understanding the multiple aspects of chemistry involved in disease, such as sickle cell anemia, and the very human attributes and repercussions of this disease encourage students to see the connections between these ideas, pushing them towards deeper learning (Muire et al. 1999).

8.3.2.3 Reflecting on Quality Criteria

In Chapter 3, I described the quality criteria for each of my data chapters:

1. Richardson's quality criteria for writing fiction (relating to Chapter 4)
2. Guba and Lincoln's quality criteria for the ethnographic data (relating to Chapters 5 and 6)
3. Bateson's criteria for a metalogue (relating to Chapter 7)

I have tried to adhere to all criteria, being sure to get member checks with students from my classroom and with biochemistry faculty in my biochemistry program within the chemistry and biochemistry department.

8.3.2.4 Reflecting on the Power of Educational Theory

Being originally a biochemist, I knew the power of utilizing a theory in understanding science. For example, without the atomic theory, kinetic-molecular theory, molecular orbital theory, the theory of evolution, etc., where would we be today in science?

I started realizing the power of learning educational theory once I tried to make sense of my data. Armed now with educational theory, I ask different questions of myself and can move the analysis much further than I could have without theory. Educational theory provides me with the impetus and guidance to transform and modify my teaching in order to improve the learning of my students.

CHAT and Sewell's theory of structure|agency are powerful tools to help me learn about human interactions. For instance, I use CHAT and Sewell's theory of structure|agency as I implement weekly meetings with a representative group of students from my biochemistry classroom, where we cogenerate ideas together on improving the learning environment. These meetings are called cogenerative dialogues (Geelan et al. 2006). Here is a list of the issues my biochemistry cogen students and I address:

1. Identifying the key patterns and contradictions in the learning environment in our classroom
2. Discussing what should be strengthened and what should change
3. Discussing new rules and roles for me as the instructor and you as students
4. Deciding what is to be done next time (and we will cogenerate decisions in all cases)
5. Deciding what data to "collect" to determine whether or not progress has been made to agreed upon changes/practices
6. Discussing the meaning and obligations associated with shared responsibility for making progress

Conducting this recent research on cogenerative dialogue during the semester in which I teach these students has been exciting. I can share the ideas we cogenerate with my students, and they can see the results of their suggestions. All students have a location on Blackboard where they can post (either anonymously or with their name) feedback on the ideas to discuss and the ideas generated in the cogen group.

Using Sewell's theory of structure|agency, I try to provide my current students *access* to me, *appropriation of resources* and a *structure*, with *human*, *material* and *symbolic* aspects, by which students can grow and learn, thereby enhancing their *agency* (Fig. 3.1). In terms of CHAT, I try to provide my students with *tools*, *communities*, *division of labor*, and *schemas* that allow them to work towards achieving their *objects* so that they can move towards their goals and *outcomes* (Fig. 3.2). This is work still in progress but each semester I focus on the aspects the students need (as learned through the cogenerative process), and incorporate the aspects that work into my teaching repertoire.

8.3.2.5 Reflecting on Ideas to Implement in the Future Teaching

I feel that I learned significantly about using technology and collaborative groups through my action research. I still utilize both technology and collaborative learning in my current classrooms, but I use them in different ways than the study reported here. In my action research described here, I did everything to the hilt, with each group preparing ten Web sites and presenting three of them, thereby increasing the dynamics within collaborative groups. From these multitudes of interactions and my examination of them, I learned new ways to improve the learning environment. I believe my method of teaching in my current classrooms, with collaborative groups and technology, improved considerably, because of the action research described here and my consistent efforts to better my students' learning environment.

For instance, in *Introduction to Biochemistry*, where I teach health science majors, a different group of students than the students in this study worked in collaborative groups, but only prepared and presented one collaborative group project per semester. These students had more time to get to know each other before they started on their collaborative project as they worked together in active learning activities in the lecture and the laboratory (in a combined lecture–laboratory course). In the action research study reported in this book, in contrast, the students had to jump into their collaborative projects during the first week of class, rather than easing into a single group project later in the semester, like I have done more recently.

In another semester, I again tried something new. This time I taught the second semester of the biochemistry course for science majors, *General Biochemistry II*. I had not taught this course beforehand. Professor Timothy Logan, a fellow biochemist, and I co-taught two sections of the course, each for half of the semester, and attended each other's lectures for the other half of the semester. We both had office hours all semester and together he and I cogenerated questions for quizzes and hour examinations. For the first time since I had taught at my university did I discuss teaching biochemistry as much as I did for the semester.

For each semester I continue action research in my teaching, in order to test various strategies to determine ways to improve the learning environment in my classroom.

The process of continual personal growth and learning has become well embedded within me.

8.3.2.6 Reflecting on the Culture Within Higher Education

To summarize this book, I wrote about my experiences and perceptions during my action research study, by examining the three crises of representation (Chapter 1), the relevant background literature that influenced by research study Chapters (2, 4–6), the theories that contributed to my thinking (Chapter 3), the quality criteria for a qualitative research study of my own classroom (Chapter 3), the fictionalized story of my biochemistry classroom (Chapter 4), my students' perceptions of learning in a collaborative group (Chapter 5) while using technology (Chapter 6), a metalogue with a senior, now retired, biochemistry colleague (Chapter 7), and my reflections on the study (this Chapter 8).

I close this book with a challenge to the higher education culture by "inviting it to dance at the ongoing reform party" (e-mail, Peter Taylor, 2 February 2004). We have many avenues open for pursuit to improve the teaching and learning of science in higher education. As more science faculty become involved in the reform, we can develop a critical mass. Students will become accustomed to learning in new ways that allow them to choose new methods of learning than those that come easily to them, opening up new routes of communication and education. Today, students need to learn to use technology and collaborate with peers in powerful ways as they move into their new professions.

Instead of approaching science as "just the facts, ma'am," we need to teach science more as a process of our understanding of the systems under study. Science is an amazing process of learning about the world. Often we discourage people from pursuing science because we traditionally teach the sciences by lecturing our constructions of the facts, rather than encouraging our students to be active in their learning and constructing their own knowledge webs. This outcome not only hurts them and their growth as educated people, but hurts us as well, because we do not get the public's full support in scientific research we believe to be important for society at large.

Therefore, I invite scientists to become involved in education, learn about new research on teaching and learning, and, most importantly, bring those new ideas to our students. We as scientists are responsible for educating not only the next generation of scientists and engineers, but also K-12 teachers and the general public. We must be aware not only of the new research in our scientific field of expertise, but also in the fields of teaching and learning. I challenge all scientists to conduct action research in their classrooms, evaluate the data, and listen to their students' ideas on improving the learning environment. Reflect and write on the issues in your classroom, share your action research with others as you do your scientific research, and become part of the blossoming educational research community.

References

Abbas AO, Goldsby KA, Gilmer PJ (2002) Promoting active learning in a university chemistry class: metaphors as referents for teachers' roles and actions. In: Taylor PC, Gilmer PJ, Tobin K (eds) Transforming undergraduate science teaching: social constructivist perspectives. Peter Lang, New York, pp 183–210

Adamson SL, Banks D, Burtch M, Cox F III, Judson E, Turley JB et al (2003) Reformed undergraduate instruction and its subsequent impact on secondary school teaching practice and student achievement. J Res Sci Teach 40(10):939–957

Adler PA, Adler P (1994) Observational techniques. In: Denzin NK, Lincoln YS (eds) Handbook of qualitative research. Sage, Thousand Oaks, CA, pp 377–392

Allen RD, Stroup DJ (1997) Enhancing critical thinking. In: Siebert ED, Caprio MW, Lyda CM (eds) Effective teaching and course management for university and college science teachers. Kendall/Hunt, Dubuque, IA, pp 35–44

American Association for Higher Education (AAHE) (1994) Peer review of teaching. http://www.aahe.org/teaching/nov94bull...May_18.htm. Accessed 15 Nov 2003

American Association for Higher Education (AAHE) (1995) From idea to prototype: peer review of teaching. (in a presentation by James Taylor). http://www.aahe.org/teaching/guagenda.htm. Accessed 15 Nov 2003

Atwood CH, Taylor JW, Hutchings PA (2000) Why are chemists and other scientists afraid of the peer review of teaching? J Chem Educ 77(2):239–243

Bateson G (1972) Steps to an ecology of mind: Collected essays in anthropology, psychiatry, evolution, and epistemology. Chandler, San Francisco, CA

Belenky MF, Clinchy BM, Goldberger NR, Tarule JM (1986) Women's ways of knowing: the development of self, voice and mind. Basic Books, New York

Berliner D (2001) Our schools vs. theirs: averages that hide the true extremes. *The Washington Post*, January 28

Biochemistry Program (2008) Biochemistry program scientific vision, communicated by Professor Timothy Cross, Florida State University

Bodner GM (1986) Constructivism: a theory of knowledge. J Chem Educ 63(10):873–878

Bodner GM, Orgill M (2007) Theoretical frameworks for research in chemistry/science education. Prentice Hall, Upper Saddle River, NJ

Bourdieu P (1991) *Language and symbolic power* (ed: Thompson JB). Harvard University Press, Cambridge, MA

Bourdieu P (1993) The field of cultural production (ed: Johnson R). Columbia University Press, New York

Boyer Commission on Educating Undergraduates in the Research University (1998) Reinventing undergraduate education: A blueprint for America's research universities. Carnegie Foundation for the Advancement of Teaching. {also available now at http://naples.cc.sunysb.edu/pres/boyer.nsf.]

Bowen CW (2000) A quantitative literature review of cooperative learning effects on high school and college chemistry achievement. J Chem Educ 77:116–119
Bowen C (2002) From connections to survival: Diane's experiences in the chemistry classroom. In: Taylor PC, Gilmer PJ, Tobin K (eds) Transforming undergraduate science teaching: social constructivist perspectives. Peter Lang, New York, pp 45–67
Bransford JD, Brown AL, Cocking RR (1999) Committee on Developments in Science of Learning and Commission on Behavioral and Social Sciences and Education. How people learn: brain, mind, experience, and school. National Academy, Washington, DC
Bratton DD III, Gilmer PJ (2009) Undergraduate biochemistry education. In: Roth W-M, Tobin K (eds) The world of science education: handbook of research in North America. Sense, Rotterdam, pp 207–220
Britzman DP (1991) Practice makes practice: a critical study of learning to teach. State University of New York Press, Albany, NY
Brown JS (2002) Plenary address: the philosophy/psychology of collaboration. http://www.hhmi.org/grants/for_grantees/meetings/2002/brown.html. Accessed 29 Aug 2003
Bruffee KA (1993) Collaborative learning: higher education, interdependence, and the authority of knowledge. The Johns Hopkins University Press, Baltimore, MD
Bruner J (1986) Actual minds, possible worlds. Harvard University Press, Cambridge, MA
Burroway J (1996) Writing fiction. A guide to narrative craft, 4th edn. HarperCollins College, New York
Calvin K, Gilmer PJ (eds.) (2nd printing) (2008) Real science for the real world: Doing , learning & TEACHING! Chipley, FL: Panhandle Area Educational Consortium. http://www.chem.fsu.edu/~gilmer/monographs.html. Accessed 15 July 2009
Capra F (1996) The web of life: a new scientific understanding of living systems. Anchor Books, New York
Cavazos LF (2002) Kappan. http://www.pdkintl.org/kappan/k0205cav.htm. Accessed 1 July 2007
Cobb P, Glasersfeld E von (1983) Knowledge as environmental fit. Man-Environ Syst 13:216–224
Collins A, Spiegel SA (1997) So you want to do action research? In: Spiegel S, Collins A, Lappert J (eds) Action research: perspectives from teachers' classrooms. SERVE, Tallahassee, FL
Computer-Assisted Personal Approach (CAPA) (2007) http://capa4.lite.msu.edu/homepage/. Accessed 1 July 2007
Conant JB, Nash LK, Roller D, Roller DHD (eds) (1948a) Harvard case histories in experimental science, Vol. 1. Harvard University Press, Cambridge, MA
Conant JB, Nash LK, Roller D, Roller DHD (eds) (1948b) Harvard case histories in experimental science, Vol. 2. Harvard University Press, Cambridge, MA
Coppola BP, Jacobs DC (2002) Is the scholarship of teaching and learning new to chemistry? In: Huber MT, Morreale SP (eds) Disciplinary styles in the scholarship of teaching and learning: exploring common ground. American Association for Higher Education and The Carnegie Foundation for the Advancement of Teaching, Washington, DC, pp 197–216
Curtin University of Technology (2009) http://www.curtin.edu.au/. Accessed 21 July 2009
Darling-Hammond L (2007) Evaluating 'No Child Left Behind.' The Nation, May 21st issue. http://www.thenation.com/doc/20070521/darling-hammond. Accessed 18 June 2009
Davis KS (2001) Peripheral and subversive: women making connections and challenging the boundaries of the science community. Sci Educ 85:368–409
Dawson V (1999) Bioethics education in the science curriculum: Evaluation of strategies for effective and meaningful implementation. Unpublished doctoral thesis, Curtin University of Technology, Perth, Western Australia
Denzin NK, Lincoln YS (eds) (1994) Handbook of qualitative research. Sage, Thousand Oaks, CA
Denzin NK, Lincoln YS (eds) (2000a) Handbook of qualitative research, 2nd edn. Sage, Thousand Oaks, CA
Denzin NK, Lincoln YS (2000b) Introduction: the discipline and practice of qualitative research. In Denzin NK, Lincoln YS (eds) Handbook of qualitative research (2nd edn). Sage, Thousand Oaks, CA, pp. 1–28

Dewey J (1920) The child and the curriculum. University of Chicago Press, Chicago, IL

Djerassi C (2000, February) Contraception vs. conception – a millennial prognosis. Paper presented at the annual meeting of the American Association for the Advancement of Science, Washington, DC

Druger M (2002) Teaching the introductory college science course: a career specialty. J Coll Sci Teach 32:148–149

Druger M, Siebert ED, Crow LW (eds) (2004) Teaching tips: innovations in undergraduate science instruction. NSTA, Arlington, VA

Duggan-Haas D, Moscovici H, McNolty B, Gilmer PJ, Eick CJ, Wilson J (2003) Symbiosis on campus: collaborations of scientists and science educators. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Philadelphia, PA. http://www.people.cornell.edu/pages/dad55/ScienceEdCollab.htm. Accessed 31 Aug 2003

Edelson DC (2002) Design research: what we learn when we engage in design. J Learn Sci 11(1):105–121

Ellis C (1997) Evocative autoethnography: writing emotionally about our lives. In: Tierney WG, Lincoln YS (eds) Representation and the text: re-framing the narrative voice. State University of New York Press, Albany, NY, pp 115–139

Ely M, Vinz R, Downing M, Anzul M (1997) On writing qualitative research: living by words. Falmer, Washington, DC

Engeström Y (1987) Learning by expanding: an activity-theoretical approach to developmental research. Orienta-Konsultit, Helsinki

Engeström Y (1999) Activity theory and individual and social transformation. In: Engeström Y, Miettinen R, Punamäki E-L (eds) Perspectives on activity theory. Cambridge University Press, Cambridge, UK, pp 29–38

Engeström, Y. (2001) Center for activity theory and developmental work research. http://www.edu.helsinki.fi/activity/. Accessed 31 Aug 2003

Engeström Y, Miettinen R (1999) Introduction. In Engeström Y, Miettinen R, Punamäki R-L (eds) Perspectives on activity theory. Cambridge University Press, Cambridge, UK, pp 1–16

Engeström Y, Miettinen R, Punamäki E-L (eds) (1999) Perspectives on activity theory. Cambridge University Press, Cambridge, UK

Erickson F (1998) Qualitative research methods for science education. In: Fraser BJ, Tobin KG (eds) International handbook of science education. Kluwer, Great Britain, pp 1155–1173

Florida State University (FSU) (2003) Guide to computing resources. http://gtcr.fsu.edu/. Accessed 24 Aug 2003

Florida State University (FSU) (2007) Carnegie Foundation classification. http://registrar.fsu.edu/webtest/ugr024.htm. Accessed 2 July 2007

Gabel DL (1999) Improving teaching and learning through chemistry education research: a look to the future. J Chem Educ 76:458–553

Gabel DL (2004) A model for reform in teaching chemistry: with a focus on prospective elementary teachers. In: Sunal DW, Wright EL, Day JB (eds) Reform in undergraduate science teaching for the 21st century. Information Age, Greenwich, CT, pp 425–443

Gallagher JJ (2000) Teaching for understanding and application of science knowledge. Sch Sci Math 100(6):310–318

Gardner MB, Ayres DL (eds) (1998) Journeys of transformation: A statewide effort by mathematics and science professors to improve student understanding. Maryland Collaborative for Excellence in Teacher Preparation. http://www.wam.umd.edu/~toh/MCTP.html. Accessed 15 July 2009

Geelan D (2003) Weaving narrative nets to capture classrooms: multimethod qualitative approaches for educational research. Kluwer, Dordrecht, The Netherlands

Geelan D, Gilmer PJ, Martin SN (2006) Forum: dialogue about dialogue-cogeneration, research and science education. Cult Stud Sci Educ 1(4):721–744

Geertz C (1988) Works and lives: the anthropologist as author. Polity, Cambridge

Geertz C (1993) Local knowledge: further essays in interpretive anthropology. Fontana, London

Gergen MM, Gergen NK (2000) Qualitative inquiry: tensions and transformations. In: Denzin NK, Lincoln YS (eds) Handbook of qualitative research, 2nd edn. Sage, Thousand Oaks, CA, pp 1025–1046

Gilmer PJ (1998) Teaching a web-enhanced biochemistry course. Presented at the annual biochemistry/structural biology retreat, Wakulla Springs, FL

Gilmer PJ (1999a) Developing a discourse community: teaching biochemistry using the World Wide Web. In: Chambers J (ed) Selected papers from the 10th international conference of college teaching and learning. Florida Community College at Jacksonville, Jacksonville, FL, pp 49–57

Gilmer PJ (1999b) Teaching a web-enhanced course using the discourse of biochemistry. Poster presentation presented at the Gordon conference on innovations in college chemistry teaching, New London, CT

Gilmer PJ (1999c) Web-based portfolios in a university-level science course. Presented at the annual meeting of the Association for the Education of Teachers in Science, Austin, TX

Gilmer PJ (2000a) Alternative genre of reporting science education research: fictionalized story. Presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA

Gilmer PJ (2000b) Fictionalized narrative of collaborative learning in a university science class. Presented at the 11th International Conference on College Teaching and Learning, Jacksonville, FL.

Gilmer PJ (2000c) Transformative educative change: action research in a university science classroom. Presented at the meeting of the World Congress: 5th on Action Learning, Action Research & Process Management & 9th on Participatory Action-Research, University of Ballarat, Victoria, Australia.

Gilmer PJ (2002) Opalescence at the triple point: teaching, research, and service. In: Taylor PC, Gilmer PJ, Tobin K (eds) Transforming undergraduate science education: social constructivist perspectives. Peter Lang, New York, pp 423–462

Gilmer PJ (2004) Transforming university biochemistry teaching through action research: utilizing collaborative learning and teaching. Unpublished doctoral thesis. Curtin University of Technology, Perth, Western Australia.

Gilmer P (2007) As a woman becoming a chemist, a biochemist, and a science educator. In: Tobin K, Roth W-M (eds) The culture of science education: its history in person. Sense, Rotterdam, pp 133–145

Gilmer PJ (2009) Faculty homepage: Penny J. Gilmer. http://www.chem.fsu.edu/~gilmer/index.html. Accessed 14 July 2009

Gilmer Kury P (1972) A stopped-flow and temperature-jump investigation of the mechanism of binding of 5-deoxypyridoxal to pyridoxamine-pyruvate transaminase. Unpublished doctoral dissertation, University of California, Berkeley, CA

Gilmer PJ, Engel P (1996) A molecular metaphor for learning. Presented at the annual meeting of the National Association for Research in Science Teaching, St. Louis, MO

Gilmer PJ, Kirsch J (1977) Pyridoxamine-pyruvate transaminase: II. A temperature-jump and stopped-flow kinetic investigation of the rates and mechanism of the reaction of 5-deoxypyridoxal with the enzyme. Biochemistry, 16:5246–5253

Giroux HA (1990) Rethinking the boundaries of educational discourse: modernism postmodernism, and feminism. Coll Lit 17(2/3):1–50

Giroux HA (1992) Border crossings: cultural workers and the politics of education. Routledge, New York

Glaser RE (2003) Complexity in chemistry education. Chem Int 25:3–6

Glaser RE, Carson KM (2005) Chemistry is in the news. Taxonomy of authentic news media based learning activities. Int J Sci Educ 27:1083–1098

Glaser RE, Poole MJ (1999) Organic chemistry online: building collaborative learning communities through electronic communication tools. J Chem Educ 76(5):699–703

Glasersfeld E von (1984) An introduction to radical constructivism. In P. Watzlawick (ed) The invented reality: How do we know what we believe we know? Norton, New York, pp 17–40

Glasersfeld E von (1989) Cognition, construction of knowledge, and teaching. Synthese 80:121–140. [reprinted in 1998, In Matthews MR (ed) Constructivism in science education: a philosophical examination. Kluwer, Boston, MA, pp. 11–30]

Glasersfeld E von (1995) A constructivist approach to teaching. In: Steffe LP, Gale J (eds) Constructivism in education. Lawrence Erlbaum Associates, Hillsdale, NJ, pp 3–15

Glesne C, Peshkin A (1992) Becoming qualitative researchers: an introduction. Longman, White Plains, NY

Goals 2000 (1994) Education America Act. http://www.ed.gov/legislation/GOALS2000/TheAct/index.html. Accessed 16 January 2010

Goldberg N (1990) Wild mind: living the writer's life. Bantam Books, New York

Green JP, Forster G (2003) Public high school graduation and college readiness rates in the United States. Education Working Paper, with the Manhattan Institute for Policy Research (3). http://www.manhattan-institute.org/html/ewp_03.htm. Accessed 21 July 2005

Grenfeld M, James D (1998) Bourdieu and education: acts of practical theory. Falmer, Bristol, PA

Griffiths N (2002) What does that word mean? The importance of language in learning biology. In: Taylor PC, Gilmer PJ, Tobin K (eds) Transforming undergraduate science teaching: social constructivist perspectives. Peter Lang, New York, pp 69–90

Guba EG, Lincoln YS (1982) Epistemological and methodological bases of naturalistic inquiry. Educ Commun Technol: J Theory Res Dev 30(4):233–252

Guba EG, Lincoln YS (1989) Fourth generation evaluation. Sage, Newbury Park, CA

Guba NK, Lincoln YS (1994) Competing paradigms in qualitative research. In: Denzin NK, Lincoln YS (eds) Handbook of qualitative research. Sage, Thousand Oaks, CA, pp 105–117

Habermas J (1972) Knowledge and human interests (2nd ed) (trans: Shapiro JJ). Heinemann, London

Hannafin MJ, Land SM, Oliver K (1999) Open learning environments: foundations, models, and methods. In: Reigeluth C (ed) Instructional-design theories and models, 2. Erlbaum, Mahwah, NJ, pp 115–140

Hertz R (ed) (1997) Reflexivity and voice. Sage, Thousand Oaks, CA

Humerick R (2002) Effective strategies for active learning in the small chemistry classroom or laboratory. In: Taylor PC, Gilmer PJ, Tobin K (eds) Transforming undergraduate science teaching: social constructivist perspectives. Peter Lang, New York, pp 211–230

International Human Genome Sequencing Consortium (2001) Initial sequencing and analysis of the human genome. Nature 409:860–921

Janesick VJ (2000) The choreography of qualitative research design: minuets, improvisations, and crystallization. In: Denzin NK, Lincoln YS (eds) Handbook of qualitative research, 2nd edn. Sage, Thousand Oaks, CA, pp 379–400

Johnson DW, Johnson RT (1991) Joining together: group theory and group skills, 4th edn. Prentice Hall, Englewood Cliffs, NJ

Johnson DW, Johnson RT, Smith KA (1991) Cooperative learning: Increasing college faculty instructional productivity. ASHE-ERIC Higher Education Report No. 4, The George Washington University, School of Education and Human Development, Washington, DC

Jonassen DH (2000) Transforming learning with technology: beyond modernism and post-modernism or whoever controls the technology creates the reality. Educ Technol 40:21–25

Jonassen DH, Hernandez-Serrano J, Choi I (2000) Integrating constructivism and learning technologies. In: Spector JM, Anderson TM (eds) Integrated and holistic perspectives on learning, instruction, and technology. Kluwer, Dordrecht, Netherlands

Kincheloe JL (1991) Teachers as researchers: qualitative inquiry as a path to empowerment. Falmer, London

Kincheloe J (1997) Fictional formulas: critical constructivism and the representation of reality. In: Tierney WG, Lincoln YS (eds) Representation and the text: re-framing the narrative voice. State University of New York Press, Albany, NY, pp 57–79

Kovac J, Sherwood DW (2001) Writing across the chemistry curriculum: an instructor's handbook. Prentice Hall, Upper Saddle River, NJ

LaBerge S (2000) Exploring the world of lucid dreaming. Ions Noetic Sci Rev (September–November):14–19

Lather P (1986) Research as praxis. Harv Educ Rev 56(3):257–277

Lederman M, Bartsch I (eds) (2001) The gender and science reader. Routledge, New York

Lemke JL (1995) Textual politics: discourse and social dynamics. Taylor & Francis, Bristol, PA

Lemke JL (2001) Articulating communities: sociocultural perspectives on science education. J Res Sci Teach 38:296–316

Leonard WH (2000) How do college students best learn science? An assessment of popular teaching styles and their effectiveness. J Coll Sci Teach 29(6):385–388

Levi P (1984) The periodic table. Schocken Books, New York

Lewin K (1946) Action research and minority problems. J Soc Issues 2:34–46

Lincoln YS (1997) Self, subject, audience, text: living at the edge, writing in the margins. In: Tierney WG, Lincoln YS (eds) Representation and the text: re-framing the narrative voice. State University of New York Press, Albany, NY, pp 37–55

Lincoln YS, Denzin NK (2000) The seventh moment: out of the past. In: Denzin NK, Lincoln YS (eds) Handbook of qualitative research, 2nd edn. Sage, Thousand Oaks, CA, pp 1047–1065

Lincoln YS, Guba EG (2000) Paradigmatic controversies, contradictions, and emerging confluences. In: Denzin NK, Lincoln YS (eds) Handbook of qualitative research, 2nd edn. Sage, Thousand Oaks, CA, pp 163–188

Linn MC (1998) The impact of technology on science instruction: historical trends and current opportunities. International handbook of science education (Part 1). Kluwer, Boston, MA, pp 265–294

Linn MC, Burbules NC (1993) Construction of knowledge and group learning. In: Tobin K (ed) The practice of constructivism in science education. AAAS, Washington, DC, pp 91–119

Lord TR (1997) Collaborative learning. In: Siebert ED, Caprio MW, Lyda CM (eds) Effective teaching and course management for university and college science teachers. Kendall/Hunt, Dubuque, IA, pp 21–34

Macala J (2003) Must we teach as we were taught? http://www.neiu.edu/~ctc/dl_right0.htm. Accessed 7 Dec 2003

MacCallum J, Macbeth J (1996) Collaborative learning: working together in small groups [Video], (ISBN 0-86905-502-X). Murdoch University, Perth, Western Australia

Manner BM (2003) Technology in the science classroom. In: Tomei LA (ed) Challenges of teaching with technology across the curriculum: issues and solutions. Information Science, Hershey, PA, pp 90–113

Martin S (2005) Not so strange in a strange land: an autobiographical approach to becoming a science teacher in an urban high school. In: Tobin K, Elmesky R, Seiler G (eds) Improving urban science education: new roles for teachers, students, and researchers. Rowman & Littlefield, New York, pp 225–243

Matthews CK, van Holde KE (1996) Biochemistry, 2nd edn. Benjamin/Cummings, Menlo Park, CA

Mattson SA (1997) When world views collide: a study of interdepartmental collaboration to develop a biology course for preservice elementary school teachers. Unpublished doctoral dissertation, Florida State University, Tallahassee, FL

Mattson S (2002) What it means to achieve: negotiating assessment in a biology course. In: Taylor PC, Gilmer PJ, Tobin K (eds) Transforming undergraduate science teaching: social constructivist perspectives. Peter Lang, New York, pp 245–274

McDonald JB, Gilmer PJ (eds) (1997) Science in the elementary school classroom: portraits of action research. SERVE, Tallahassee, FL. http://www.chem.fsu.edu/~gilmer/monographs.html. Accessed 15 July 2009

Mezirow J & Associates (2000) Learning as transformation: critical perspectives on a theory in progress. Jossey-Bass, San Francisco, CA

Muire C, Gilmer PJ, Nazarian M (1999) Web-based technology in a constructivist community of learners. Br J Educ Technol 30:65–68

Mulholland J, Wallace J (2000) Restorying and the legitimation of research texts. Presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA

National Center for Educational Statistics (n.d.). Trends in international mathematics and science study. http://nces.ed.gov/timss/results07_science07.asp. Accessed 29 Jan 2009

National Research Council (NRC) (1996) National science education standards. National Academy, Washington, DC. http://books.nap.edu/catalog.php?record_id=4962

National Research Council (NRC) (1997) Science teaching reconsidered: a handbook. National Academy, Washington, DC. http://books.nap.edu/catalog/6482.html

National Research Council (NRC) (1999) Transforming undergraduate education in science, mathematics, engineering, and technology. National Academy, Washington, DC. http://books.nap.edu/catalog/6453.html

National Research Council (NRC) (2001) Educating teachers of science, mathematics, and technology. New practices for the new millennium. Committee on Science and Mathematics Teacher Preparation. National Academy, Washington, DC. http://www.nap.edu/openbook.php?isbn=0309070333

National Research Council (NRC) (2003) Evaluating and improving undergraduate teaching in science, technology, engineering, and mathematics. National Academy, Washington, DC. http://www.nap.edu/openbook.php?isbn=0309072778

National Science Foundation (NSF) (1996) Shaping the future: New expectations for undergraduate education in science, mathematics, engineering, and technology. National Science Foundation, Arlington, VA. http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf96139

National Science Teachers Association (NSTA) (1998) Standards for science teacher preparation. Originally retrieved on September 7, 1998, in draft form from, http://www.iuk.edu/faculty/sgilbert/draftstand.htm. http://www.nsta.org/professionals. Accessed 5 Aug 2002

Nobel Prize (1980) The Nobel Prize Internet archive (Chemistry). http://www.nobelprizes.com/nobel/nobel.html. Accessed 31 Aug 2003

Novitt-Moreno AD (1995) How your brain works. Ziff-Davis, Emeryville, CA

O'Sullivan DW, Copper CL (2003) Evaluating active learning: a new initiative for a general chemistry curriculum. J Coll Sci Teach 32(7):448–452

Ortiz-Taylor S (1998) Coachella. University of New Mexico Press, Albuquerque, NM

Paul R, Elder L (2007) Miniature guide to critical thinking: concepts and tools. Foundation for Critical Thinking, Dillon Beach, CA

Piaget J (1967) Biologie et connaissance. Gallimard, Paris

Piaget J (1970) Science of education and the psychology of the child. Orion, New York

Polkinghorne DE (1997) Reporting qualitative research as practice. In: Tierney WG, Lincoln YS (eds) Representation and the text: re-framing the narrative voice. State University of New York Press, Albany, NY, pp 3–22

QSR (1997) Software for Qualitative Data Analysis 4.0 for Macintoshes. Qualitative Solutions & Research Pty Ltd., Melbourne, Victoria, Australia

Richardson L (1994) Writing: a method of inquiry. In: Denzin NK, Lincoln YS (eds) Handbook of qualitative research. Sage, Thousand Oaks, CA, pp 516–529

Richardson L (1997) Fields of play: constructing an academic life. Rutgers University Press, New Brunswick, NJ

Richardson L (2000) Writing: a method of inquiry. In: Denzin NK, Lincoln YS (eds) Handbook of qualitative research, 2nd edn. Sage, Thousand Oaks, CA, pp 923–948

Roth W-M (1993) Construction sites: science labs and classrooms. In: Tobin K (ed) The practice of constructivism in science education. Lawrence Erlbaum, Hillsdale, NJ, pp 145–170

Roth W-M, Tobin K (2002) College physics teaching: from boundary work to border-crossing and community building. In: Taylor PC, Gilmer PJ, Tobin K (eds) Transforming undergraduate science teaching: social constructivist perspectives. Peter Lang, New York, pp 145–180

Roth W-M, McRobbie CJ, Lucas KB (1998) Four dialogues and metalogues about the nature of science. Res Sci Educ 28(1):107–118

Scantlebury K, Gilmer PJ, Jones L (2001) A snake in the nest or in the snake's nest? Equity praxis and pedagogy within the sciences. Paper presented at the annual meeting of the National Association for Research in Science Teaching, St. Louis, MO

Schaller JS, Tobin K (1998) Quality criteria for the genres of interpretive research. In: Malone JA, Atweh BA, Northfield JR (eds) Research and supervision in mathematics and science education. Lawrence Erlbaum Associates, Mahwah, NJ, pp 29–60

Schön DA (1983) The reflective practitioner: how professionals think in action. Basic Books, New York

Third International Mathematics and Science Study (1995) TIMSS 1995 Home Page. http://timss.bc.edu/timss1995.html. Accessed 11 July 2004

Trends in International Mathematics and Science Study (1999) National Center for Education Statistics. TIMSS 1999 results. http://nces.ed.gov/timss/results.asp. Accessed 1 July 2007

Trends in International Mathematics and Science Study (2003) National Center for Education Statistics. TIMSS 2003 results. http://nces.ed.gov/timss/results03.asp. Accessed 1 July 2007

Trends in International Mathematics and Science Study (2007) National Center for Education Statistics. TIMSS 2007 results. http://nces.ed.gov/timss/results07.asp. Accessed 15 July 2009

Sewell WH (1992) A theory of structure: duality, agency, and transformation. Am J Sociol 98:1–29

Sewell WH (1999) The concept(s) of culture. In: Bonnell VE, Hunt L (eds) Beyond the cultural turn: new directions in the study of society and culture. University of California Press, Berkeley, CA, pp 35–61

Seymour E (1992) 'The problem iceberg' in science, mathematics, and engineering education: student explanations for high attrition rates. J Coll Sci Teach 21:230–238

Shepherd LJ (1993) Lifting the veil: the feminine face of science. Shambhala, Boston, MA

Shibley IA Jr, Zimmaro DM (2002) The influence of collaborative learning on student attitudes and performance in an introductory chemistry laboratory. J Chem Educ 79(6):745–748

Siebert ED (1997) Linking science discoveries to teaching. In: Siebert ED, Caprio MW, Lyda CM (eds) Effective teaching and course management for university and college science teachers. Kendall/Hunt, Dubuque, IA, pp 113–122

Siebert ED, Caprio MW, Lyda CM (eds) (1997) Effective teaching and course management for university and college science teachers. Kendall/Hunt, Dubuque, IA

Sienko MJ, Plane RA (1961) Chemistry, 2nd edn. McGraw-Hill Book Co., New York

Smist J (2004) Small groups are worth the effort. In: Bunce DM, Muzzi CM (eds) Survival handbook for the new chemistry instructor. Pearson Prentice Hall, Upper Saddle River, NJ, pp 97–104

Solomon J (1987) Social influences on the construction of pupils' understanding of science. Stud Sci Educ 14:63–82

Spiegel SA, Collins A, Lappert J (eds) (1995) Action research: perspectives from teachers' classrooms. SERVE, Tallahassee, FL. http://www.eric.ed.gov/ERICWebPortal/custom/portlets/recordDetails/detailmini.jsp?_nfpb=true&_&ERICExtSearch_SearchValue_0=ED403138&ERICExtSearch_SearchType_0=no&accno=ED403138

Springer L, Stanne MEE, Donovan SS (1999) Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: a meta-analysis. Rev Educ Res 69:21–51

Stern J (1991) Making shapely fiction. Dell, New York

Sunal DW, Wright EL, Day JB (2004) Reform in undergraduate science teaching for the 21st century. IAP Information Age, Greenwich, CT

Sweeney AE, Bula OA, Cornett JW (2001) The role of personal practice theories in the professional development of a beginning high school chemistry teacher. J Res Sci Teach 38(4):408–441

Swidler A (1986) Culture in action: symbols and strategies. Am Sociol Rev 51:273–286

Taylor P (1993) Collaborating to reconstruct teaching: the influence of researcher beliefs. In: Tobin K (ed) The practice of constructivism in science education. Lawrence Erlbaum, Hillsdale, NJ, pp 267–298

Taylor P (1998) Constructivism: value added. In Fraser BJ, Tobin KG (eds) International handbook of science education. Part 2. Kluwer, Dordrecht, The Netherlands, pp 1111–1123

Taylor PC (2002) On being impressed by college teaching. In: Taylor PC, Gilmer PJ, Tobin K (eds) Transforming undergraduate science education: social constructivist perspectives. Peter Lang, New York, pp 3–43

Taylor PC, Timothy JF (2000) LatnemirepXe represenTation: a crOss-culTural research aLLiance in a …a…a…postmodern(ist?) climate. Presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA

Taylor PC, Williams M (1993) A critical constructivist view on reforming the traditional high school mathematics classroom. Paper presented at the annual conference of the Australian Association for the Educational Research, Fremantle, Western Australia

Taylor PC, Gilmer PJ, Tobin K (eds) (2002) Transforming undergraduate science education: social constructivist perspectives. Peter Lang, New York

Thompson T, Flick L, Gummer E (2003) Science education meets engineering: a case study in collaboration. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Philadelphia, PA

Tierney WG (1997) Lost in translation: time and voice in qualitative research. In: Tierney WG, Lincoln YS (eds) Representation and the text: re-framing the narrative voice. State University of New York Press, Albany, NY, pp 23–36
Tobias S (1990) They're not dumb, they're different: stalking the second tier. Research Corporation, Tucson, AZ
Tobias S (1992) Revitalizing undergraduate science: why some things work and most don't. Research Corporation, Tucson, AZ
Tobin K (1997) The teaching and learning of elementary science. In: Phye GD (ed) Handbook of academic learning: construction of knowledge. Academic, Orlando, FL, pp 369–403
Tobin K (1998) Qualitative perceptions of learning environments on the World Wide Web. Learn Environ Res 1:139–162
Tobin K (2000) Becoming an urban science educator. Res Sci Educ 30:89–106
Tobin K (2002) Learning to teach science using the Internet to connect communities of learners. In: Taylor PC, Gilmer PJ, Tobin K (eds) Transforming undergraduate science education: social constructivist perspectives. Peter Lang, New York, pp 323–348
Tobin K, Tippins D (1993) Constructivism as a referent for teaching and learning. In: Tobin K (ed) The practice of constructivism in science education. AAAS, Washington, DC, pp 3–21
Tobin K, Tippins DJ, Gallard A (1994) Teachers as learners in the reform of science education. In: Gabel D (ed) Handbook for research on science teaching. Macmillan, New York, pp 45–93
Truchan L, Gurria G, Loacker G (1997) In Siebert ED, Caprio MW, Lyda CM (eds) Effective teaching and course management for university and college science teachers. Kendall/Hunt, Dubuque, IA, pp 123–134
University of Virginia (2007) Cooperative/collaborative learning for active student involvement. http://trc.virginia.edu/Publications/Teaching_Concerns/Fall_1992/TC_Fall_1992_Cooperative_Collaborative.htm. Accessed 20 July 2009
Venter JC et al (2001) The sequence of the human genome. Science 291:1304–1351
Vico G (1710) De antinquissima Italorum sapienta (Italian trans: Pomodoro FS), Stamperia de' Classica Latini, Naples, 1858
Vygotsky LS (1962) Thought and language. MIT Press, Cambridge, MA
Vygotsky LS (1981) The genesis of higher mental functions. In: Wretch JV (ed) The concept of activity in Soviet psychology. Sharpe, Armonk, NY, pp 144–188
Wertsch JV (1998) Mind as action. Oxford University Press, New York
White HB (2002) Confronting undergraduate dualism in problem-based learning. In: Taylor PC, Gilmer PJ, Tobin K (eds) Transforming undergraduate science teaching: social constructivist perspectives. Peter Lang, New York, pp 231–243
Wikipedia (2009) http://www.wikipedia.org/. Accessed 14 July 2009
Wilber K (2000) A theory of everything: an integral vision for business, politics, science, and spirituality. Shambhala, Boston, MA
Williams MC (2002) Dreams in computing education: a heuristic self-study. In: Taylor PC, Gilmer PJ, Tobin K (eds) Transforming undergraduate science education: social constructivist perspectives. Peter Lang, New York, pp 395–420
Wright JC (1996) Authentic learning environment in analytical chemistry using cooperative methods and open-ended laboratories in large lecture courses. J Chem Educ 73(9):827–832
Wright EL, Sunal DW (2004) Reform in undergraduate science classrooms. In: Sunal DW, Wright EL, Day JB (eds) Reform in undergraduate science teaching for the 21st century. Information Age, Greenwich, CT, pp 33–51
Wright JC, Millar SB, Kosiuk SA, Penberthy DL, Williams PH, Wampold BE (1998) A novel strategy for assessing the effects of curriculum reform on student competence. J Chem Educ 75:986–992
Wright EL, Sunal DW, Day JB (2004) Improving undergraduate science teaching through educational research. In: Sunal DW, Wright EL, Day JB (eds) Reform in undergraduate science teaching for the 21st century. Information Age, Greenwich, CT, pp 1–11

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