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.

P.J. Gilmer, *Transforming University Biochemistry Teaching Using Collaborative Learning and Technology: Ready, Set, Action Research!*, DOI 10.1007/978-1-4020-4981-1_2,

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.

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[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

[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.

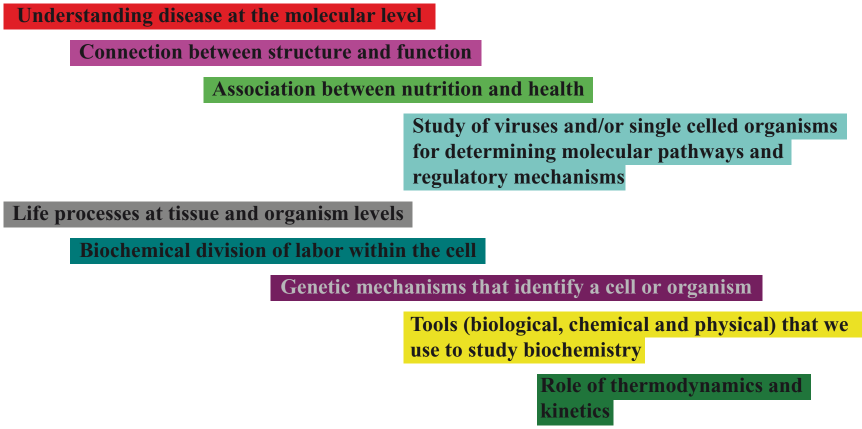

Fig. 2.1 Common strands in biochemistry (the nine strands that I hoped my students would be able to weave together to construct an understanding of the basic processes of biochemistry)

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.

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

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Transforming University Biochemistry Teaching Using
Collaborative Learning and Technology
Ready, Set, Action Research!
Gilmer, P.J.
2010, XV, 208 p., Hardcover
ISBN: 978-1-4020-4980-4