2006-06-14

Active Learning in a Large Enrollment Introductory Biology Class: Problem Solving, Formative Feedback, and Teaching as Learning

Diane Flint Robison
Brigham Young University - Provo

ACTIVE LEARNING IN A LARGE ENROLLMENT INTRODUCTORY

BIOLOGY CLASS: PROBLEM SOLVING, FORMATIVE FEEDBACK,

AND TEACHING AS LEARNING

by

Diane F. Robison

A dissertation submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Department of Instructional Psychology & Technology

Brigham Young University

June 1, 2006

BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

of a dissertation submitted by

Diane F. Robison

This dissertation has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

Date	Richard R Sudweeks, chair
Date	John Bell
Date	Charles Graham
Date	David D Williams
Date	Stephen Yanchar

BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the dissertation of Diane F. Robison in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

Date

Richard R Sudweeks
Chair, Graduate Committee

Accepted for the Department

Richard R Sudweeks
Graduate Coordinator

Accepted for the College

K. Richard Young
Dean, McKay School of Education

ABSTRACT

ACTIVE LEARNING IN A LARGE ENROLLMENT INTRODUCTORY BIOLOGY CLASS: PROBLEM SOLVING, FORMATIVE FEEDBACK, AND TEACHING TO LEARN

Diane Robison

Department of Instructional Psychology and Technology

Doctor of Philosophy

The purpose of this study was to take a case study approach to exploring student learning experiences in a large enrollment introductory biology class. Traditionally such classes are taught through the lecture method with limited instructor-student interaction and minimal student-centered learning (Lewis & Woodward, 1984; Wulff, Nyquist, & Abbott, 1987). Biology 120 taught at Brigham Young University winter semester 2006 by John Bell was chosen as the case for the study due to its large enrollment (263) and its innovative pedagogy. In the classroom, students applied their learning through a variety of student-centered activities including solving problems, discussing concepts with peers, drawing diagrams, and voting. Outside of the classroom students were assigned, in addition to reading from the textbook and homework problems, to teach each week's concepts to another student. Formative feedback was emphasized in classroom activities and through a unique assessment system. Students took self-graded weekly assessments designed to provide regular and timely feedback on their performance. The only

traditionally-graded assessment was the final exam. Students were expected to understand, apply, and think analytically with their knowledge and this was reflected in the assessment items. Student learning, as measured by a pretest and a posttest, increased from an average of 44% correct to 77% correct on a set of 22 items common to both tests. Responses to pre and post-surveys indicated that students increased in their orientation towards understanding as apposed to grades during the course. Qualitative data suggested that during the course many students deepened their learning approach and increased in feelings of personal control over their learning.

ACKNOWLEDGMENTS

I would like to express my appreciation to the faculty and staff of the Instructional Psychology and Technology Department of the David O. McKay School of Education at Brigham Young University for the excellent teaching and support given to me during my graduate studies. Special thanks must go to my advisory committee members and most particularly to my committee chair, Dr. Richard Sudweeks, whose exactness and dedication have elevated my work. I also appreciate the help and support of Dr. John Bell, a caring and innovative teacher, for opening his classroom to my research. Thank you to his students who so willingly shared their learning experiences with me. Above all, I must thank my good husband, Reid Robison, for supporting, gently encouraging, and even becoming my secretary and housekeeper as I spent many long hours away from our family researching and writing this dissertation.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Students, as the consumers of education, have meaningful opinions about their experiences. The following statements are taken from a description of typical college student concerns (Fink, 2003, pp. 4-5):

1. Courses are uninteresting.
2. We just sit and take notes and then cram for exams.
3. There is little value in what we learn.
4. Instructors rely too much on lectures.
5. There is too little hands-on learning.
6. Textbooks keep getting larger and larger.

These statements contrast sharply with the following comments (from Student Ratings Survey, Brigham Young University, April 2006):

1. This course really taught me how to analyze an experiment and to think like a scientist. This will be beneficial for all of my future science classes and has already proved beneficial in my research for an English class.

2. I don't enjoy biology so much; it is difficult for me to grasp, but this class made it a lot more understandable . . . I've never had a teacher so dedicated to the success of his students. He let us know exactly where we needed to be and gave us everything he could to help us attain the level that we wanted. The results from this class are all based on personal effort and I really feel that my grade will match the amount of effort that I have put forth. It was an exceptional class. Class time was essential. I learned, applied and solidified a

lot during class time. This is how all classes should be. The structure was perfect. The environment was comfortable. The teacher was willing.

3. Knows how to effectively teach students and help students to learn how to learn: long term learning not just rote memory.
4. He did a very fine job of explaining difficult concepts. His teaching methods are different than any other class, however, I have found them to be most effective
5. Finally . . . a teacher who GETS IT! If professors have anything wrong with their class, you can be pretty sure I'll notice it, but I struggle to think of a way this class could be improved.

The second set of comments was taken from a large enrollment introductory biology class taught by John Bell during winter semester 2006 at Brigham Young University. Students were mostly positive about their experiences in that course. Seventy-five percent of student comments were similar to those listed above. The contrast between these two sets of comments provokes a question: what is it about the students' experiences in Bell's course that engendered such positive responses? I feel that this question is worthy of careful consideration.

Teaching in higher education has always been, and continues to be, a challenging process. Today's college teachers are faced with ever-growing domains of conceptual knowledge plus the challenge to produce students who learn and retain that knowledge, think critically, and improve in their self-efficacy and other affective qualities. In addition, many students are expected to achieve such outcomes in large enrollment classes. Educational research on pedagogies that cope successfully with these challenges is important.

Teachers in the sciences tend to share the challenges described above. According to William Leonard, editor of the Research and Teaching section in the *Journal of College Science Teaching* has asserted that, “The vast majority of college students are not successfully learning science” (2000, p. 8). Concerns such as this have fostered a shift, on the part of science teachers, from a focus on teaching a collection of facts to be memorized towards stimulating the development of higher-order thinking skills (Chin, 1993; Mintzes & Wandersee, 1998; Taconis, Ferguson-Hessler, & Broekkamp, 2001). This shift involves a concurrent redirection in the teaching process from the transmission of knowledge through lecture, text, and demonstration towards the facilitation of active scientific inquiry in the classroom. As Halpern (1992) stated

> Students at all levels of education are expected to acquire information and recall it at some later time, discover and solve novel problems, evaluate the strength and nature of evidence, use reasons to support conclusions, recognize propaganda and other persuasive techniques, consider likely outcomes of actions, and question bogus claims. Yet, they are rarely taught how. (p. 5)

In order to accomplish this directive, teachers need support from the research community. According to Kuhn, Amsel, and Loughlin (1988)

> Science educators have long been in agreement that a major goal of science education ought to be fostering skills of scientific thinking. Implementation of this goal, however, has been constrained by the very limited body of research data identifying the specific nature of such skills. (p. 1)

Changing teaching objectives and practices is a complex process and pedagogical traditions can be surprisingly tenacious. In an effort to foster reform in education the National Research Council (NRC) commissioned *How People Learn: Bridging Research and Practice*. The authors of that publication (Donovan, Bransford, & Pellegrino, 1999) proposed a research agenda made up of five goals. Two of those goals are

1. Conduct research in terms that combine the expertise of researchers and the wisdom of practitioners.
2. Extend the frontier of learning research through more intensive study of classroom practice. (p. 3)

The authors also recommended a number of specific areas of focus including the following:

1. Research on formative assessment.
2. Investigation of successful and creative educational practice, particularly using a case study approach in order to "investigate the principles of learning that underlie successful educational experiments." (p. 59)

Black and Wiliam (1998) expressed a similar need after conducting a meta-analysis of the literature on formative assessment:

> What teachers need is a variety of living examples of implementation, as practiced by teachers with whom they can identify and from whom they can derive the confidence that they can do better. They need to see examples of what doing better means in practice. (p. 146)

They also indicated that

> There is a body of firm evidence that formative assessment is an essential component of classroom work and that its development can raise standards of achievement. We know of no other way of raising standards for which such a strong prima facie case can be made. (p. 148)

I address these mandates in this dissertation. As suggested by the authors cited above, this research is based in classroom practice, is conducted in collaboration with practitioners, and will yield a description of a practical and context-based example of pedagogical practice that incorporates formative assessment.

Background

Dr. John Bell, a biology professor at Brigham Young University (BYU) developed a set of teaching practices focused on helping biological science students acquire conceptual knowledge, scientific-thinking skills, and positive affect. A key aspect of his pedagogy is the use of active learning and problem solving combined with frequent formative assessment: a system he refers to as *formative format* instruction.

Bell has collaborated with others to evaluate and improve his teaching over the years and found that his formative format teaching practices, when compared to other pedagogies he used in the past, produced superior performance and improved affective outcomes in students. A study was conducted on the use of the formative format pedagogy in an upper division cellular biology course (Biology 320) at Brigham Young University over a period of three years. Student performance (measured by a problem-based final exam) and affective outcomes (measured by a survey) improved during three years of fine-tuning the course and were consistently better than outcomes from the same course taught by Bell using a traditional assessment format (Kitchen, E., King, S. H., Robison, D. F., Sudweeks, R. R., Bradshaw, W. S., & Bell, J. D., in press). Positive affect and student performance were consistently high under the formative format in spite of the challenging circumstances, common to so many instructors in higher education, of large class size (100-250 students) and vast amounts of material to be covered.

Bell teaches a large enrollment introductory biology class, but he still promotes deep and active student participation in the learning process through a pedagogy based on interactive classroom activities and the regular and frequent use of authentic biology problems as both learning and assessment tools. Students are expected to learn and understand each week's assigned biology concepts before coming to class and then teach those concepts to a partner outside of class. The majority of class time is devoted to activities that require students to use their knowledge, usually through solving problems, followed by feedback and reflection on ways to improve. These practices are combined with an inventive assessment system. Approximately once per week, students participate in cumulative assessments designed to evaluate their emerging conceptual knowledge and scientific thinking skills. These assessments are similar to short exams but the results are used formatively rather then summatively. Students grade their assessments with partners and then spend time in class determining errors, misconceptions, or gaps in skill development. They leave each assessment session with a plan for improvement.

The success of this approach in the earlier upper division cellular biology course led Bell to adapt the formative format approach to his current teaching assignment, Biology 120, an introductory course required by students majoring in the biological sciences at BYU. Preliminary feedback from classes taught during the fall term suggests that the formative format set of strategies transferred well to the new content domain and to less experienced students. In response to the calls by the NRC and others detailed above to study cases of successful classroom practice and the use of formative feedback, I explored this example of successful teaching and learning practice.

Purpose

The overall objective of this research was to describe, explore, and share the teaching practices and associated student experiences that constitute the formative format Biology 120 course. This research contributes to theory in two ways. First, much educational research begins with established theoretical constructs and uses experimental or quasi-experimental designs to systematically evaluate teaching practices (treatments) (Entwistle, 2000a). These studies give information about general student responses to a pedagogy based on operationalized measures of outcomes, but they give little information about individual students experiences and their context. Relatively few studies have been done to understand students' experiences from their perspective. This research takes such a perspective by exploring student learning using a case study ethnographic approach. This open, qualitative, student-centered research supplements theory generated by the more abstracted information from experimental studies.

Second, the teaching practices that constitute the formative format pedagogy are of current interest in educational research. As mentioned above, the NRC and other scholars have called for research on formative assessment (see for example, Bass & Glaser, 2004; Black & Wiliam, 1998; Donovan, Bransford et al., 1999; Earl, 2003;). The effectiveness of problem based learning as a structured curriculum originating in medical education has been debated for years (Colliver, 2000; Dochy, Segers, Van den Bossche, & Gijbels, 2003; Farrow & Norman, 2003; Gijbels, Dochy, Van den Bossce, & Segers, 2005; Gijselaers, 1996) and the use of problem solving as a component of teaching is also of interest (Ericsson & Hastie, 1994; Fink, 2003; Lyle & Robinson, 2001; Nickerson, 1995; Taconis et al., 2001). Affective characteristics, often unexplored learning outcomes in the past, tend to be formalized as learning objectives in today's classrooms. This component of learning has engendered a substantial amount of current research (see for example Beghetto, 2004; Dweck, Mangels & Good, 2004; Entwistle, 2000a; Linnenbrink & Pintrich, 2004; McCune et al., 2002). This research took an integrated and student-centered look at these current issues of interest and may provide support, clarification, or contradiction of current theory.

Objectives

This open and exploratory research was based upon the ethnographic research model. I explored the culture of student learning within the course and allowed themes and patterns to emerge that contributed to an understanding of the teaching/learning process. But there are certain aspects of teaching/learning that served as foci either because they are prevalent in the literature or of importance to the instructor. They are: (a) formative assessment, (b) problem solving, (c) self-efficacy towards studying and learning, (d) learning versus grade orientation, and (e) learning/study approaches. The following research questions emerged from these areas of focus:

1. What is the nature of the formative format pedagogy and its context in the Biology 120 course taught at BYU winter term, 2006?
2. What is the nature of students' learning experiences in this course?
3. In what ways do students improve or extend their biology-related knowledge and skills during the course?

4. According to students, what components of the course tend to foster this improvement, if any?
5. What opinions do students have about the advantages and disadvantages of the formative assessment pedagogy?
6. How, and to what extent, do students' approaches to learning change during the course?
7. How, and to what extent, do students' attitudes towards learning change during the course?
8. How, and to what extent, does students' self-efficacy towards studying and learning biology change during the course?
9. In what ways do the responses to the above questions vary by individual students or subgroups of students?
10. What are the implications for theory?

Chapter 2: Review of the Literature

Because of the broad and exploratory nature of this research, there are a number of weighty topics that are pertinent. The extensive nature of the literature relating to these topics necessitates a focused selection of sources to include. I concentrated on the most current empirical research as well as research reviews and meta-analyses. There are five topics that pertain to student outcome goals:

1. Conceptual knowledge
2. Thinking skills
3. Self-efficacy
4. Learning goals
5. Learning approaches

Three topics pertain to the teaching practices that form the foundation of the formative format pedagogy:

1. Problem solving
2. Formative assessment
3. Teaching as learning

After a general discussion of literature on teaching large lecture style classes, I reviewed current literature relating to each of these eight topics.

Teaching Large Classes

Large enrollment classes are offered at many universities in order to meet high student demand with limited faculty resources (Hensley & Oakley, 1998). Often it is the introductory level classes that are the largest. "It is a sad commentary on our universities that the least engaging class size and the least involving pedagogy is often foisted upon the students at the most pivotal time of their undergraduate careers: when they are beginning college." (Cooper & Robinson, 2000, p. 7)

The challenges of teaching large enrollment classes are numerous. Geske (1992) listed five drawbacks:

1. The distance between instructor and many students is too great.
2. It is almost impossible to break into small discussion groups.
3. There is an impersonal atmosphere.
4. Individual participation is unwieldy.
5. Instructors become remote and inaccessible authority figures at the front of the class.

A study by Carbone and Greenberg (1998) identified six student concerns about large classes:

1. Limited interaction with faculty members (in and out of class)
2. Lack of structure in lectures
3. Lack of or poor discussion sections
4. Insufficient contact with teaching assistants
5. Inadequate of classroom facilities and environment
6. Lack of frequent tested or graded assignments

Wulff, Nyquist, and Abbot (1987) found that "Foremost among the dimensions of large classes that hindered students' learning was the lack of instructor-student interaction and with opportunities for questions and discussion" (p. 21). Cooper and Robinson (2000) add that students are rarely asked to process their learning and tests often call for low levels of student understanding.

Instruction in large classes generally takes the form of lecture. "It is no accident that these large classes are commonly referred to as 'large lecture' or 'large lecture sections,' for faculty members generally teach the way they were taught in these settings – via the lecture" (Cooper & Robinson, 2000, p. 7). Lewis and Woodward (1984) observed 19 large (100 students and larger) classes at the University of Texas at Austin and found that instructors lectured an average of 80-95% for each class session. Desirable student learning outcomes such as retention, transfer, and motivation may be hindered in lecture style classes. According to Cooper and Robinson (2000),

> In order for students to gain mastery of academic content they need to move it into long-term memory and embed it in their own cognitive structures. For this to happen, they need to actively use the material they are learning and construct their own understanding of it, not simply hear about it or read about it in a lecture. (p. 10)

Cooper and Robinson (2000) suggest that despite the difficulties outlined above, there are instructors who are implementing and evaluating unique methods to improve students' experiences in large classes:

> Many faculty members simply cannot conceive of large classes being anything but a 100 percent lecture-and-test-driven routine. But other strategies are possible.

> Many educational pioneers are working to make large classes small by systematically creating occasions for students to spend more time together in active, meaningful learning and thinking. (p.14)

The following are six examples of innovative instructional approaches designed to overcome some of the challenges of large class size:

1. In an American Government class, students were assigned to write opinion papers on a series of controversial topics taken from their text. They were then divided into groups and assigned to prepare to debate one side of one of those issues. They worked with TAs to prepare and presented the debates during class when the issue was covered (Hensley & Oakley, 1998).
2. Instructors made a regular practice of calling on students who did not have their hands up by name (involuntary participation) to answer questions in an introductory psychology class (Martino & Sala, 1996).
3. After discussing a topic in class, advertising students paused to write three-minute theses (Geske, 1992).
4. Groups of students role played guests on a talk show discussing issues relevant to their advertising class (Geske, 1992).
5. When a lecture was short, an instructor would finish the class with a few minutes of a trivia type game (Geske, 1992).
6. After talking about an issue or viewing a video advertising students were assigned to write down their reactions in a three-minute thesis (Geske, 1992).

Conceptual Knowledge

Anderson and Krathwohl (2001) defined conceptual knowledge by placing it within a knowledge dimension taxonomy. They identified four categories of knowledge:

1. Factual knowledge (basic elements students must know)
2. Conceptual knowledge (interrelationships among the basic elements)
3. Procedural knowledge (how to do something)
4. Metacognitive knowledge (knowledge of one's own cognition)

They also identified four subcategories within the conceptual knowledge category:

1. Knowledge of classifications and categories
2. Knowledge of principles and generalizations
3. Knowledge of theories, models, and structures

Clearly, conceptual knowledge is an essential target in science education, but in order to be retrieved and applied it must be organized and accessible. In his classic book on problem solving titled *How to Solve It*, Polya (1973) stated

> A well-stocked and well-organized body of knowledge is an asset to the problem solver. Good organization which renders the knowledge readily available may be even more important than the extent of the knowledge. (p. 73)

Piburn (1993) found that knowledge is a significant predictor of academic achievement in the domain of science. He conducted a quantitative synthesis of multivariate studies in science education in order to form a model of achievement and recommend instructional strategies. He found that variance in performance was predicted by spatial visualization and verbal ability (beyond that shared with general intelligence) as well as cognitive ability, scientific reasoning, and prior knowledge. Quantitative ability was not uniquely separate from cognitive ability. Domain-specific declarative and procedural knowledge were important predictors of achievement (22% of variance accounted for). Also important were ability variables (27%) and neo-Piagetian variables (21%). These results suggest a model for scientific achievement similar to Piburn's (1993) description of the contemporary view of expertise:

> General intelligence, although a factor, is surprisingly unimpressive as a predictor of scientific achievement, as it is of other forms of outstanding performance. On the other hand, content-specific background knowledge, both procedural and declarative, emerges as a more decisive factor in predicting achievement than has been previously demonstrated. (p. 21)

Silver and Marshall (1990) presented a constructivist view of conceptual understanding in their summary of research on mathematical and scientific problem solving:

> Designers of instruction will need to attend to the underlying organization of knowledge that is constructed by learners, to the preexisting constructions the learner brings to the instructional setting, and to the instructional conditions and experiences that need to be provided to optimize learning. (p. 266)

The question is: how do we create organized and accessible knowledge? Silver and Marshall make three suggestions:

1. Identification of misconceptions: Instructors should be aware of common misconceptions in their field and address them in instruction.

2. Promotion of pattern recognition: Experts tend to recognize patterns in their domains. This is exemplified in DeGroot's oft-cited study on expert chess players (DeGroot & Gobet, 1996). Experts are superior in recognizing meaningful arrangements rather than random patterns of information. Explicit attention to patterns associated with typical science problems could assist students in developing pattern recognition skills.
3. Focus on the underlying knowledge structure: Knowledge should be well organized and readily available for retrieval. Efficient retrieval of knowledge may depend on how it is organized in the long-term memory. Schema (abstractions of concepts or phenomena consisting of conceptual and procedural information) development is an important aspect of knowledge structures. Development may be fostered by experiences with numerous examples of the concept involved. Students tend to perform better on problem-solving tasks when they are taught in a hierarchical manner where relationships between concepts are highlighted. This may relate to the development of an organized knowledge base.

The ability to solve previously unencountered problems is evidence of conceptual understanding. "Problem solving success is the ultimate test" (Mintzes, Wandersee, & Novak, 1998, p. 345). Problem solving, in the context of the science classroom, can be loosely defined as those activities that require students to apply their knowledge in a concrete way. There is discussion in the literature regarding the relative value of conceptual knowledge and problem-solving skills. It is widely accepted that students need both skills and a knowledge base in order to think analytically and successfully solve problems but there is controversy regarding the level of interdependence between these two domains.

Perkins and Salomon (1989) composed a historical sketch of the arguments between a generalist (domain-independent skills) position and a specialist (domain dependent knowledge) position. They proposed a synthesis of these viewpoints and based their conclusion on empirical studies. They used Polya (1973) as an example of the earlier generalist viewpoint. Later studies, such as one on expert and novice chess players, catalyzed a shift towards a specialist position due to its portrayal of experts' ability to reason with chunks of information on chess piece configurations (DeGroot & Gobet, 1996). Perkins and Salomon (1989) hypothesized that expert chess players' depth of content knowledge allowed them to develop successful problem-solving (chess-playing) strategies. These chess experiments inspired similar exploration in other domains resulting in the development by Perkins and Salomon (1989) of three characteristics of problem-solving expertise:

1. A large knowledge base of domain-specific patterns
2. Rapid recognition of situations where these patterns apply
3. Reasoning that moves from such recognition directly toward a solution by working with patterns (forward reasoning). (p. 4)

But, does this mean there is no value in knowing general problem-solving strategies? Or, as Salomon and Perkins put it, "So, are cognitive skills context bound?" (1989, p. 8). Their answer was, "yes and no." They criticized early studies on general problem-solving skills for overlooking the need for a rich knowledge base and promoted an interdependence view of these two concepts. "To be sure, general heuristics that fail to make contact with a rich, domain-specific knowledge base are weak" (p. 8). At the same time they criticized the strictly specialist view claiming that "when a domain-specific knowledge base operates without general heuristics, it is brittle – it serves mostly in handling formulaic problems" (p. 9). Their synthesis view highlights the need for problem-solving strategies to be tied to, and firmly based in, a well-organized content domain.

This synthesis view is supported by Taconis et al. (2001) who reviewed the literature on scientific problem solving. They conducted a rigorous qualitative review and quantitative meta-analysis of 22 articles containing 40 experiments. They found that the construction of an adequate knowledge base was an important variable influencing problem-solving performance. Focus on strategic knowledge alone had a negative effect. They identified four types of knowledge necessary to solve problems:

1. Strategic knowledge of approach and methods
2. Situational knowledge needed to classify and problem and to select declarative knowledge needed for the solution
3. Declarative knowledge of facts, principles, and laws of the discipline for drawing conclusions about the situation and planning and executing the solution
4. Procedural knowledge for applying declarative knowledge in executing the plan

They also identified important skills:

1. General problem-solving skills such as analyzing, planning, and doing calculations

2. Skills specific to science problems such as scientific thinking skills and proportional reasoning
3. Skills in building adequate mental representations out of the schemata available

Thinking Skills

Anderson and Krathwohl's (2001) six components of the cognitive process dimension based on Bloom's taxonomy provide a foundation for understanding thinking skills:

1. Remember (retrieve knowledge from long-term memory)
2. Understand (construct meaning)
3. Apply (carry out or use a procedure)
4. Analyze (break material into its constituent parts and determine how the parts relate to one another)
5. Evaluate (make judgments based on criteria)
6. Create (put elements together to form a coherent or functional whole)

Thinking skills are based upon remembering and understanding and they encompass the cognitive processes of analyzing and evaluating. Students with thinking skills are better able to take what they have learned and use it in new situations (Mayer, 1992).

There are many terms used in education literature that refer to thinking skills including problem solving, analytical thinking, critical thinking, and scientific reasoning. However, there is confusion regarding their individual definitions. According to Pithers, who conducted a review of the literature on critical thinking, "Not surprisingly, lack of clarity about the nature of critical thinking leads to confusion about how good thinking might be assessed: assessment and evaluation of critical thinking has been sore neglected worldwide" (2000, p. 239). She defined critical thinking as

> Abilities that are brought to bear in identifying a problem and its associated assumptions; clarifying and focusing the problem; and analyzing, understanding and making use of inferences, inductive and deductive logic, as well as judging the validity and reliability of the assumptions, sources of data or information available. (p. 239)

Stuessy (1984) defined scientific reasoning as

> Consistent, logical thought patterns which are employed during the process of scientific inquiry that enable individuals to propose relationships between observed phenomena; to design experiments which test hypotheses concerning the proposed relationships; to determine all possible alternatives and outcomes; to consider probabilities of occurrences; to predict logical consequences; to weigh evidence, or proof; and to use a number of instances to justify a particular conclusion. (p. 2)

The term *thinking skills* is used here as a general term encompassing all of the above definitions.

A number of scholars have called for increased focus on thinking skills. Pithers stated, "It is important for all sectors of education to prepare individuals who are able to think well and for themselves" (2000, p. 237). According to Nickerson (1995), "The ability to acquire new skills quickly, to adapt to rapidly changing workplace conditions, and to exercise judgment and intellectual initiative will be increasingly valued in the work force" (p. 409). Greeno (1992) described two different views of the relationship between thinking and classroom learning:

1. Thinking with the basics: the major goal of teachers is to impart basic knowledge to students so they can use it in thinking.
2. Thinking is basic: the major goal of teachers is to help students learn to think scientifically and mathematically.

Ideally, students' thinking skills will, through their educational experiences, become more and more like those of experts. Glaser (1992) identified six general qualities of problem-solving expertise:

1. Proficiency is context specific.
2. Large and meaningful patterns are perceived intuitively.
3. Knowledge is structured for efficient retrieval.
4. Concepts are tied to procedures and rules for their application.
5. Self-regulatory processes are used to monitor problem solving activities.
6. Proficiency can be routinized or adaptive.

Clearly, enhanced analytical reasoning ability is an important outcome in courses emphasizing scientific problem solving. Transfer of that ability has been mentioned in the literature as well (Brown, Collins, & Duguid, 1989; Donovan, Bransford, & Pellegrino, 2000; Owen & Sweller, 1985). Transfer is the ability to apply what is learned in one context to new contexts (Donovan et al., 2000). Successful problem solving and transfer of that ability appear to be built upon foundational learning outcomes including acquisition of higher order thinking skills as well as enhanced conceptual knowledge and skills (Donovan et al., 2000).

Self-Efficacy

Bandura's pioneering theoretical and experimental work defined the study of self-efficacy. In his book, *Self-Efficacy: The Exercise of Control* (1997) he reviewed and synthesized numerous empirical studies. He found that perceived self-efficacy is a more accurate predictor of performance than measures of skills alone. It influences performance directly by affecting the quality of thinking and indirectly by heightening persistence.

Others have worked to support his theories empirically. Pintrich and Zusho (2000) conducted extensive correlational studies involving 4,000 college students. They integrated their own research with an extensive review of the literature on motivation and learning. Their findings agree with Bandura's experimental studies and indicate that self-efficacy is one of the strongest positive indicators of actual achievement in courses. In their synthesis of the literature they found that self-efficacy accounted for 9% to 25% of the variance in grades.

Multon, Brown, and Lent (1991) performed a meta-analysis on self-efficacy and its relationship to academic outcomes. They surveyed literature from 1977 to 1988 using only studies that allowed the calculation of effect size. They particularly focused on the outcome of persistence which they operationalized as time spent on task, number of tasks attempted or completed, and number of academic terms completed. According to their analysis, self-efficacy accounted for 14% of the variance in academic performance and 12% of the variance in academic persistence.

Pajeres (1995; 1996) conducted extensive empirical research on self-efficacy in the domain of mathematics. In one study on 329 high school mathematics students he used path analysis to test Bandura's hypothesis regarding the predictive and mediational role of self-efficacy. His model accounted for 61% of the variance in performance. The general consensus among these researchers and others is that self-efficacy influences academic and other affective outcomes. Key elements of this relationship are summarized in the following list:

1. Self-efficacy influences performance, monitoring of problem-solving strategy, choice to rework problems in the face of failure, and accuracy on those reworked problems (Bandura, 1997).
2. In addition to affecting academic performance, self-efficacy plays an influential role in choice of major, career choice and development, range of career options considered, and persistence and success in a chosen field (Bandura, 1997; Multon et al., 1991; Pajeres, 1995).
3. Self-efficacy is tied to interest (Bandura, 1997).
4. Students at all ability levels are more successful at solving problems and managing their work when they have positive self-efficacy beliefs (Bandura, 1997).
5. Students with higher self-efficacy beliefs tend to set higher expectations for themselves, show greater flexibility in their search for solutions to problems, achieve higher performance, and be more accurate in evaluating the quality of their performance than students with lower self-efficacy beliefs (Bandura, 1997).
6. Efficacy beliefs influence how consistently and effectively students apply what they know. Performance is impacted directly by the influence of self-

efficacy on the quality of thinking and indirectly by its influence on heightening persistence (Bandura, 1997; Pajeres, 1995).

7. Self-efficacy is particularly important when students face challenging tasks. Self-efficacy beliefs foster the ability to apply knowledge persistently and skillfully when facing difficulties in problem solving (Bandura, 1997; Pajeres, 1995, 1996).
8. Failures in intellectual performance often arise from lack of cognitive and metacognitive skills rather than lack of knowledge. Thus, the impact of self-efficacy on strategy and persistence ultimately influences success (Bandura, 1997).
9. Self-efficacy beliefs become more crucial when tasks are complex and demand high levels of self-directedness (Bandura, 1997).
10. The relationship between self-efficacy and performance varies by student achievement status and was seen to be strongest among low achieving students. This suggests that fostering self-efficacy may be particularly helpful for low achieving students (Multon et al., 1991).
11. The impact of ability and background on performance is mediated by self-efficacy (Pajeres, 1995).
12. Self-efficacy has a strong effect on anxiety which, in turn, has a weak direct effect on performance (Pajeres, 1995).

Pajeres (1995) asked the question: how much confidence (self-efficacy) is too much? Based on his path analysis study he concluded that successful functioning is best served when efficacy judgments slightly exceed actual ability. However, he cautioned

> We strongly discourage efforts to lower students' efficacy percepts, but we see value in developing intervention strategies and instructional techniques aimed at helping students develop more accurate self-appraisals rather than raising already overconfident beliefs. Improving students' calibration will require helping them to better understand what they know and do not know so that they may more effectively deploy appropriate cognitive strategies during the problem-solving process, but the challenge is to accomplish this without lowering their confidence and optimism. (p. 21)

An interesting aspect of self-efficacy discussed by Pintrich and Zusho (2000) is its change in degree across the span of a course. Their correlational studies reveal that the average levels of self-efficacy and perceived task value tend to drop over time within a course. They speculated that after receiving feedback and the inevitable distribution of grades, students tended to lower their self-efficacy levels.

Factors that Influence Self-Efficacy

According to the Pintrich and Zusho model (2000), self-efficacy is influenced by personal characteristics, classroom context, and self-regulatory processes. Bandura's four factors that influence self-efficacy fit within this model:

1. Performance accomplishments (classroom context)
2. Vicarious learning or modeling (classroom context)
3. Verbal persuasion (classroom context)
4. Physiological arousal such as anxiety (motivational processes) (1977)

Bandura (1977) outlined the following strategies for promoting self-efficacy:

1. It is helpful to focus on the process rather than the product of problem solving in individuals with low self-efficacy beliefs. Setting manageable sub-goals may foster this focus. Distal goals tend to foster lower focus than proximal goals.
2. Crediting progress or success in academic tasks to ability promotes greater self-efficacy than attributing it to hard work. This may be mediated by a person's belief in source of ability (through effort or inherent).
3. On the other hand, self-efficacy is promoted when failure is attributed to lack of knowledge or cognitive skills that are acquirable.
4. Instruction and feedback focused on the mastery of strategies that enable one to achieve success are more helpful than focus directed only to the level of performance attainments.

According to Bandura (1997) efficacy beliefs are influenced by cognitive skills but are not a mere reflection of them.

Measuring Self-Efficacy

Bandura (1997) suggested that self-efficacy is best tested with intractable problems. If readily solvable problems are used in studies, the solution may be found too rapidly with no need for students to persist in the face of difficulty. The qualities of persistence and strategy management, linked in theory to self-efficacy beliefs, may not be called upon and, thus, measured. Bandura hypothesized that self-efficacy is related to persistence (1997); however, according to Multon et al. (1991), most studies do not test students under maximally challenging conditions. Persistence is often operationalized as the number of target problems completed or amount of time spent. The problem is that high self-efficacy students often complete more problems quickly, thus appearing to have lower levels of persistence. They suggest that researchers need to be more cognizant of task difficulty, stage of learning, and performance skills in measuring self-efficacy.

Learning Goals

Learning goals are students' purposes for engaging in achievement-directed behavior (Beghetto, 2004). According to Schoenfeld (1985),

> Purely cognitive behavior – the kind characterized by the discussion of resources, heuristics, and control alone – is rare. The performance of most intellectual tasks takes place within the context established by one's perspective regarding the nature of those tasks. Belief systems shape cognition, even when one is not consciously aware of holding those beliefs. (p. 35)

Goal orientation or directed behavior is context sensitive and serves as a basis for students' definition of their own competence. Motivation can influence the amount of time and effort students are willing to devote to learning (Donovan et al., 2000).

Mastery Versus Learning Orientation

A number of researchers described a dichotomy between two modes of goal orientation: mastery, learning, or task orientation versus performance, grade, or ego orientation (Beghetto, 2004; Black & Wiliam, 1998a; Brookhart, 1997b; Dweck et al., 2004; Eison, 1981; Nichols, 1984; Pintrich & Zusho, 2000). These constructs are not identical but have a common conceptual base (Seegers, Cornelis, & Cornelis, 2002). Students with a mastery orientation tend to define competence in terms of self-improvement and are inclined to focus on learning, skill development, and understanding. This approach yields desirable outcomes including positive attitudes towards learning (enhanced interest), viewing of errors as informational, attribution of failure to lack of effort rather than lack of ability, preference for challenging tasks, use of effective learning strategies, and increased academic effort and engagement (Beghetto, 2004; Brookhart, 1997b; Pintrich & Zusho, 2000). Performance orientation, on the other hand, yields attribution of failure to lack of ability, orientation towards relative ability, minimal expansion of effort on learning, and focus on outperforming others (Black & Wiliam, 1998a). According to Beghetto (2004), performance orientation can be subdivided into performance approach and performance avoidance. Students with a performance approach orientation tend to engage in behaviors for the purpose of demonstrating their ability, outperforming others, and obtaining recognition. They define their competence in relation to others. This orientation appears to be linked to high levels of achievement as measured by grades and anxiety during evaluation (Beghetto, 2004; Pintrich & Zusho, 2000).

Students with a performance avoidance orientation tend focus on avoiding looking less able then others. They are concerned with protecting themselves and are more likely to engage in self-sabotaging behaviors such as avoiding help when needed and cheating. This orientation is linked to viewing errors as lack of ability, high levels of anxiety, exertion of less effort, giving up in the face of difficulty, and ultimately lower levels of achievement (Beghetto, 2004). But it is important to note that goal orientation is context sensitive and students may have varying combinations of these achievement goals (Beghetto, 2004).

Dweck et al. (2004) reviewed research on the effect of motivational beliefs and goals on attitude, cognitive strategies, and intellectual performance. Their report was based on evidence from the literature and their own empirical research. They related goal orientation to students' theories about intelligence. Students who believed that intelligence was fixed found it critical to validate their fixed ability through performance. On the other hand, students who believed their intellectual skills could be increased through effort (incremental theory of intelligence) became less concerned with the current evaluation of their ability and more concerned with cultivating abilities in the longer term. They also looked at the impact of goal orientation on learning strategies and found, in a study of students in a difficult high-stakes introductory chemistry course, that students with learning goals reported engaging in deeper processing of course materials and this tendency was predictive of higher grades.

The same authors (Dweck et al., 2004) took research on goal orientation in a new direction by conducting an electrophysiological study. They identified a certain brainwave that indicated anticipatory vigilance (SPN). Two groups of students were monitored for this brainwave: those who held fixed intelligence theories and those with incremental intelligence theories. Researchers recorded the presence of the SPN brainwave as students experienced two different kinds of feedback: ability relevant (grade) and learning relevant (informational). Both groups of students had SPN brainwaves while anticipating ability relevant feedback but only students with an incremental theory of intelligence produced SPN brainwaves before learning relevant research. This suggests that students holding the fixed intelligence theory were not motivated to attend to this type of information.

Control

Goal orientation is related to students' perceptions of locus of control for their learning. One of the most important things educators can do for students is to "convince them to take responsibility for their education" (Young, 2005, p. 1). Pintrich and Zusho (2000) described three sources of perceived control: internal, external, and unknown. They suggested that efficacy is related to control and that students with internal control tend to experience higher levels of positive outcomes. Brookhart's views agree with this positive view of internal control:

> Students who through feedback from others and from observing their own behavior, come to see that achievement is their own responsibility and amenable to sustained and consistent effort, may be said to view school achievement as having an internal locus of control and being stable and controllable. These attributions affect persistence in a task, choice of task, and the intensity of approach to a task. (1997, p. 173)

According to Hom and Murphy (1983), students who take greater responsibility for their learning experience higher levels of achievement, are more motivated to learn, are more efficient in their learning, and better understand their strengths and weaknesses as learners. In order for students to manage their own learning it is important to give students what they need, most importantly clear feedback. "Since understanding is viewed as important, people must learn to recognize when they understand and when they need more information" (Donovan et al., 2000, p. 12).

The learning environment can influence students' perceptions of personal control over their learning. Jones, Valdez, Nowakowsk & Rasumussen (1995) stated

> In engaged learning settings, students are responsible for their own learning; they take charge and are self-regulated. They define learning goals and problems that are meaningful to them; have a big picture of how specific activities relate to those goals; develop standards of excellence; and evaluate how well they have achieved their goals. They have alternative routes or strategies for attaining goals—and some strategies for correcting errors and redirecting themselves when their plans do not work. They know their own strengths and weaknesses and know how to deal with them productively and constructively. Engaged learners are also able to shape and manage change. (p. 8)

Learning Approach

While goal orientation refers the intention of learning, learning approaches are the strategies used to accomplish learning goals. The earliest studies on learning approaches were directed at categorizing learning personalities and thinking patterns. Heath (1964) described three personality types: non-committers (cautious), hustlers (competitive, insensitive), and plungers (impulsive, emotional). Over time he found that these personality types followed a developmental path ending in the reasonable adventurer type, characterized by curiosity and an alternation of involvement and attachment.

Perry (1978) identified a developmental thinking pattern consisting of four stages:

1. Dualism (belief in the existence of right or wrong answers)
2. Multiplicity (realization that there is more than one way to look at a situation)
3. Relativism (different interpretations can be drawn from the same evidence)
4. Commitment (own personal interpretation)

According to Perry, only a few students reach the commitment level of thinking.

Saljo (1979) asked students, “What do you mean by learning?” and found a range of sophistication in their views of learning. The simplest view defined learning as the acquisition of information by routine memorization. The more sophisticated view of learning involved personal engagement with a task, transforming information, and changing as a person.

Later studies (Pask, 1988; Saljo & Marton, 1976) examined students’ approaches to completing tasks. A dichotomy between deep and surface levels of processing was identified. Entwistle (2000a) did a phenomenological study of students’ experience while reading an article and found this same dichotomy. However, he found that learning approach is related to context:

> The approach adopted depends on the student’s motivation in relation to a specific task, and yet students do show a certain consistency across the range of tasks they experience, with some students more likely to adopt one approach and others to choose a different one. (p. 173)

It is important to note that it is students’ perception of the learning environment, not the environment itself, that is significant. “Different students may perceive the same setting in a variety of ways and prefer teaching of different kinds, leading to different effects on their learning” (Hounsell & McCune, 2002, p. 10).

Later interviews on everyday studying led Entwistle to identify the strong influence assessment procedures had on learning and studying (Entwistle, 2000c). This caused him to add another category to the deep/surface dichotomy that he titled strategic approach: an approach to studying focused on assessment demands. Entwistle described intentions and strategies related to each learning approach (2000b) (Table 1).

Table 1

Features of Entwistle's Three Learning Approach Categories

Learning Approach	Intention	Strategies
Deep Approach	Seek meaning	Relate ideas to previous knowledge and experience Check evidence and relate it to conclusions Become actively interested in course content
Surface Approach	Routine reproducing	Study without reflecting Treat course as unrelated bits of knowledge Memorize facts and procedures Difficulty in making sense of new idea Undue pressure and worry
Strategic Approach	Achievement of highest possible grade	Consistent study effort Find right conditions and materials for study Manage time and effort Alert to assessment criteria Gear work to perceived preferences of instructor

Students' conceptions of learning affect the way they tackle academic tasks and this is in turn related to academic performance. Students who take deep or strategic approaches tend to perform better than students who take a shallow approach but Entwistle (2000b) suggests a qualification:

> A deep strategic approach to studying is generally related to high levels of academic achievement, but only where the assessment procedures emphasize and

reward personal understanding. Otherwise surface approaches may well prove more adaptive. (p. 4)

Problem Solving

Traditional science classes tend to be taught using instructor-centered, content-driven lectures. Concepts and principles are often presented first, followed by idealized examples. Memorization is explicitly or implicitly stressed rather then conceptual understanding and application. Students tend to play a passive role and through this process gain inert knowledge that is difficult to retrieve and transfer (Allen, Duch, & Groh, 1996). By contrast, information that is presented in the context of solving problems is more likely to be spontaneously used than information presented in the form of simple facts (Bransford & Schwartz, 1997). Presenting problems in multiple contexts and emphasizing meta-cognition are two strategies that can increase this utilization and transfer of information (Bransford & Schwartz, 1997).

Stewart and Hafner reviewed literature on problem solving performance in genetics in order to make recommendations for its continuation. They found that by practicing problem solving in the context of its scientific domain, students tend to develop a more "highly structured and functional understanding of the conceptual knowledge of that domain, general and domain-specific problems solving strategies, and insight into the nature of science as an intellectual activity" (1994, p. 295). This process occurred as conceptual content and problem solving experience combined to create, elaborate, or revise explanatory models of scientific phenomena.

Problem-Based Learning

There are diverse designs for incorporating problem solving into classrooms ranging from Problem Based Learning (PBL), a complete curriculum based on problem solving, to the intermittent use of problems as learning activities. The PBL system provides evidence for the effectiveness of a problem-solving pedagogy. It is a structured learning system designed specifically to produce individuals with the ability to think creatively and critically, solve problems, and transfer their knowledge to diverse situations.

Problem-based learning background. Problem-based learning was introduced at McMaster University Medical School in the early 1970s as educators became increasingly aware that physicians needed better preparation for the demands of professional practice. Educational programs in the health sciences were criticized for their failure to equip graduates with skills in problem solving including the ability to acquire essential data, to synthesize data into a possible hypothesis, and to test those hypotheses (Wilkerson & Gijselaers, 1996). Other medical schools followed suit and by the early 1980s a number of medical schools with conventional curricula developed components of their programs based on problem-based learning. Today this approach has been integrated into a wide range of programs including education in professional schools, college-level courses and even primary and secondary schools (Wilkerson & Gijselaers, 1996).

Problem-based learning characteristics. There are many variations of PBL but they are based on the original model created at McMaster University. The original characteristics of the PBL model are

1. Learning is student-centered.
2. Learning occurs in small student groups.
3. Teachers are facilitators or guides.
4. Problems form the organizing focus and stimulus for learning.
5. Problems are vehicles for the development of clinical problem-solving skills.
6. New information is acquired through self-directed learning (Wilkerson & Gijselaers, 1996).

Generally, PBL involves students working on problems in small groups while coached by a tutor. Problems are encountered before all relevant knowledge has been acquired so learning takes place in the context of solving the problem. The educational objects that spurred the development of PBL are (Wilkerson & Gijselaers, 1996):

1. Acquisition of an integrated knowledge base.
2. Acquisition of a knowledge base structured around the cues presented by patient problems.
3. Acquisition of a knowledge base enmeshed with problem-solving processes used in clinical medicine.
4. Development of effective self-directed learning skills and team skills.

The original McMaster Medical School version of PBL has been widely adapted into medical school curricula. The percentage of medical schools reporting self-instruction (a synonym for PBL, although it can include other types of instruction) was

79% in 1994-1995 and increased to 94% in 1998-1999. PBL pedagogies have been adapted and used in many different educational contexts including business education (Stinson & Milter, 1996), leadership education (Bridges & Hallinger, 1996), calculus (Seltzer, Hilbert, Maceli, & Robinson, 1996) and chemical engineering.

Problem-based learning effectiveness. A number of meta-analyses have been conducted to ascertain the effectiveness of PBL and the results are mixed. Vernon and Blake (1993) evaluated 35 research projects from 1970-1992 in medical and nursing education. They performed five statistical meta-analyses and found that PBL was significantly superior in student performance and student attitude towards their programs. No significant difference was found between PBL and conventional students on tests of factual and clinical knowledge. However, PBL students scored lower on the *National Board of Medical Examiners Step 1*.

Albanese (1993) performed a meta-analysis in that same year. English-language international literature was reviewed from 1972-1992. He found that, compared to conventional instruction, students involved in PBL had positive attitudes towards the pedagogy, performed as well or better on clinical examinations and faculty exams, in some instances scored lower on basic science examinations, and tended to view themselves, in comparison to their conventionally trained counterparts, as less well prepared in the basic sciences.

Berkson (1993) also searched the medical literature through 1992 for evidence regarding PBL effectiveness. She created a narrative analysis covering six topics: problem solving, imparting knowledge, motivation to learn medical science, promoting self-directed learning skills, student and faculty satisfaction, and financial costs. The analysis indicated that there was no significant difference between PBL and conventional instruction but suggested that PBL was unreasonably expensive and may be stressful for students and faculty. Reasons for the negative results produced by her meta analysis may be failure to categorize literature by variety of PBL (Distlehorst, 1994) or differences in criteria used to include or exclude studies (Vernon & Blake, 1994).

Colliver (2000) reviewed the analyses cited above and added literature published from 1992 through 1998 from the primary sources for research in medical education. He found that PBL, in comparison to conventional pedagogies, did not improve knowledge base and clinical performance of a magnitude that would warrant the use of resources required for a change to PBL. However, Albanese (2003) critiqued Colliver's findings, claiming that his requirement for large effect sizes was not reasonable.

Dochy, Segers, Van den Bossche, and Gijbels (2003) included studies outside the domain of medical education. They examined the effects of PBL on two categories of outcomes: knowledge and skills. They selected 43 empirical studies on PBL in tertiary education that met their criteria for inclusion. Results were compiled on effect size and vote count. Based on vote count and positive effect size, they found a strong positive effect on skill. They fond that no single study reported negative effects. The effect of PBL on knowledge was negative based on combined effect sizes but this was strongly influenced by two studies. Vote count differences related to knowledge did not reach a significant level.

Because of the diverse results obtained from meta-analyses, Newman conducted a pilot study hoping to encourage methodologically rigorous criteria for a review of research on the effectiveness of PBL. Twelve studies on PBL in higher education programs for health professional education met the criteria for inclusion. A noticeable feature of the included studies was that the assessments used to measure performance were almost exclusively multiple-choice tests measuring accumulation of knowledge. This may have been due to the stringent criteria for inclusion of research reports. Higher-level cognitive outcomes, said to be promoted by PBL, were not assessed in studies that met criteria for review. This represents a significant problem in evaluating the quality of PBL. Within this category of performance some studies favored PBL and some favored the conventional instruction. The two largest effect sizes favored the conventional instruction. Results were limited because the purpose of this study was to pilot review selection criteria and analysis procedures.

The most recent review (Gijbels et al., 2005) examined the influence of level of assessment on the reported effects of PBL by reviewing studies that were empirical, based on the PBL traditional model, and derived from higher education in all possible subject domains. Forty studies met the selection criteria. Sugrue's model of cognitive components of problem solving was used to categorize assessments into (a) understanding of concepts, (b) understanding of principles that link concepts, and (c) linking of concepts and principles to conditions and procedures for application (1995). Results indicated that PBL students performed better at the second and third levels of knowledge structure. No study reported significant negative findings at the third level and only one study reported negative findings at the second level. At the first level, five studies yielded a significant negative effect and three studies yielded a significant positive effect with a resulting overall negative effect due to PBL. But this difference was not significant at the .05 alpha level. Because PBL effects differ according to the cognitive component assessed, type of assessment may be an unexamined moderator variable in the studies discussed above.

The results of the meta-analyses are mixed and do not present compelling criteria for the effectiveness of PBL. However, these results, as suggested by the Gijbels et al. (2005) review, may be compromised by the level of cognition assessed. Empirical studies, especially those that meet the criteria for inclusion in meta-analyses tend to use objective assessment methods that measure lower level cognition. The definition of what makes a good doctor (or practitioner in another field) may be a construct of the tests themselves, or how they are represented in the analyses (Farrow & Norman, 2003). This reveals a problem with meta-analyses of the type described above: the focus is on analysis and evaluation rather than understanding and explaining. "By ignoring the explanation of the results in a wider context, the non-tested attributes are marginalized" (Farrow & Norman, 2003, p. 1130).

Tasks

The problems or tasks chosen as part of instruction may have a significant impact on students' academic achievement as well as their learning strategies. Ames (1992) reviewed the literature on classroom structures and their impact on student motivation and took a careful look at tasks:

> A central element of classroom learning is the design of tasks and learning activities. Students' perceptions of tasks and activities not only influence how they approach learning; these perceptions also have important consequences for how they use available time. Embedded in tasks is information that students use to

make judgments about their ability, their willingness to apply effortful strategies, and their feelings of satisfaction. (p. 5)

She outlined characteristics of tasks that tend to promote positive learning outcomes:

1. Tasks that involve variety and diversity
2. Tasks with personal relevance and meaningfulness
3. Tasks that offer personal challenge
4. Tasks that allow students personal control over process
5. Tasks that are defined in terms of specific and short-term goals
6. Tasks are delivered in a manner that promotes engagement

Wiggins (1993) would add tasks that are authentic to this list. According to Wiggins, authentic tasks should meet the following criteria

1. Tasks should be engaging and worthy problems or questions of importance in which students must use knowledge to fashion performances effectively and creatively. The tasks are either replicas of or analogous to the kinds of problems faced by adult citizens and consumers or professionals in the field.
2. Tasks should be faithful representation of the contexts encountered in a field of study or in the real-life "tests" of adult life. The formal options, constraints, and access to resources are apt rather than arbitrary. In particular, the use of excessive secrecy, limits on methods, the imposition of arbitrary deadlines or restraints on the use of resources to rethink, consult, revise, and so on—all with the aim of making testing more efficient—should be evaluated and minimized.

3. Tasks should be non-routine and multistage. Recall or "plugging in" is insufficient or irrelevant. Problems require a repertoire of knowledge, good judgment in determining which knowledge is apt when and where, and skill in prioritizing and organizing the phases of problem clarification and solution.
4. Tasks should require the student to produce a quality product and/or performance.
5. Tasks should be tied to clear criteria and standards. This allows for thorough preparation as well as accurate self-assessment and self-adjustment by the student.
6. Tasks should ask the student to justify answers or choices and to respond to follow-up or probing questions.

Earl (2003) related task qualities to Vygotsky’s zone of proximal development. Tasks are appropriately challenging when they cause students to risk and move into the unknown while still knowing how to get started. While attempting such tasks students should they have support for reaching new levels of learning. In this zone students get stuck, but have the skills to consider options and get themselves unstuck.

According to Doyle, “Students’ academic work is defined by the academic tasks that are embedded in the content they encounter on a daily basis. Tasks regulate the selection of information and the choice of strategies for processing that information” (1983, p. 5). He organized tasks into four general categories:

1. Memory tasks
2. Procedural or routine tasks
3. Comprehensive or understanding tasks

4. Opinion tasks

Different tasks require different cognitive strategies and students tend to adjust their study strategies to fit the nature of tasks they expect to face in the classroom (Doyle, 1983). He characterized these tasks on two dimensions: high or low risk and high or low ambiguity. He said that memory and routine tasks are low in ambiguity but can be high or low in risk depending on difficulty. Opinion tasks are high in ambiguity but low in risk. Understanding tasks are high in both ambiguity and risk. According to Doyle, there is evidence that students adjust their learning strategies to manage the ambiguity and risk associated with tasks. Students tend to "restrict the amount of output they give to a teacher in order to minimize the risk of exposing a mistake" (Doyle, 1983, p. 184).

As students work with tasks, they can learn through experience rather than through direct instruction. Doyle (1983) described the value of indirect instruction:

> Such instruction emphasizes the central role of self-discovery in fostering a sense of meaning and purpose for learning academic content. From this perspective, students must be given ample opportunities for direct experience with content in order to derive generalizations and invent algorithms on their own. (p. 177)

In a review of literature on formative feedback, Black and Wiliam (1998a) suggested that tasks should help students establish their own self-referenced goals by providing meaningful, interesting, and reasonably demanding challenges. These tasks should then be tied to feedback focused on individual improvement and mastery.

Bandura (1997) related tasks to self-efficacy. He recommended that in order to promote interest, problems should be within the perceived capabilities of students but still challenging and interesting. Solving such problems, tied with clear feedback on progress, provides a sense of satisfaction from aiming for and achieving success.

Formative Assessment

Many scholars have reported that the assessment structure of the classroom has a significant impact on learning (Black & Wiliam, 1998; Brookhart, 1997; Stiggins, 2002). However, there are various assessment foci. Stiggins (2002) differentiated between assessment *of* learning and assessment *for* learning. Earl (2003) identified three categories of assessment:

1. Assessment of learning (traditional summative assessment)
2. Assessment for learning (feedback to teachers to improve instruction)
3. Assessment as learning (directed at students to motivate them to bring their knowledge and talents to bear on decisions and problems)

The most recent and complete publication on formative assessment is Black and Wiliam's (1998a) review of the literature. The authors actually published two articles, one written for the scholarly community (Black & Wiliam, 1998a) and another more accessible version for educators (Black & Wiliam, 1998b). This was an effective approach and their second publication titled "Inside the Black Box: Raising Standards Through Classroom Assessment" has been widely distributed and read. They found challenges in conducting their review and were not able to perform a meta-analysis because of the lack of rigor in quantitative studies. Black and Wiliam questioned the value of some earlier meta-analyses because of their focus on narrow aspects of formative work and because key variables were sometimes ignored. They suggested that a great deal of theory building is still needed regarding formative assessment. In order to improve the conceptualization of formative assessment they created a list of important and relevant factors (Black & Wiliam, 1998a):

1. Assumptions about learning underlying the curriculum and pedagogy
2. Rationale underlying the composition and presentation of the feedback
3. Precise nature of the various types of assessment evidence revealed by the learner's responses
4. Interpretative framework used by both teachers and learners in responding to this evidence
5. Divisions of responsibility between learners and teachers in these processes
6. Perceptions and beliefs held by the learners about themselves as learners, about their own learning work, and about the aims and methods for their studies
7. Perceptions and beliefs of teachers about learning, about the abilities and prospects of their students, and about their roles as assessors
8. Nature of the social setting in the classroom, as created by the learning and teaching members and by the constraints of the wider school system as they perceive and evaluate
9. Issues relating to race, class and gender, which appear to have received little attention in research studies of formative assessment
10. The extent to which the context of any study is artificial and the possible effects of this feature on the generalizability of the results.

This extensive list reveals the potential complexity of formative assessment studies. Black and Wiliam called for new approaches in assessment research combining traditional quantitative methods with “richer qualitative studies of processes and interactions within the classroom. If, as we believe, there is a need to evolve new approaches as quickly as possible, such studies might well focus on the problems of change and attendant disorientations” (1998, p. 48). Many studies report successful innovations but fail to give clear and thorough descriptions of important elements such as the classroom methods used, measures of success, motivation and experience of teachers, and the outlooks and expectations of students (Black & Wiliam, 1998b).

Effect of Formative Assessment on Learning

Black and Wiliam defined formative assessment as activities undertaken by teachers or by their students which provide information to be used as feedback to modify teaching and learning activities (1998a). They indicated two core actions that make up formative assessment: perception by the learner of a gap between a desired goal and the present state, and action taken by the learner to attain the desired goal. The relationship between these two actions is multifaceted. “There are complex links between the way in which the message is received, the way in which that perception motivates a selection amongst different courses of action, and the learning activity which may or may not follow” (1998b, Students and formative assessment section, ¶ 1).

After controlling for mediating variables, Black and Wiliam (1998a) found that formative assessment does improve learning. The gains in achievement were considerable. In fact the effect sizes ranging from 0.4 to 0.7 were, according to the authors, among the largest ever reported in educational interventions:

> Furthermore, despite the existence of some marginal and even negative results, the range of conditions and contexts under which studies have shown that gains

> can be achieved must indicate that the principles that underlie achievement of substantial improvements in learning are robust. Significant gains can be achieved by many different routes, and initiatives here are not likely to fail through neglect of delicate and subtle features. (p. 56)

Many of the studies reviewed by Black and Wiliam (1998a) revealed that formative assessment helped low achievers more than other students, thus reducing the range of achievement while raising overall achievement.

Kluger and DeNisi (1996) also conducted an extensive review of the literature related to feedback interventions. They reviewed over 3,000 reports selecting only those that were of experimental or quasi-experimental design. This resulted in 131 reports yielding 607 effect sizes. They found an average effect size of 0.4 but the standard deviation of the effect sizes was almost 1.0. Over one third of the effect sizes were negative. In order to explain this variability they examined several potential moderators of the effectiveness of feedback interventions such as type of feedback cue, task characteristics, situational variables and methodological variables. They identified four broad classes of potential action describing a student's response to receiving feedback communicating a gap between the actual and reference levels of some attribute:

1. Change behavior in accordance with feedback
2. Change the standard so it matches present feedback
3. Reject the feedback
4. Escape the situation

The question asked was: which of these behaviors will occur? Because of the moderating variables the answer to that question was difficult to predict. Kluger and DeNisi (1996) concluded that current theory, based upon feedback-standard comparisons, is too simple to allow predictions.

Brookhart synthesized two bodies of literature: classroom assessment and social-cognitive theories of learning. She coined the term *classroom assessment environment* to describe the "sociocultural reality experienced and interpreted by individuals"(1997, p. 162). This environment is created by teachers and reflects classroom instructional and assessment practices. Underlying this assessment environment are teacher attitudes, orientations and beliefs, teacher knowledge and skills, the classroom climate, and institutional policies (Brookhart, 1997b).

Based on the studies described above it appears that there is firm evidence that innovations designed to strengthen formative feedback directed towards students will yield significant learning gains. According to Brookhart, "…information that a student can use to make himself or herself more competent is intrinsically motivating" (1997b). The use of challenging assignments and extensive feedback leads to greater student engagement and higher achievement (Black & Wiliam, 1998a). However, there is a complex interaction between students' personal characteristics and the formative feedback classroom context (Black & Wiliam, 1998a). Brookhart (1997b) indicated that the functional significance of feedback, that is whether it is experienced as informational or controlling, is determined by the classroom assessment environment. She stated

> Functional significance is an intervening variable between the nature of the feedback and perceived self-efficacy – the feeling that a student can do a task, that he or she is competent to reach specified goals. A student who receives feedback that clearly can be used to feel empowered to improve performance is likely to

feel empowered to do better next time. A student who receives feedback that is strictly judgment (e.g., “fair”) without information is likely to feel that the teacher has meted out an external reward or punishment. (p. 171)

Rewards and Competition

A competitive classroom environment may have an impact on motivation by increasing anxiety and lowering self-efficacy and self-worth; however, according to Pintrich and Zusho (2000), the findings are complicated and no simple generalizations can be drawn. Rewards have a complex relationship with interest. Bandura (1997), in reviewing pertinent empirical studies, indicated that rewards can increase, decrease, or have no effect on interest but they generally tend to diminish interest when they are perceived to be controlling and enhance interest when they convey information about competency.

Grading is one form of classroom reward. It is generally necessary to track students’ progress, but a number of empirical studies have found that traditional grading practices may have a negative impact on learning. Kohn (2004) identified three potential negative outcomes:

1. Reduction of student interest in learning (Benware & Deci, 1984; Butler, 1987; Butler & Nisan, 1986; Hughes, Sullivan, & Mosley; Salili, Maehr, Sorensen, & Fyans, 1976)
2. Reduction in student preference for challenging tasks (Hartner, 1978)
3. Reduction in quality of student thinking (Butler, 1987; Butler & Nisan, 1986)

According to Black and Wiliam (1998b)

When the classroom culture focuses on rewards, "gold stars," grades, or ranking, then pupils look for ways to obtain the best marks rather than to improve their learning. One reported consequence is that, when they have any choice, pupils avoid difficult tasks. They also spend time and energy looking for clues to the "right answer." Indeed, many become reluctant to ask questions out of a fear of failure. (p. 142)

The challenge for educators, then, is to balance the need for summative assessment with the impact of negative outcomes associated with grading and to promote the use of formative assessment in the classroom.

Characteristics of Effective Feedback

Generally, feedback is most effective when designed to correct errors or misconceptions. The quality of student work is related to the quality of the close-the-gap comments (Earl, 2003). If students are only given marks, they are less likely to benefit from the feedback (Black & Wiliam, 1998a). Feedback improves learning when it gives students specific guidance on their strengths and weaknesses. In order to be most helpful, assessments should be designed in alignment with current knowledge structure models so that feedback can be directed toward students' progress in acquiring those structures. Most traditional tests are inadequate to this purpose (Black & Wiliam, 1998a).

Feedback characteristics can also influence affective outcomes. "Feedback to any pupil should be about the particular qualities of his or her work, with advice on what he or she can do to improve, and should avoid comparisons with other pupils" (Black & William, 1998a, p. 9). Feedback that draws attention away from the task and toward self can have a negative impact on attitudes and performance (Black & Wiliam, 1998a).

Bandura (1997), focused on self-efficacy, said that it is important for assessments to focus on the process rather than the product of problem solving in individuals with low self-efficacy belief. Setting manageable sub-goals may foster a focus on process. Instruction and feedback focused on the mastery of strategies that enable one to achieve success is also more likely to promote self-efficacy than focus directed only at the level of performance attainments. This effect may be mediated by a person's belief in the source of their ability. If students feel ability is derived from effort they are more likely to be positively affected by feedback but if they belief ability is inherent, their self-esteem may be threatened by feedback perceived as criticism.

Earl (2003) summarized seven components of good feedback:

1. Provides direct evidence on the accuracy of an idea
2. Fosters reflection on learning
3. Gives recognition for achievement and growth
4. Targets specific learning needs
5. Gives clear direction for improvement
6. Allows students time to consider and respond to suggestions
7. Focuses on quality and learning

According to Black and Wiliam (1998a) feedback should focus on individual improvement and mastery. It should also be private, linked to opportunities for improvement, and should encourage the view that mistakes are a part of learning.

The timing of feedback is also important. Feedback that cuts off students' efforts by providing answers to problems too accessibly or quickly may circumvent important learning processes. Learning through discovery is learning based on feedback from the task rather than from an external agent and this type of learning may be superior to learning through feedback interventions (Kluger & DeNisi, 1996). However, feedback should not be put off too long. Generally, feedback from a test given at the end of a unit is too late to be beneficial (Black & Wiliam, 1998a).

Self-Assessment and Self-Scoring

According to Black and Wiliam (1998a)

> Self-assessment by pupils, far from being a luxury, is in fact an essential component of formative assessment. When anyone is trying to learn, feedback about the effort has three elements: recognition of the desired goal, evidence about present position, and some understanding of a way to close the gap between the two. All three must be understood to some degree by anyone before he or she can take action to improve learning. (p. 143)

In Black and William's review of the literature (1998a) they found that self-scoring of assessments increased trust in the assessment process and improves performance. Some of the studies evaluated the quality of student scoring and found a correlation between student and teacher assessments of .71. Feedback on self-scoring improved the quality and depth of students' scoring. Students tended to feel that self-scoring made them think and learn more.

Teaching as Learning

Teaching as learning, in this research, refers to the mutually beneficial practice of students teaching one another concepts and skills. This practice falls within the larger domain of cooperative or collaborative learning where students work together in small groups in order to achieve learning goals (Vazin & Reile, 2006). Davidson (1994, p. 14) defined five attributes of collaborative learning:

1. A common task or learning opportunity suitable for group work
2. Small-group learning
3. Cooperative behavior
4. Interdependence
5. Individual accountability and responsibility

According to collaborative learning theory, students perform at higher intellectual levels when working in groups than when working individually. Collaborative learning may promote the active exchange of ideas, critical thinking skills, and retention (Johnson & Johnson, 1986). There is an extensive literature on collaborative learning beginning with Piaget (1932) and Vygotsky (1978). The benefits of collaborative learning continue to be debated (see for example; Delucchi, 2006; Foyle, 1995; Keith, 2005; Totten, Sills, Digby & Russ, 1991).

O'Donnell and Dansereau (1987) evaluated a program called *scripted cooperative learning* where students worked together, generally in pairs, to master material. The learning process was scripted to specify the roles played by the participants and the sequence of activities. Generally, one partner summarized material from a text and the other provided feedback on errors or omissions and then the process was reversed. Evaluation of this program suggested that the scripts had an impact on performance. Students who were not told to detect errors and omissions in their partner's explanation subsequently remembered less information than partners who were directed to be critical.

Research also revealed that pairs who were scripted to emphasize elaborative activities performed best on transfer tasks (O'Donnell, Dansereau, Hall, & Rocklin, 1987).

Think-Pair-Share (TPS) is a collaborative learning strategy that was developed for college classrooms. Under this system an instructor poses a question during a lecture, asks students to think about the topic individually for a minute, and then has them discuss their conclusions in pairs. Usage of TPS resulted in increased participation and improved retention of information as well as higher levels of learner confidence (Gunter, Estes, & Schwab, 1999).

The benefits from teaching to learn and other cooperative learning activities may derive from their tendency to foster active learning. According to Cooper and Robinson (2000),

> Information presented in lectures must be moved into long-term memory by having the students develop into communities of learners who discuss, debate, and summarize academic content. . . . Most people know from experience that a powerful way to learn material at a deep level it to teach it to others. (p. 10)

Another aspect of teaching as learning is the effect that the anticipation of teaching a topic has on the learning of that topic. Annis (1983) performed a study to determine the effectiveness of learning in order to teach. College students were asked to read an article under five different conditions: (a) reading only, (b) reading to teach but not actually teaching, (c) reading and actually teaching, (d) being taught by another, and (e) reading and being taught. Students in the two read to teach groups had significantly greater content specific and cognitive gains. Those who prepared to teach and then taught scored higher, in most cases than students who prepared to teach but did not actually teach. This suggests that the actual teaching process itself promotes learning. A similar study was conducted by Benware and Deci (1984). Students were also given an article to read but there were only two groups: the experimental group, who were told they would teach the contents of the article to another student, and the control group, who were told they would be examined on the material. Two weeks after reading the article, students were given a questionnaire and a performance examination. The read to teach group rated their activity level (how active the learning was) higher and performed better on conceptual learning items than the control group. There was no significant difference between the two groups on rote learning items. These positive outcomes may be due to the active nature of reading or studying in order to teach.

Writing to learn, while not a cooperative learning activity, is a pedagogical practice related to teaching to learn. In writing to learn, as in teaching to learn, students benefit from the process of organizing and sharing their thoughts. Students, when writing to learn, are forced to rethink material and express themselves in an organized fashion. This gives them an opportunity to use the information they have learned (Moore, 1992). In their book *How to write to learn science*, Tierney and Dorroh (2004) suggest that writing helps students think through problems. They also propose that it helps students diagnose their own learning: "As they write they have a sense of what they already know and, more importantly, what they don't understand" (p. 3). Ambron (1987) argued that students who write to learn biology, particularly through journal writing, are able to improve their understanding and personalize their knowledge. However, there is controversy concerning the benefits of writing to learn. Ackerman (1993) reviewed 35 studies on writing and learning and found that there was little empirical validation for writing as a mode of learning.

Chapter 3: Method

Participants

As stated in Chapter 1, the purpose of this research was to describe, explore, and share a particular example of successful biology teaching and the associated student experiences. In order to accomplish this, Dr. John Bell's section of the Biology 120 course taught during winter term of 2006 was studied intensively. The formative format pedagogy was chosen because it represents a collection of innovative teaching practices that have been successful in the past. This particular class was chosen because it was an accessible information-rich example of the formative format pedagogy: (a) assessments were given weekly, (b) students actively participated and interacted while in the classroom, and (c) the instructor was willing to collaborate in collecting information on the students' learning experiences.

Research subjects included students, teachers, and teaching assistants in the Biology 120 course. Because this course is the first in the core biology curriculum for those majoring in biology and related disciplines, most students taking this course are in their first or second year of university study. There were 263 students in the class (79 females and 184 males) including 103 students with declared majors in the biological sciences. Students represented all class levels: 105 freshman, 94 sophomores, 48 juniors, and 16 seniors.

Design

This research took a mixed-method case study approach to data collection and analysis. The case, as described above, was the formative format Biology 120 course taught winter term at BYU. According to Merriam, "Case study research, and in particular qualitative case study research, is an ideal design for understanding and interpreting educational phenomena" (1988, p.2). This approach tends to be inductive and is particularly useful when important variables are unidentified (Merriam, 1988). "In general, case studies are the preferred strategy when 'how' or 'why' questions are being posed, when the investigator has little control over events, and when the focus in on contemporary phenomenon within some-real life context" (Yin, 2002, p. 1). A case study approach allowed me to maintain a holistic view of learning by retaining the meaningful characteristics of real-life events (Yin, 2002).

Both qualitative and quantitative methods were employed in the process of exploring this case. Within a mixed method design, qualitative and quantitative methods can vary in sequencing and weight (Creswell, Goodchild, & Turner, 1996). In this research, the emphasis was on qualitative data collection and analysis. However, in order to better understand and describe particular aspects of this case, quantitative methods were inserted into the overall qualitative paradigm. Both types of data were collected continuously during the case study. "Unquestionably all research designs are flawed. By integrating both qualitative and quantitative research, however, the deficiencies of one approach can be offset by the advantages of another" (Creswell et al., 1996, p. 115).

Because one of the objectives of this research was to understand students' experiences or culture, qualitative data collection and analysis were informed by Spradley's participant observation (ethnographic) method. According to Spradley (1980),

> The ethnographer observes behavior but goes beyond it to inquire about the meaning of that behavior. The ethnographer sees artifacts and natural objects but goes beyond them to discover what meanings people assign to these objects. The

ethnographer observes and records emotional states but goes beyond them to discover the meaning of fear, anxiety, anger, and other feelings. (p. 7)

I tried to maintain balance between etic theory-driven questions such as "How and to what extent do students' approaches to learning change during the course?" and the emic desire to remain open to revelations that may come from the students themselves. This necessitated flexibility in the ongoing process of collecting and analyzing data. The pattern of ethnographic research is cyclical rather than linear. "In ethnographic inquiry, analysis is the process of discovery" (Spradley, 1980, p. 33) and those discoveries modified the methods chosen and sometimes even the questions asked during the course of this research.

Data Collection

Course Observation

Observations of the Biology 120 course were the most important source of data in this research. I attended classes, extra help sessions, and other activities associated with the course. My level of participation ranged between passive and active; sometimes I sat quietly in the classroom, carefully observing the situation and recording fieldnotes, and other times I interacted with the students as they participated in class activities. I also conducted informal interviews with students when it was possible during class activities. These interviews became part of my fieldnotes. The focus of the observations was broad and general at first but became progressively sharper based upon emerging findings from ongoing data collection and analysis. I took field notes during each observation session and as soon as possible afterward, I expanded upon those notes and added personal interpretations.

Student Interviews

Thirteen students were selected to serve as informants (Stake, 1995). The criteria for the selection process was to maximize what could be learned about students' experiences in the Biology 120 course (Stake, 1995). After the pre-survey and the first assessments results were evaluated, I emailed the class asking for volunteers to participate in the interview process. I then consulted with Bell to identify students from the volunteer group representative of differing demographics, ability and attitude. Six students were invited to participate in a series of three interviews. When possible the interviews were tape-recorded. They took place on campus and lasted about 20 minutes each. Interviews probed the students' attitudes and approaches to their learning providing detailed, and individualized information about selected students' learning experiences to balance the broader sample of more limited information obtained from class level data sources. Students were given summaries of their interview transcripts in order to check then for accuracy (member checking).

After conducting initial interviews with the first six students, I realized the diversity was not as broad as I had hoped. I subsequently sent a second email inviting students who had experienced challenges in the course to participate in the interviews. Six more students from that group as well as one student recommended by Bell were chosen to serve as additional interview subjects.

The interview protocol followed Spradley's ethnographic interview model (1979). He described three different types of questions, each of which were used in the informant interviews:

1. Descriptive questions will provide general information about students' learning approaches and experiences (Tell me what you do as you prepare for Friday assessments.).
2. Structural questions will help characterize domains or units of cultural knowledge important in the learning process (What are the steps you take as you read your textbook?).
3. Contrast questions will be designed to reveal the dimensions of meaning students use to distinguish events related to their learning (What is the difference, in your mind, between reading and studying?).

Instructor and Teaching Assistant Interviews

I interviewed Bell and the TAs on a regular basis. I often remained after class and participated in an informal discussion with them on the day's events. I also met with Bell about once per week to talk about students' learning and to plan strategies for improving data collection. TA interviews were generally informal and conducted during help sessions and before and after class. Interviews were either recorded as field notes or tape-recorded.

In-class Questions

The instructor administered a total of six questions as part of the weekly assessments to the entire class during the term (Appendix C). The open-ended questions probed students' opinions on various aspects of the course and their attitudes towards learning and studying. Questions were integrated into the assessments and designed to be as unobtrusive as possible. They were administered in three different manners: (a) asked orally when students finished the writing the assessment, (b) displayed on a PowerPoint slide while students were taking the assessment, or (c) written on a page at the end of the assessment. The general topics for the questions were based upon Entwistle's approaches to learning research (Entwistle, 2000a, 2000c; Entwistle et al., 2002; Entwistle & Tait, 1993) but were also informed by themes that emerged from ongoing data collection and analysis. These data were valuable because they were representative of individuals in the class, thus allowing diversity to be explored. They also provided information about changes in students' approaches to learning during the course.

Pre/post Survey

In order to triangulate ethnographic data with a quantitative data source, a ratings scale survey was administered to consenting students on the first day of class and at the end of the semester. This quantitative source of data balanced and enhanced the qualitative observation and interview data. The survey consisted of three subscales measuring: (a) self-efficacy towards biology, (b) learning orientation, and (c) learning approach. There are existing instruments that measure these domains; however, to mimize disruption the course instructor asked that the scale be kept to eighteen items. In order to develop a concise instrument I searched the literature and existing scales for information on defining and measuring the domain of each construct. Survey items were then selected or created to suit the particular context of the Biology 120 course. The development of each subscale is detailed below. A draft of the survey was submitted to Dr. Richard Sudweeks, a specialist in measurement, for critique and revision and then administered to five volunteers for usability testing (survey instrument and results in Appendix A).

Self-efficacy. "Self-efficacy is the belief in one's capabilities to organize and execute the course of action required to manage prospective situations" (Bandura, 1995, p. 2). Self-efficacy is always directed towards a specific target but the target can be quite general (ability to succeed in college) or more specific (ability to solve a defined problem). In this research a middle level of specificity was selected: ability to learn biology. This selection was based upon the instructor's interest in this affective outcome and his course objectives of helping students learn to think like biologists. A research paper by Witt-Rose (2003) provided models for the five self-efficacy items (items 1-5) used in the subscale. A reliability analysis of responses to the post survey yielded a Cronbach's Alpha of .74.

Learning orientation. Learning orientation refers to students' goals or purposes for engaging in learning activities. Eison described two contrasting learning goals: learning orientation and grade orientation (1981). Students with a learning orientation tend be intrinsically motivated and focused on self-improvement while students with grade orientation tend to be focused on achieving a desired grade with minimal effort. Eison's LOGO scale served as a source for four of the six items making up this scale (items 6,7,8, and 11) (1981). I wrote the other two items in consultation with Dr. Sudweeks (items 9 and 10). A reliability analysis of responses to the post survey yielded a Cronbach's Alpha of .82.

Learning approach. While learning orientation refers to a goal, learning approach refers to the strategies students use to attain their educational goals (Entwistle, 2000c). Researchers from the Enhancing Teaching-Learning Environments in Undergraduate

Courses (ETL) Project created three questionnaires designed to measure learning approach:

1. *The Learning and Studying Questionnaire* (LSQ)
2. *The Experiences of Teaching and Learning Questionnaire* (ETLQ)
3. *The Approaches and Study Skills Inventory for Students* (ASSIST).

Two original items were created (items 12, 17). The others were based upon items in the LSQ (items 13,14), ASSIST (item 16), and the LOGO (item 18) scales. A reliability analysis of responses to the post survey yielded a Cronbach's Alpha of .93.

Course Evaluation

A modified version of an existing course evaluation survey designed for evaluating the formative format Biology 120 course was administered at the same time as the post-survey. The items were modified over a five-year period in order to improve the scale and were slightly changed to adapt to the purposes of this research. The scale was made up of 20 rating scale items (survey instrument and results in Appendix B).

Existing Course Instruments

I had access to measures already in use in the class. Students kept a record of attendance, completion of assigned reading, and completion of homework problems. They also reported their weekly assessment scores, strengths, areas that needed improvement, and plans to improve. This self-report document was turned in at the end of the course (Appendix D).

Students also composed a one-page grade justification document at the end of the course. Its purpose was to give students the opportunity to propose a grade based upon evidence from performance on the weekly assessments. This document provided personal and individualized descriptions of students' view of their learning experiences.

Performance data was provided by weekly formative assessments and by a pretest and a posttest. The weekly assessments provided an indication of learning progress across the semester. They were made up of approximately 4 to 23 selected-response items designed to assess comprehension, application, and analysis (Anderson & Krathwohl, 2001). The pretest was optional but encouraged and students took it during the first two weeks of the course. The posttest was given as a final exam on the last day of the course. Both tests were made up of selected-response items and they had 22 items in common. The 60-item posttest served as a summative measure of student learning.

Students also completed a university-designed course evaluation survey (Brigham Young University Student Ratings Survey). It was delivered online and made up of 23 selected response items and one open-ended item measuring students' evaluation of the course and instructor (Appendix E).

Procedures

On the first day of class, the instructor was away so I used the time to introduce myself to the students and explain the purposes of my research. I was quite identifiable during subsequent classes because of my age (50s) in relation to theirs (20s) so it was not possible to unobtrusively blend into the group. Instead, I made myself known to students and enlisted their help in understanding their learning experiences. Data collection began on that first day with the signing of IRB permission forms and the administration of the pre-survey. Students were asked to take a pretest at the testing center to be completed during the first two weeks of the semester. This was standard course procedure. The survey and pretest data provided information about students' affect and performance at the beginning the course and were compared to data from the post-survey and the final exam. They were also used to select students to participate in formal interviews.

Starting with the second class session, I sat with the students in class, observed, took field notes, and participated in class activities. I chatted with students before class and I remained after the class to note questions and concerns students brought to the instructor and teaching assistants. I also attended some of the student help sessions in order to observe and talk to students about their learning strategies and progress. These observations and informal interviews continued throughout the course with changing focus as themes and patterns emerged from ongoing data analysis. Formal interviews started six weeks into the course. I interviewed 13 students who served as informants to help me better understand, in depth, their experiences as they prepared for class, participated in class activities, took assessments, and progressed in their learning. I also regularly interviewed the instructor and the teaching assistants.

The focus of this research necessarily started out broad, but each week I analyzed and reviewed the data, both qualitative and quantitative, collected to that point. This process directed the focus of subsequent data collection. It oriented my observations and informal interviews and influenced questions that were used in the formal interviews. I also met with the instructor each week to discuss findings from data analysis and to strategize ways to collect data on emerging issues. He helped me create unobtrusive measures to probe students' attitudes and learning strategies during the course.

In order to check the quality of my analyses, I incorporate emerging findings into subsequent data collection and asked students for their input (member checking). I also regularly checked my data collection and analysis procedures with David Williams, an expert in qualitative research and evaluation (peer review). Both of these activities shaped the ongoing research process.

Analysis

Various analytical procedures were used depending on the type of data and the questions addressed. They are summarized by research question in Appendix F. Because this research was primarily qualitative in nature, the focus of this section will be on the general approach to analyzing observation, interview and other qualitative data. Data analysis procedures were largely derived from Spradley (1980). The analytical process was cyclical rather than linear. Data analysis, and even the preliminary writing up of results, took place intermittently during the data collection process rather than at the end. This approach served to generate questions while it was still possible to collect new data. The desired end result of this analysis was a description of categories, themes, and their relationships pertaining to students' learning experiences in Biology 120. This process occurred by following Spradley's established qualitative procedures, integrating those findings with the results of quantitative data analysis, and considering both sources of information in the context of previous research (Entwistle, 2000).

Ethnographic Analysis

According to Spradley, "Analysis of any kind involves a way of thinking. It refers to the systematic examination of something to determine its parts, the relationship among parts, and their relationship to the whole. Analysis is a search for patterns" (1980, p. 85). He recommended twelve steps in conducting ethnographic research (1980):

1. Locate a social situation.

2. Do participant observation.

3. Make an ethnographic record.

4. Make descriptive observations.

5. Make a domain analysis.

6. Make focused observations.

7. Make a taxonomic analysis.

8. Make selected observations.

9. Make a componential analysis.

10. Discover cultural themes.

11. Take a cultural inventory.

12. Write an ethnography.

Steps one through ten, those related to the data analysis portion of Spradley's ethnographic method, will be described here.

Domain analysis. "A cultural domain is a category of cultural meaning that includes other smaller categories" (Spradley, 1980, p. 88). Examples of a domain that may be important to this research are "types of learning activities" or "steps in completing a homework problem." There are many possible domains involving a number of semantic relationships between the domain title and its categories. The analytic task was to search for domains embedded in data that was collected. From this a list of domains and their categories was created. Domains were discovered by reviewing field notes and responses to in-class questions. When there were multiple references to certain categories within domains, as in the responses to in-class questions, I added a quantitative component to the domain analysis. I coded question responses by category and counted the number of times each category was mentioned. This allowed me to describe the relative weight of the different domain categories.

Focused observations. Because it is difficult to analyze and describe an entire cultural scene, observations must eventually become focused. Focus can be quite broad but shallow or deep but limited in range. In this research, a compromise between these two extremes was sought. I endeavored to gain a surface understanding of student experiences as a whole, but to also focus deeply on a few selected domains. These domains were determined as research progressed and were informed by the research questions outlined in chapter one. I focused on students' attitudes towards learning, strategies for studying, confidence in ability to learn biology, and experiences with problem solving and formative assessment. Within those foci, I asked students or searched the data for answers to structural questions designed to amplify the existing domain descriptions. For example, one domain of focus was formative feedback. I composed the following structural question: what are all of the types of formative feedback activities in class? This question focused my future observations and interview questions and added to my existing description of that domain.

Taxonomic analysis. A taxonomy describes the relationships among items included within a cultural domain. Important domains were selected for taxonomic analysis based upon the principles outlined in the preceding section and a taxonomy of categories and subcategories was created. This was accomplished by both searching existing data and obtaining new data. If possible and appropriate, a quantitative component was included in order to weight the categories and subcategories.

Selected observations. Selected observations further expanded the description of each domain. The purpose was to discover dimensions of contrast between items within a domain. This was accomplished by searching the data and/or asking students contrast questions to determine how members of a domain were alike or different (What is the difference between preparing for class discussions and preparing for an assessment? Which two of the following typical in-class activities are the most alike: drawing a diagram, discussing ideas in small groups, voting on answers to questions posed by the instructor?).

Componential analysis. Componential analysis builds upon each of the steps described above and results in a summary of attributes and dimensions of contrast associated with selected cultural domains. It is a search for meaning associated with the identified domains and contrasts. First, I selected domains of focus for analysis; then I inventoried all contrasts previously discovered prepared a paradigm worksheet (Spradley's term) identifying the dimensions (levels) of contrast and the relationships among them. For example, one domain of interest was change in learning approach. The domain analysis yielded a list of categories of changes students indicated they planned to do before a subsequent assessment. I then identified a contrast within those categories: change in approach versus increased effort on an existing approach. Each category in the domain was then categorized on the worksheet according to that contrast. Because the data for this analysis came from responses to an in-class question, I included the frequency each category was mentioned and this provided information on relative weights of the dimensions of contrast. The finished product facilitated understanding by providing a visual summary of each selected domain and its set of contrast (an example of a paradigm worksheet can be found in Appendix G.

Cultural themes. A cultural theme is "any principle recurrent in a number of domains, tacit or explicit, and serving as a relationship among subsystems of cultural meaning" (Spradley, 1980, p, 141). Themes often recur throughout different parts of a culture and serve to connect cultural subsystems. In order to discover cultural themes I examined the descriptions, analyses, taxonomies, and paradigm worksheets of all important cultural domains and then searched for higher level contrasts and organizing principles among those domains. This focused attention on the culture as a whole and allowed themes to emerge. The search for themes was an ongoing process conducted during the research so that emerging ideas could be checked through further data collection and analysis. The final step, at the conclusion of the research, was to summarize the themes and associated domains.

Quantitative Analysis

In addition to the qualitative steps proposed above, survey and assessment data were analyzed using quantitative procedures. Quantitative data were treated in two ways: as aggregated data producing class or subgroup descriptive statistics and as measures of individual student's latent traits. Both levels of data were important in this research. Data from selected individuals was described or graphed in order to highlight individual differences. Aggregated data was used to describe general trends among the entire group or subgroups.

Pre/post-survey and course evaluation survey. These surveys were designed to measure affective traits and students' opinions about the course. Students responded on a ratings scale, and depending on the purpose, responses were treated either as frequency data or scaled data. Student response counts were reported in frequency tables.

The pre and post-surveys consist of three subscales: self-efficacy towards learning biology (Items 1-5), learning orientation (Items 6-11), and learning approach. Negatively worded items were recoded and subscale scores were calculated by averaging student responses across the items in each subscale. Pre and post-survey subscale score means could then be compared using a t-test.

Assessments. Weekly assessments and the pretest and posttest consisted of selected response dichotomously scored items. Item difficulty levels were calculated for each item and total scores, as well as average proportion correct, were calculated for each student. Scores were examined individually or aggregated into groups or subgroups to produce descriptive statistics that were compared across time and across groups or individuals.

Gain scores per item and per person were calculated for the items in common on the pretest and posttest by calculating the proportion of correct responses (per item or per person) and subtracting the pretest value from the posttest value. A qualitative component was added to item gain scores by examining item difficulties on the pre and posttests. Difficulty levels below .70 were qualified as difficult and levels above .70 were qualified as easy. Items were then categorized by their pair of difficulty levels on the pre and post tests into easy/easy items (EE), easy/difficult items (ED), and difficult/difficult items (DD).

Integration

Qualitative data analysis produced categories, domains, taxonomies, and themes. Quantitative data analysis produced measures of learning and affect. In order to facilitate an integrated view of the qualitative and quantitative data from individual students, an Excel spreadsheet was created with a row for each student and a column for each source of individual data. Most scores and question responses were entered into the spreadsheet along with demographic and any other individual information that arose during the research. Data were coded as needed to create subgroups among students. This allowed quick access, through the Excel sort function, to information on subgroups of students. It also facilitated the exploration of data through the calculation of descriptive statistics. In order to identify the relationship between scaled variables I selected an appropriate quantitative measure for each research question and then calculated a correlation matrix.

The purpose of this research was to explore and describe student learning. Because learning is a multifaceted process, and the data produced by this research were complex, it was not feasible to perform every possible calculation and examine the data from every potential angle, however I hope that the end result is a descriptive and sensitive view of students' experiences that fosters an appreciation of the complex process of learning. In the words of Robert Stake, "The function of research is not necessarily to map and conquer the world but to sophisticate the beholding of it" (Stake, 1995, p. 43).

Theoretical Approach

Personal Assumptions

There are important philosophical underpinnings to the choices of methodology described above. I did not look at the research questions and then work backwards to define an appropriate theoretical and methodological rationale. I worked forward from my basic beliefs about the nature of reality, about the development of knowledge, and about what it means to be human and to learn. These beliefs informed my choice of research topic and methodology. Consequently, they will be overviewed here. I generally concur with a constructionist epistemology as defined by Crotty:

> All knowledge, and therefore all meaningful reality as such, is contingent upon human practices, being constructed in and out of interaction between human beings and their world, and developed and transmitted within an essentially social context. (Crotty, 1998, p. 42)

I believe that learning is social, unique to the individual, and context bound. Any thorough exploration and description of such a complex phenomenon, in my opinion, should at least explore these elements. This stands in contrast to most experimental research where the goal is to control extraneous variables. Bloomberg's comments on observation in medicine illuminate this issue (Quoted in Entwistle, 2000) :

> In medicine, where observational science is crucial, the complexities of a phenomenon can be understood, at least in part, by repeated observations of a whole organism or a population of organisms under a wide range of circumstances; all the variables are retained and as many as possible are examined. . . . By contrast, in a reductionist approach, experiments are designed

to simplify the study of natural phenomenon by eliminating all but a few variables, and the explanation is in terms of the most essential element that is causative, but this is often not knowable and may be a fiction of the investigators desire to have simple answers to complex problems. . . .Understandings which are on the border between chaos and order where, according to some, many of the problems of nature lie, may not provide exact solutions but rather those which can allow application and understanding to emerge. (p. 211)

This holistic approach is applicable to educational research. “Research methods that retain a view of the whole organism . . . in a wide range of circumstances can play an important role in creating descriptions that are closer to reality, and can be applied to practice” (Entwistle, 2000, p. 211).

Intertwined with this constructivist and context based view of knowing is my vision of what it means to be human. I believe that each individual is unique and that it is difficult to adequately describe the richness of human experience through generalized and abstracted labels and measures. I also believe that humans are agents who enjoy the possibility of acting for themselves but who are, at the same time, influenced by both their past and their future (Slife & Williams, 1995). I consider learners to be constructors of their own knowledge and I agree with Kelly (1955) that learning is an active process of successively constructing approximations and testing them against experience.

This set of beliefs underlies each choice I have and will in planning and conducting this research. I hope that the design and implementation of this research reflects the respect I have for the complexity of the teaching and learning process.

It is important to note here, while revealing my assumptions and biases, that I have been working with the formative format pedagogy for the past two years and have developed a positive attitude towards the set of teaching practices. I have personally observed the students' positive attitudes and improved performance in the context of a pilot study I conducted on a cellular biology course taught by Bell. I consciously tried to put these feelings aside and remain open to evidence contradicting my current views of the pedagogy.

Choice to Insert Quantitative Methods into a Qualitative Paradigm

Quantitative methods do not necessarily presuppose a positivist epistemology. Numbers are not inherently positivistic. According to Yanchar (in press) it is their use and interpretation that must be examined:

> Put simply, the problem is not numbers per se, but the appropriation of numbers into a framework that cannot do justice to the meaning and possibilities of human existence. From this perspective, there is no a priori reason why researchers interested in contextual, interpretive understandings must categorically reject all forms of quantitative data and numeric interpretation. (p. 8)

In this study quantitative data were viewed as one form of evidence that was useful in describing a phenomenon.

Yanchar (in press) described the integration of quantitative methods into a contextual paradigm as "contextual-quantitative" inquiry. He suggested the following four areas (section titles) be examined in conceptualizing such an integrated approach.

Quantitative variables. In quantitative research individual behaviors are abstracted into variables said to represent certain natural processes. These variables then sometimes become the focus of analysis. In order to temporize the tendency to view these variables as accurate representations of a shared universal quality rather than imperfect measures of an operationalized latent trait, I will consciously and overtly qualify group statistics as abstracted, but useful, information about general trends across groups of individuals. Group analyses will be supplemented with descriptions (quantitative and qualitative) of individual experiences.

Measurement. According to Yanchar (in press) sophisticated measurement techniques are often viewed as tools for revealing hidden traits:

> It is assumed, often implicitly, that this identification provides a glimpse into some underlying aspect of the human experience—some set of individual difference factors—that are consistent across situations and time and that can be used to better predict other mental processes and behavior. (p. 20)

I plan to use quantitative methods to provide information about latent traits such as learning and affect. I will overtly acknowledge that these measurements can only represent the state of one particular group in one particular context and that they are imperfect but helpful measures of an operationalized latent trait. I hope that the use of these statistical procedures will add to the quality of the description and analysis in a way that will produce findings that are potentially transferable by consumers of this research to other unique situations.

Validity. Concern about the quality of data analysis and resultant conclusions is expected and welcome. In order for the results of this study to be persuasive and helpful, they must be perceived as and actually be credible. According to Entwistle (2000),

> Credibility depends on the researchers ability to ground the analysis in the existing literature, to use established procedures in considering the data, and to argue the conclusions out of that data. In the long run, acceptance will depend on the reactions of other researchers criticizing the conclusions or offering alternative interpretations. (p. 161)

A number of qualitative researchers have suggested specific approaches to establishing credibility or trustworthiness (Lincoln & Guba, 1989; Patton, 2002). Patton distinguished between traditional scientific research criteria, with its standards of objectivity, validity, reliability, and generalizability, and social construction and constructivist criteria that are more applicable to this study. I addressed each of his criteria in the following manner:

1. Subjectivity acknowledged (discusses and takes into account biases): Potential researcher biases were made explicit to the extent possible, rival conclusions were considered, and negative cases were searched for, analyzed, and reported.
2. Trustworthiness: I selected, described, and implemented rigorous qualitative and quantitative methods that have been tested and published. I kept a research journal detailing each data collection and analysis decision and its justification. I periodically conducted a peer review by checking my decisions with an expert advisor.
3. Authenticity: The nature of the study promoted authenticity. Research was primarily based in the classroom and oriented towards student' actual lived experiences. Those student experiences were thoroughly and carefully described.

4. Triangulation: Patton suggested four kinds of triangulation: methods, sources, analyst, and theory/perspective. I triangulated method by using the set of qualitative and quantitative methods described above. I did not triangulate data sources on the case level because only one class was observed, but I did triangulate data sources on the student level by observing and interviewing many different students and by asking them to comment on information produced by each other (member checking). I was the only analyst, but I used expert audit review to enhance the quality of my work. Because this research took an ethnographic, and thus emic, approach, I considered many different theories and perspectives and also remained open to new emerging theory.
5. Reflexivity: "Even when he is well-intentioned and cooperative, the research subject's knowledge that he is participating in scholarly research may confound the investigator's data" (Webb, Campbell, & Schwartz, 1966, p. 13). This may be a problem because I was obviously an outsider to the class during my observations and interviews. It is difficult to limit interactions between investigators and respondents in qualitative research and, according to Lincoln and Guba (1985), "In order for the human instrument to use all of these abilities (tacit knowledge and prepositional knowledge and the ability to be adaptable) to the fullest extent possible, there must be frequent, continuing, and meaningful interaction between the investigator and the respondents or other objects of investigation" (p. 107). I used triangulation, member checks, prolonged engagement, and persistent observation to counteract distortions to the research due to reflexivity (Lincoln & Guba, 1985).

6. Praxis: Praxis refers to how one acts in the world (Patton, 2002). This research is designed to provide helpful, context based, real world information. In order for this research to be useful to practitioners, I have attempted to make the writing and organization of this document as simple and helpful as possible. The content will include thick description to aid in transfer.
7. Particularity (doing justice to the integrity of unique cases): Because the research objective is to describe and explore students' experiences, particularity is built into this study. In order to enhance particularity, I searched for individual differences during observations, I chose students with diverse characteristics for the interview protocol, and I highlighted individual differences in discussions and representations of quantitative and qualitative data.
8. Enhanced and deepened understanding (*Verstehen*): In order to enhance understanding, I designed this study to be a mostly qualitative and deep exploration of students' experiences. This will complement the large number of experimental or quasi-experimental studies that have been conducted on problem solving, formative assessment, and other focus issues of this research.
9. Contributions to dialog (Patton, 2002): There is ongoing dialog about formative assessment (Bass & Glaser, 2004; Black & Wiliam, 1998a; Stiggins, 2002), grading (Kluger & DeNisi, 1996; Kohn, 2004; Krumboltz & Yeh, 1996), learning approach (Beghetto, 2004; Dweck et al., 2004; Entwistle, 2000a; Entwistle et al., 2002), affect (Beghetto 2004; Dweck, Mangels et al.,

2004; Entwistle et al., 2002; Linnenbrink & Pintrich, 2004), and problem based learning (Dochy et al., 2003; Gijbels et al., 2005; Newman, 2003). I related the final results of this research to current theory and included a discussion of that relationship in this document.

Generalizability. Research findings, if they are to be generalizable, should be applicable in contexts beyond their original source. In this study, the contextual nature of any findings was frequently acknowledged, but the findings were explored for their implications in related contexts (Yanchar, in press). The focus was on the transfer of findings from their original source to other related contexts. Those who receive the study rather than those who produce it must undertake this transfer process and it is contingent upon the researcher to provide enough rich and descriptive information to foster that transfer.

The methodological approach of this dissertation required careful planning and attention to coherence. There are no clear precedents to determine its effectiveness or utility but moving forward into new realms is an important part of conducting research. According to Yanchar (in press),

> The most promising research programs will not be paradigmatically orthodox, but contextual and evolving theories of inquiry that involve well-thought-out, indigenous assumptions about the subject matter to be investigated and fallible research strategies—adopted, modified, or innovated—that cohere with those assumptions and appear to provide the most appropriate resources for fruitful investigation. (p. 8)

I hope that this research design and the critical examination of its underlying assumptions will add to the current dialog on integrating diverse methods into educational research.

Chapter 4: Results

This chapter will be organized by research questions. Question 1 addresses the pedagogy associated with the Biology 120 course. Questions 2 through 9 focus on learning from the students' point of view. Question 10, concerning implications for theory, will be addressed in Chapter 5. Two levels of data will provide answers to Questions 2 through 9:

1. Class level data (n = 263)
2. Case studies (n = 3)

Research Question 1

Question 1 asks: What is the nature of the formative format pedagogy and its context in the Biology 120 course taught at BYU winter term 2006? The answer to this question establishes the context for the results and discussion that follow. In order to address this question, I observed 30 of the 42 Biology 120 class sessions. I also interviewed the instructor directly about his pedagogy. The following description is a summary of the information gained from these two data sources.

Instructor

Dr. John Bell is currently an Associate Dean in the College of Biology at Brigham Young University. Despite his administrative duties he is, and has always been, a dedicated teacher. As an undergraduate at BYU he taught Spanish to future Latter-day Saint missionaries. He quickly realized that rote drill was insufficient to learn a language. At that point he started to wonder about how people learn and if it was possible to do something better as a teacher. Later, as a graduate student, he taught in a medical school. His concern at that time was mainly focused on presentation techniques. As part of this assignment he became a tutor to struggling students and began to appreciate the challenges faced by some students. When he came to BYU he taught physiology lectures and was quickly regarded, because of student reviews, as a good teacher who cared about students and gave clear and comprehensible lectures.

A few years later, as he was preparing for tenure review, he had two experiences that had a major impact on his teaching. First, a colleague, Dr. William Bradshaw, attended one of his lectures as part of his tenure evaluation. The topic of the class was osmosis. At the end of the lecture Bradshaw sat down with Bell and told him that the presentation was excellent; however, he then asked Bell if he thought that the students who heard that lecture would be able to solve a problem on osmosis. This caused Bell to realize two things: First, he had no idea if his students could solve an osmosis problem and, second, what he had done in class had not prepared his students to do so.

Bradshaw also triggered the second experience. He came to Bell's office as he was working on a lecture and asked him what he was doing. Bell replied that he was preparing what he was going to teach that day. Bradshaw replied, "How much time do you spend preparing what the students are going to do?" Bell was startled by that comment because he realized he was doing nothing or very little to plan what the students would do. That, in conjunction with attending a few nationally run workshops on active teaching, caused Bell to realize that he needed to do something more active in the classroom. Not long after that he started teaching cell biology and introduced into the classroom the idea of having application problems. He had the students spend time in the classroom working in small groups to solve data analysis problems. These experiences mark the beginning of a career of dedication to understanding and fostering active student learning.

In the process of developing a more active problem-based approach to learning Bell had to learn how to assess whether such learning was really taking place. In his words:

> As soon as we learned to assess better it opened a Pandora's box with respect to questions we had about how students were learning and how to help them learn better and all kinds of learning strategies came out of that. (Bell, personal interview, April 2006)

He decided that students needed an opportunity to iterate problem solving. They needed multiple opportunities to try, receive feedback, and try again. They had been doing homework problems, but he felt those assignments were not authentic enough. He also wondered about the fact that students progress at different rates in acquiring a skill such as problem solving:

> If our job is to help students reach a certain level, how important is the path leading up to that? It is important for an individual student to have a path that is successful but the trajectory doesn't matter. It doesn't matter if a student develops a skill early or late. The question is, did they develop the skill? (Bell, personal interview, April 2006)

Consequently, he decided that it was unfair to grade students incrementally during the semester. According to Bell, the grade ought to be based on their abilities at the end of the course. He started wondering what would happen if, instead, students had multiple opportunities to find out how they were doing in an authentic high-stakes environment. Under his original midterm exam assessment system of four midterms and a final exam, the first time students got feedback was after one fourth of the course was over and their next opportunity was a month later. In this system, there were only four opportunities to iterate, the stakes were too high, and the feedback was not immediate enough. This thinking led to the creation of the formative assessment system used in the Biology 120 course.

Course Objectives

There are both overt and unstated objectives for students in the Biology 120 course. In order to shift the focus of Biology 120 from the retention of large amounts of information to the development of thinking and problem solving skills, Bell had to address the tension between breadth and depth. It was impossible to address every pertinent topic so Bell carefully selected the topics that were most important for new biology students to master. He then created a set of objectives. These overt objectives were listed in the course syllabus (Course syllabus, Biology 120, Section 1, Winter 2006):

1. Be able to explain the following foundational concepts:
    A. Cell theory and biological compartments
    B. Chemistry of life (biochemical unity, Central Dogma)
    C. Bioenergetics (biotransformation of energy)
    D. Reproduction (fission, mitosis, meiosis, etc.)
    E. Evolutionary theory
2. Be able to explain and use the scientific method:

A. Apply critical thinking to the purposes and objectives of scientific studies and data.

B. Become observant of and curious about patterns and processes in living things.

C. Ask essential, specific, answerable questions about observations.

D. Form hypotheses about biological patterns and processes that are testable.

3. Be able to explain and use basic descriptive statistics and presentation of experimental results:

   A. Examine data collected from experiments.

   B. Analyze variation in the collected data and how it impacts conclusions.

   C. Summarize and present data in tables, figures, and conclusion statements.

   D. Determine and express how much confidence can be placed in the conclusion.

   E. Defend the probability that a relationship exists or that it resulted from chance.

   F. Calculate the probability of biological relationships from sets of data.

4. Be able to explain the design of a simple experiment and draw basic conclusions from its results:

   A. Design experiments to test predictions, determine variables to change and measure.

B. Understand how sampling and replication impact results and conclusions.
C. Draw conclusions based on sets of data gathered from simple experiments.

In addition to these content-related objectives, Bell organized his course to promote changes in student approaches to learning. He wanted students to move from a leaning strategy that focused primarily on the recall of isolated bits of information to one that was synthetic and focused on the understanding of fundamental concepts and applications of those concepts to solving problems. He also wanted students to come away from the Biology 120 course with an understanding of how some fundamental quantitative techniques integrate with biology. He hoped that this experience would help students move away from the tendency to apply a formulaic set of rules to problem solving and towards a deep understanding of the relevant concepts and skills. Based on this he hoped that students would be able to make decisions in their own lives the way that scientists make decisions: based on data.

Course Organization

The winter semester Biology 120 class met on Mondays, Wednesdays, and Fridays from 12:00-12:50 pm. Instruction generally followed a weekly schedule. Mondays were used to present a new concept, Wednesdays were used to practice problem solving related to that concept, and Fridays were assessment days. Students were expected to have completed a weekly reading assignment related to the week’s concept before class each Monday and sometimes Wednesday. In addition to reading the material, students were to write a one-sentence summary describing the central message of the reading assignment, a short paragraph or diagram illustrating important points, and a list of questions reflecting elements of the reading that needed clarification. This encouraged active reading. Students were to come to class with a basic understanding of the concept so that class could be used to do something with, and build upon, that understanding. Students were given homework assignments each week. They were either reading or problem solving assignments from a course packet or elaborative questioning (explained in detail below) based on the week's topic.

Grades were based on self-reported completion of reading and homework assignments (27%) and the final exam (73%). But, students had the opportunity, if they wished, to add a third variable to their grade calculation. They could propose a self-assigned course grade based on their performance on the weekly assessments. This proposed grade, if higher than the actual grade earned on the final exam and supported by convincing evidence, would be averaged with the final exam grade. According to the syllabus,

> At the end of the semester, you will have the option of writing a one-page paper on which you indicate the grade you believe you deserve for the course and a defense of that grade using data from the weekly assessments. You will choose how to apply these assessments. For example, if you observe significant improvement in your performance, you may wish to justify your proposed grade based on that improvement. After I have graded your final exam, I will compare your grade to that which you proposed. If your proposed grade is higher than the one from the final exam, I will examine your justification and the file of your weekly assessments. If I agree with your appraisal, I will adjust your final grade

to reflect a 50% contribution from the weekly mini-exams. (Course syllabus, Biology 120, Section 1, Winter 2006)

This purpose of this practice was to add weight to the weekly assessments so that students would put effort into preparing for and taking them and also to mitigate students' concern about the high degree of impact that final exam performance would have on their course grades.

Three teaching assistants (TAs) helped with the class. They were actively involved in the classroom. When students were asked to solve problems or talk to a neighbor the TAs roved throughout the classroom checking on student progress and answering questions. They also scheduled office hours and held help sessions as needed throughout the semester.

Assessments

Ten assessment days were held, approximately once per week, during the course. On a typical assessment day, students spent the first 20-30 minutes of the class time completing the assessment. They seemed to treat the formative assessments like exams because class atmosphere while taking them was quieter and more serious than during other class days. After completing the assessments, students spent approximately ten minutes scoring them collaboratively with a partner. The last 10-20 minutes of class time were spent receiving feedback on the problems from the assessment and on how to improve their performance for future assessments. Bell encouraged students to note their errors and make commitments on how they planned to correct them.

Students were not required to take the assessments, but they did receive points for attendance on assessment days. Students completed an average of 8.5 of the 10 possible assessments. One of the assessments did not count towards attendance because the instructor was away. Five students did not complete any assessments and 107 completed all 10. The average performance on the assessments was 78%.

Each assessment contained between 5 and 23 items. The items were mainly selected-response format but some of them required a diagram or a short answer. All items required thinking beyond the recall level and most demanded application or analysis (see Appendix H for a sample assessment). Most items focused on the concepts taught during the pervious week but each assessment also included items on topics taught earlier in the course. This allowed students to check and recheck their levels of understanding and skill.

Students were also given a 30-item pretest and a 60-item posttest (final exam). All items were selected-response format. Most items assessed higher order thinking but some posttest items assessed basic understanding and recall. The pretest was designed to identify students who were eligible to test out of the course. It also gave students an early view of the level of understanding expected of them. Seventy percent of the students took the pretest and all but 14 students took the final exam. Both exams included items covering the entire course content.

Class Activities

Bell believes that students must be actively involved in their learning. He tries to balance class time between useful clear explanations and student-centered activities. He comes to class each day having identified the learning objectives for the day and equipped with an array of potential learning activities. Interaction with the students during the class guides his choice of activities. Because of this, students experience a variety of learning activities during the Monday and Wednesday classes. I examined my fieldnotes from a sample of six of the twenty-five instruction-based classes (Mondays and Wednesdays) in order to determine the percentage of class time spent on different categories and subcategories of class activities (Table 2). Student-centered activities occurred an average of 23% of the time. Combined with the proportion of class time spent on student generated questions (17%), student-based learning took place an average of 40% of the time in class. An average of 53% of class time was spent on instructor-centered explanations with the rest of the time spent on mixed activities such as question and answer sessions.

Table 2

Percent of Class Time Spent Per Class Activity Category and Subcategory

Category	Sub-category	Category Mean	Category Standard Deviation	Category Minimum	Category Maximum	Category Total
Instructor-centered activities	Demonstration	7.67	9.67	0	24	52.67
	Lecture	39.33	17.47	20	68	
	Learning strategy pep talk	5.67	3.20	0	8	
Student-centered activities	Vote on correct answer	3.00	3.29	0	6	22.66
	Predict outcome	3.00	5.02	0	12	
	Talk to peer	9.33	6.77	2	20	
	Work problem	2.33	4.08	0	10	
	Draw	3.00	5.62	0	14	
	Write	0.67	1.63	0	4	
	Shout answers	1.33	1.63	0	4	
Mixed activities	Instructor explanation with short student responses	3.33	5.32	0	12	3.33
Questions	Instructor questions	4.67	5.75	0	14	4.67
	Student questions	16.67	13.84	4	38	16.67

A variety of student-centered learning activities occurred during those six classes:

1. Students discussed concepts in pairs.
2. Students voted on answers to a question by raising hands.
3. Students voted on answers to a question by shouting out the answer.
4. Students wrote down answers to questions.
5. Instructor posed question, students answered individually.
6. Instructor posed question, the class called out the answer.
7. Students posed questions to the instructor.
8. Students worked on problems.
9. Students drew diagrams that illustrated concepts.
10. Instructor had students predict what would happen next in an experiment
11. Instructor had students tell him what to do to solve a problem.
12. Students were asked to work in pairs and prepare to present a concept to the class, then the instructor asked for volunteers to present.

Instructor-centered activities from those six classes included explanations with PowerPoint illustrations, metaphors, PowerPoint-based animations, demonstrations, and in-class experiments.

Formative Feedback

While Bell's interest in active learning is an unstated emphasis in the classroom, his dedication to formative feedback is clearly promoted. The theme of the class, repeated many times to students is, “expose yourself.” At the beginning of the first day of class he said something like this:

> There is something that is critical for you to know – the theme of the class. Don’t get nervous. Our motto is going to be “exposure.” There won’t be anything weird, no strange demonstrations. In order to learn, an interesting process has to occur. You may not have thought about this. You arrive here with a sense of what the world is – what’s true and what’s not in science – how things work. But some of your ideas are wrong. They are misconceptions. You will discover them, get rid of them, and replace them with truth. Often what happens is that students fail to discover their misconceptions. They just dress them up and then go back to those misconceptions after the course. A way to deal with this is to expose yourself. Success in this course may depend on how many things you find out you misunderstood rather than what you understand. I am asking for your trust and your willingness to expose these things. (Class fieldnotes, January 11, 2006).

The formative assessment system is an outgrowth of Bell’s desire to provide feedback to his students as they iterate through their learning process. However, in addition to this, Bell subtly weaves opportunities for feedback throughout each day of instruction. As students actively participate in their own learning, they are often asked to do something to make their ideas concrete so that those ideas can be examined in comparison to the ideal. I reviewed fieldnotes from one class (January 18, 2006) in order to identify student opportunities for feedback that occurred during that class. Bell took two approaches to promoting formative feedback. First, he taught students about the value of managing their own learning and using feedback to identify misconceptions or lack of understanding. Examples of this type of activity include:

1. Early in the class Bell told students that their job was to get their questions answered and to identify whether or not they understood the concepts. They were told to leave the class with a checklist of things to take to the instructor or to a TA to clarify.

2. After conducting a learning activity, Bell said, "We will move on but make sure if you have residual questions you make plans to address them. Don't just forget about them and move on. They need to be resolved before Friday [assessment day]" (Fieldnotes, January 18, 2006)

3. At the end of a class Bell reminded students how to do an effective EQ. He emphasized that the person being taught was to act as interrogator and it would not be enough if they only asked questions of clarification. The listeners were to ask "why." He said, "The fact that you are putting it into words is important. If you discover that your are not able to explain something you must find that out" (Fieldnotes, January 18, 2006)

The second thing that Bell did to promote the use of formative feedback was to design activities that forced the students to make their learning concrete followed by opportunities to compare their concrete learning to the ideal. Students did the following five feedback activities during the class held on January 18, 2006:

1. Bell asked the class, "If we compared an elephant and an ant, we might imagine there are two possibilities: either they have the same number of cells

and the cells in the elephant are bigger or the elephant has more cells. We will do science by democracy. Vote your conscience." The students then raised their hands to indicate whether they thought elephants had more cells or bigger cells. After explaining the correct response Bell said, "Think about that. It may help you understand why it is critical that organisms are made up of cells."

2. Students were asked to take a minute and write down as many reasons as they could think of for why it is critical that organisms are made up of cells. Bell then showed his reasons and told students to compare their lists to his. He asked students, "Did you come up with some of these?" He then invited student comments and questions.

3. Bell told students he had a list of three functions of cell membranes. He asked students to see how many cell membrane functions they could write down on a piece of paper. He then said, "I know what some of you are thinking – I'll just wait until he tells me the answer. Don't do it!" After a minute he had students share their lists with a neighbor. He interrupted them after a few seconds, and had them stop and look at his list of cell membrane functions on the board. He told students that they needed to include that information in their discussions.

4. Students were told to draw a phospholipid and explain the properties of its two major parts to a neighbor. Students worked and talked for two minutes and then Bell gave them his explanation. Then he added, "Your answer only qualifies as correct if you put down that the head interacts with water."

5. Students were told to draw a phospholipid bilayer and explain why it is stable. They were encouraged to interact with their neighbors. After five minutes Bell called the class to order and gave his explanation.

Each instructional class includes activities such as these to emphasize the importance of formative feedback and to give students opportunities to diagnose their own learning.

Elaborative Questioning

Students were assigned to do elaborative questioning (EQs) 13 times during the semester. EQs were designed to encourage students learn by teaching concepts and skills to one another. According to the syllabus,

> The presenter explains an important concept from the pervious class as thoroughly as possible, but entirely from memory. The interrogator asks follow-up questions beginning with the word "why" or "how." When the answer is not known or a misconception arises, use the book, me, or a TA as a resource to solve the difficulty. Partners then switch roles and the procedure is repeated . . . I expect that a quality job of EQ will require 15 minutes or more of presentation and questioning for each partner. (Course syllabus, Biology 120, Section 1, Winter 2006)

Teaching to learn was a new concept to most students and they needed help understanding exactly what they were to do. Bell often took a few minutes of class time to encourage students in their EQs. He would tell them to spend time teaching important principles that came from the readings or class discussions. The person being taught was to act as interrogator by asking good questions demanding clarification. The person doing the teaching was to focus on learning through the process of putting their thoughts into words. Towards the end of the course Bell was still concerned that many students were still not experiencing quality EQs, so to prepare them for the final he modeled a good EQ. The following descriptions refers to a class held on March 16, 2006.

Bell asked for a volunteer to come to the front of the class and "be a good sport." A male student (John) raised his hand as students applauded and cheered. As he approached, Bell looked up at him and lightened the mood with a little humor: "You are tall. Good for you." Students laughed. Bell said, "Tell me about chromosomes." John explained the helix and said that chromosomes are storage for DNA during meiosis. He then said, "That is pretty much all I know." The class applauded. Bell then told the class, "You have just seen a demonstration of an EQ. John was doing the best he could. He did a good job. What was I doing?" A student said, "You didn't ask any questions." Bell asked the class if that resembled any of their EQS. He then said, "At the end of class students will come to me and say, 'Man the EQs were the best ever.' Another student will say, 'Get rid of EQs. They are a waste of time. A lot of you may be wondering how to get ready for the final. So, John, come over her to the chalkboard and draw me a chromosome." John drew a rectangle on the board. The following dialog took place:

Bell: What is a double helix?

John: It's made of a polypeptide chain.

Bell: What is a polypeptide chain?

John: (explains his idea of a polypeptide chain)

Bell: Point to the polypeptide chain in there.

John: (pointing) Here is one and here is another.

Bell: What is the difference between a nucleic acid and a polypeptide chain?

John: (no comment, looks confused)

Bell: What is the difference between a nucleotide and a nucleic acid?

John: (starts to draw) I'm not sure what a nucleic acid is.

Bell ends the EQ by telling John he has been a good sport and asking the class to give him a hand. Students applaud, cheer, and whistle. Bell then asks the class, "What was the difference about this. What did you see?" Students respond that he asked why and what questions and that he made John draw. Bell then said that John had revealed some misconceptions. He then took a minute to correct them. He said "I had no idea that any of those things were going to be a struggle for him when I heard the first explanation. Frankly, it was really good. It wasn't until I got to the point - gosh, I don't know that – that we made progress." Bell asked the class, "Do you see the difference between a quality EQ and a phony baloney EQ?" He finished by telling the class that it was important to keep asking questions during EQs and then find the answers. "If you get to the point where you are stuck, get out the book. If you can't reconcile it that way, get on the phone or email or see me or the TAs. It is better to find out you don't understand and then go to the book rather then just read the book as say to yourself, 'yes, I understand this.'" (Class fieldnotes, March 13, 2006)

Class Description

I observed and took fieldnotes on most of Bell's classes held during the 2006 winter term. While each session of the class was unique, the general atmosphere and types of learning activities can be illustrated by describing a typical session. The following description refers to a class held on Monday March 20 (Class fieldnotes, 2006).

Students begin clustering outside the large lecture style classroom between 11:45 and 11:50. They sit on stairways and line the halls. Some are chatting with one another and others are looking through papers and books. The bell rings at 11:50 and the door of the classroom opens. Students from the 11:00 class begin to exit and as the stream diminishes the waiting students begin to enter the classroom and find seats. The room is a large stadium-style classroom. Seats are divided by aisles into left, center, and right sections. The rows of seats gradually rise and widen moving from the front of the classroom to the back. On the front wall of the classroom there is a wide three-paneled chalkboard, various screens that can be extended to cover the boards, a large table equipped with a sink and other laboratory apparatus, and a podium with computer access. The room is equipped with a computer, DVD player, and projector.

As the 12:00 bell rings most students are in their seats. The classroom is quite full with only a few empty seats scattered in the back of the room and in the middle of wide rows. As is the custom in many BYU classes, the instructor, John Bell, calls upon a student to give an opening prayer. After the prayer Bell begins talking about his weekend and his sore muscles from a home improvement project. Most students are engaged with the story and chuckle at his humorous remarks. A male student from the back calls out a question, “Are you going to teach us about lactic acid build up today?” A few students get the joke and laugh. I am sitting in the back of the classroom and some of the students around me are chatting with one another and not engaged with Bell’s story. Bell finishes his story by saying, “That was intended to make you feel sorry for me before I do something that is incredibly rude. Take out a piece of paper and write these ten words down." He then displays a PowerPoint slide on one of the screens in the front of the classroom with the following ten words:

1. phenotype
2. allele
3. genotype
4. dominant trait
5. recessive trait
6. homozygous
7. heterozygous
8. segregation
9. crossing-over
10. gene

Students begin writing. Bell then instructs the class that when they have completed writing the list they should go back through it and draw an icon by each term. He demonstrates three possible icons by drawing them on the board: a smiley face, a neutral face, and a sad face. He says a smiley face indicates: "You would be happy to explain to the whole class what it means." A neutral face indicates: "You think you know what it means but would not want to explain it to a group." The sad face indicates: "I need help." He then tells the class that rather then write down definitions for each term now, they are to keep the list nearby and adjust the icons as they improve understanding or newly perceive lack of understanding. He finishes this segment of instruction saying, "By Friday they have all got to be smiley faces, folks," and suggests that if help is needed students should seek the teaching assistants, classmates, the book, or "come see me."

Six minutes have now passed and Bell directs students' attention to a PowerPoint slide illustrating an allele. The slide contains a drawing of an allele and this list of tasks:

1. Draw a diagram that teaches the principle of an allele.
2. Show in your diagram a gene that is heterozygous.
3. Use the diagram to show the molecular basis of dominant and recessive traits.

He reads the tasks out loud and asks students to work on them. There is low chattering as some students talk to their neighbors. Bell notices the chattering and says, "If you are wondering if it is OK to work with a partner on this – absolutely." The noise volume elevates. Bell and the TAs wander around the classroom glancing at students' work and pausing occasionally to answer a question.

I am able to hear two male students working together sitting behind me. Their conversation is something like this:

"You did pretty good on that."

"I did pretty much the same thing."

"It looks good to me."

"What I get mixed up on is the difference between chromosomes and chromatids."

"Chromatids are during meiosis and mitosis . . . that means you are going to have two sets of sister chromatids . . . this is a chromosome (pointing to his drawing) . . . that is something I didn't understand at first."

Bell and the TAs are roving and helping students. Three students have hands up as they wait for individual help.

After six minutes of work Bell interrupts the class to tell them there should be two chromosomes in their drawings. “If not, you have a question that needs to be answered.” The students go back to work and the chattering continues. The student behind me says. “I think I got it.”

At 12:15 Bell calls the class to order and says, “Let me share my diagram with you now. Then I will give you the opportunity to ask questions to compare what you thought with what I thought.” He puts up a slide and stands at the podium using the computer cursor to point as he explains his diagram (on a PowerPoint slide) and responds to questions. He talks about protein coding and the fact that recessive genes often code for “junk” or useless proteins. A student asks, “Does a protein only code in one place on the chromosome or can it be in several places?” Bell answers the question and then uses animation built into his slide to illustrate gene coding. He asks the class, “What is this little line meant to represent?” The class chants back “mRNA.” A student asks, “The alleles in humans – they could be for eye color or something else?” Bell responds, “One thing that it is important to understand – we are just a little more complicated then pea plants. Few traits in humans are linked to a single gene.” He goes on to explain the complexity of gene regulation.

After five minutes Bell begins moves the discussion to dominant and recessive genes. He points to a gene on the slide diagram that produces chlorophyll and asks the class, “In the language of genetics we would say this gene is. . .?” In response, the class (about 60%) chants, “dominant!” Then Bell points to the other gene and says, “And this gene is. . .?" The class chants "recessive!" A student asks, "Do we all have junk proteins floating around in our cells?" Bell responds, "Yes, you all have junk." The class laughs. Another student asks, "If the recessive trait comes through, how could this be if we all have junk?" Bell answers, "That is a brilliant question." He tries to climb up to stand on the table in the front of the room but fails and sits on the desk instead. Some students laugh as they remember his earlier story about sore muscles. Bell has climbed up and stood on the table four or five times in the past in order to make an important point. He sits on the table and says, "The recessive trait is what you get in the absence of the dominant. For example, blue eyes is the absence of pigment in the eyes. Those of you with blue eyes are mutant." The class laughs then students ask the following series of questions:

1. "What causes albino coloring?"
2. "Are there times when there are recessive traits?"
3. "Is there such a thing as two dominant alleles that are different?"
4. "If every diploid chromosome has two of every chromosome how does RNA polymerase know which gene to express?"
5. "Are there mechanisms in the cell that take care of junk proteins?"

Bell answers each of these questions and builds upon them when necessary.

At 12:30 Bell gives the class another exercise by putting up a slide titled "The Genetic Experiments of Gregor Mendel." It lists the following statements:

1. Crossed round pea plant with a wrinkled pea plant.
2. All the progeny had round peas.
3. Draw a diagram explaining why. Then teach each other.

Bell instructs the class, “If you still have questions about alleles and dominant and recessive, get your hand up and have a TA explain.”

The class then gets to work on the problem with many of students working in pairs. After two minutes Bell calls the class to order and explains that Mendel was pretty surprised with the results he obtained when he crossed the pea plants. He asks the class, “Do pea plants reproduce sexually or asexually?” The class calls out varied responses. There seems to be confusion. A few students ask questions and make comments and then Bell says, “Folks, can we agree that these plants reproduced sexually? That means that the chromosomes inside the nucleus of these cells — are they n or 2n?” The class chants the correct answer. Bell tells the class, “One thing is challenging for students so I will try to push on you from the beginning – the students that keep relating to genes on chromosomes do much better than the students who just draw the Punnett square and nothing else. Right from the beginning keep thinking of this as genes on chromosomes.”

Bell then turns to the board and with bright colored chalk draws two chromosomes under the word “round” with a capital “R” by each. He then draws two more chromosomes under the word “wrinkled” with a small “r” by each. He asks the class a series of questions to identify these chromosome pairs as homozygous. The class chants the answers. Bell then diagrams the gametes produced by each pair of chromosomes. He answers a student’s question about the chromosome replication process and then draws the new cells after fertilization. He asks the class, “Are these cells homozygous or heterozygous?” They chant the answer.

Then Bell puts up a slide showing Punnett square and explains the relationship between the gametes and the square. A student then asks, “There are two homologous chromosomes beneath the 'round' (referring to the word on the board), right?" Bell responds, "One of the biggest challenges that many of you have – you need to find a way to work past this – many of you get confused with sister chromosomes and homologous chromosomes. There is confusion between the replicated chromatids and the homologous pair. If you are confused about this be sure you latch up with me or a TA afterwards."

It is now 12:41 and there are less than ten minutes left in class. Bell explains the F1 generation as he points to the diagrams on the board. He then asks the class, "Why are they all round?" The class chants the answer and Bell builds upon this by explaining that wrinkled is the absence of round. He then puts up a slide showing what happens when the F1 generation is allowed to cross-pollinate. He tells the class to discuss this outcome with a neighbor. A student near me says, "All the children first breeding will be heterozygous. The next generation – some will be heterozygous and some homozygous and we see the probability of that." He then asks his discussion partner, "Did you do the reading?" His partner responds, "I did."

About 70% of the students seem to be discussing the concept. The others do not appear to be talking or engaged with other students. Bell and the TAs walk around the room and speak to students with raised hands. They occasionally address students who are not participating in discussions. The volume decreases after two minutes and after three minutes Bell calls the group to order. He draws the parent cells on the board explaining that they are both diploid and heterozygous and then says, "We never talk about heterozygous chromosomes, only heterozygous genes. Why is that?" One students attempts an answer and Bell says, "OK, yes, but we are not quite there yet." Another student volunteers saying, "There are a number of genes on each chromosome." Bell says, “Very good” and then repeats the answer to the class. He continues his drawing showing the daughter cells and explains probability and Punnett square. He then brings up a slide summarizing this information. He explains the expression of round and wrinkled traits.

At one minute before the end of class a student asks a clarification question and the class begins the noisy process of packing up to leave. Just before class ends, Bell says, “Be totally prepared to talk about what happens with two traits on the same or on different chromosomes. Good bye.” The bell rings and most students file out. Five students go down to the front of the classroom to talk to the TAs or to Bell.

Research Question 2

Question 2 asks: What is the nature of students’ learning experiences in this course? The previous section describes the pedagogy of Bell’s Biology 120 class. In this section, students’ experiences with that pedagogy will be explored. I examined five sources of data to understand students’ learning experiences: (a) performance data, (b) survey responses, (c) class fieldnotes, (d) grade justification documents, and (e) case study interview transcripts. These data sources provided information about three issues: student participation levels, student opinions about the course, and student descriptions of their learning experiences.

Student Participation Levels

Performance data. Based upon self-report documents students attended class an average of 39.01 out of 41 days (SD = 0.95), completed an average of 16.30 of the 18 assigned readings (SD = 0.91), and completed an average of 16.97 (SD = 0.89) of the 19 homework assignments. Homework consisted of thirteen EQs and six assignments (usually problem solving). The students also completed an average of 8.56 weekly assessments (SD = 2.21). Fourteen students did not take the final exam and there were five who completed none of the weekly assessments.

Course evaluation survey. Most students took advantage of at least one opportunity to attend the eight review sessions Bell held during the three weeks preceding the final exam. Item 32 on the course evaluation survey asked students how often they attended the sessions. Thirty-two students (23%) indicated that they attended no sessions, 49 students (35%) attended one or two sessions, 41 (30%) attended three or four sessions, 10 students (8%) attended five or six sessions and 5 students (4%) attended seven or eight sessions.

Class fieldnotes. The majority of students seemed to be highly engaged in all class activities. To check this, when observing classes I estimated the percent of students who were engaged in activities. I did this by choosing a few sections of the classroom and calculating percent of students who appeared to be participating. I examined fields notes from six classes (two each from January, February, and March) and noted percent engagement rates during student-centered activities. The rates ranged from 80% to 99% (n = 8 engagement rate notations). The average engagement rate was 92%. The lower engagement rates were during activities requiring students to raise their hands or call out an answer. I also checked engagement rates for instructor-centered activities. I considered students engaged if they were looking at the instructor or writing. The rates ranged from 75% to 99% (n = 11 engagement rate notations). The average engagement rate was 92%.

Students' Opinions of the Course

BYU student ratings survey. Most students seemed to appreciate their learning experience. They had the opportunity to evaluate the course and the instructor (Items 1 and 2) in a university-administered student ratings survey (Appendix I). The 172 students who took the survey rated the course (M = 6.3, SD = 1.36) and the instructor (M = 7.3, SD = 1.26) highly on a scale ranging from 1 (very poor) to 8 (exceptional). There was also an open-ended comments section and close to 75% of the comments were positive. The most frequently mentioned positive aspect of the course was Bell's concern for the students (36% of the positive comments). Ten students (6%) made negative comments and the most frequently mentioned negative aspects of the course were that the class moved too slow or the lack of graded assessments (each 26% of negative comments). The remainder of the student comments were neutral or contained both positive and negative remarks.

Course evaluation survey. Students completed an evaluation survey specific to Biology 120 during the last week of the class. Two questions asked students their opinions on the value of the class. Eighty-nine percent of the respondents responded definitely or probably yes to Item 15 which asked: When you consider what you learned in this course (new knowledge, skills, attitudes, perspectives, etc.) in light of what it cost in terms of personal study time and effort, was what you learned worth the effort you invested? Seventy-three percent of the respondents said they strongly or slightly agreed with the statement in Item 38: "Overall, I have enjoyed the layout of this course and wish I could have more courses with a similar testing/grading format" (see Appendix B for all survey items and results).

Learning Experiences

Grade justification documents. I searched the grade justification documents for descriptions of learning experiences and for themes emerging from those descriptions. The purpose of these documents was to suggest a final class grade based on data, particularly from the weekly assessments. Students, of course, sought to give a positive picture of their learning. But some of those students clearly described aspects of their personal experiences. Two themes appeared. First, there were repeated references to students starting the course, taking the first few assessments, and then realizing that they needed to either work harder or work differently. Making this change usually resulted in better performance on subsequent assessments. The following two quotes illustrate this theme:

1. I started this class out quite well. I was reminded by the third assessment that I have some misconceptions. Due to my poor performance on the third assessment I started a weekly study group with two other students. We would meet on a regular basis to discuss and explain to one another the topics that we were learning. This helped out a tremendous amount. . . When I did poorly on an assessment such as the third and ninth I obtained clarification I had on a specific topic

2. At first I was really stressed out by your quizzes because I had a hard time grasping all the concepts and the comprehensive way you ask questions. . . I started coming to your office hours and going over the material on BlackBoard. . . Once I started being a regular at Friday reviews I saw a huge increase in my grades. . . I feel very confident in my knowledge thus far.

The second theme was effort. Many students described hard work or increased effort during the course. These descriptions may have been influenced by students' desire to justify their grade proposals.

1. I worked hard studying for this class and did not miss a single lecture. I always did the readings and made sure I understood what I read. Before each assessment my study partners and I would do very effective EQs.

2. This semester has caused me to stretch, but I feel like I put in the work to ensure my success. I spent three to five hours in the biology lab working with our TAs each week, aside from the studying I did on my own. I had perfect attendance along with always completing the assigned reading and EQs. I was diligent to the end and attended seven out of eight review sessions.

3. During the semester I managed to complete each homework assignment, EQ , and reading assignment before its due date 100% of the time. Furthermore, when I did these assignments I didn't just read or review the minimums, I felt that I put a lot of effort into really understanding the concepts rather than surface level subjects. I genuinely explored each item in depth with notable proficiency and the assessments truly reflected such performance.

Case Studies

Three students were chosen as case studies. They came from a pool of 13 students who were interviewed during the course and were selected because they represented different years in school, different majors, different career aspirations, and very different learning experiences. Their experiences, scattered throughout this chapter, will provide personal and individual stories to balance the more general class-level data.

Julia. Julia is a junior majoring in exercise science. She has always liked science and completed a number of science classes in high school and at BYU. Her goal is to go to dental school. She generally likes the Biology 120 class. She came into the class confident in her ability to do well. She started out doing all of the normal assigned activities. She did her reading and took notes on it before class. She did the assigned EQs and prepared for the Friday assessments by reading over her notes. After the first three or four assessments she realized she was not working at the level she desired.

> I thought I understood it. Towards the middle I got progressively worse. I realized my notes weren't sufficient and I wasn't understanding it. The textbook doesn't really help that much. That is when I started asking Dr. Bell for help. (personal interview, March 2006)

She went to meet with Bell and he helped her diagnose her learning:

> He would have us explain kind of what we knew, which was not a lot, and then he would kind of help us figure it out so we were figuring it versus him just telling us and thinking you get it. You actually go through and learn what you don't get. (Personal interview, March 2006)

She found that she needed to work harder and utilize a number of different learning strategies:

> When I learn something I need to be exposed to it a couple of times. Reading kind of gave the first dose of what we were learning. In class Dr. Bell would kind of elaborate on what was discussed in the reading because the reading really was a lot of information to take in all at once and I honestly didn't get a whole lot out of

it. In class when he would go over it. The information would be presented again and I would get kind of an elaboration of it but I still wouldn't get it. I would need to go over my notes and study it. I need to connect things for me to actually learn concepts – how this concept fits with this concept and how everything plays together. So I think meeting with Dr. Bell really helped that because I had all these pieces and I didn't know how to connect them. I didn't have the entire overall picture and how the process and the concept was from start to finish. (Personal interview, March 2006)

Julia found it helpful to ask questions in class and to meet with a friend to review online PowerPoints and the class notes. After changing her learning strategies her assessment scores improved. This improvement continued and she ended up with an A in the class. She attributed most of her success to help from the instructor, explaining that,

> He's pretty effective because each person learns at a different rate, different level, and different way. He is pretty effective at providing resources in order to accommodate that. I have been very impressed with the way he has made himself available to the students who are willing to put forth the effort to take advantage of that. I know a lot of teachers that are helpful but don't put forth that effort. I think that is effective because it lets students know that he is genuinely concerned in how they do and really does want them to learn the material and do well. That, at least for me has helped me to want to do better because I feel I can go and talk to him if I need to. I can go to help sessions or go to TAs and talk to them. Everyone is kind of wanting you to do well. (Personal interview, March 2006)

Dallin. Dallin is a freshman with an undeclared major. He came to BYU thinking about majoring in business but now he is considering a major in Integrative Biology. He has not yet decided on his career. He took an introductory biology class for non-biology majors (Biology 100) last semester, so he feels that some of the work in the Biology 120 course is review. He is taking the second level introductory biology course for majors (Biology 220) concurrently with Biology 120 this semester and he finds the two courses to be quite different. He prefers the content and teaching style, and thinks he is learning more, in the Biology 220 class.

Dallin feels he learns best by reading and memorizing. In the Biology 100 class last semester he made over 100 note cards for the test. When asked if he made note cards for Biology 120 he said, "I haven't. I don't know what to make them on" (Personal interview, March 2006). During a typical week, Dallin completes all his reading and homework assignments. He takes notes in class and on his readings but does not often look at them later. He "usually tries" to participate in class activities and sometimes talking to friends in the class helps "draw my attention to something I didn't think of or they don't get and I explain it to them" (Personal interview, March 2006). But he occasionally gets frustrated: "Sometimes there is stuff I just need him to say and it clicks" (Personal interview, March 2006). He does EQs as assigned. He usually finds a roommate and spends 15 minutes explaining the current concept. The EQs vary in quality. One of his roommates is a "big science buff. He asks me questions about stuff and makes me think about it a lot" (Personal interview, March 2006). EQs with other roommates are less challenging and beneficial and overall he does not find them very helpful,

> I don't feel like they do much for me. I realize there are times I just do it to get it done. Even the times I do it with my roommate – I feel like he is just asking me things I already know. And if there is something that I don't know I just need to go back in the book and look at it. I think the assessments do fine for pointing out what I know and don't know. (Personal interview, March 2006)

To prepare for the weekly assessments Dallin reviews the readings and tries to think about what was emphasized. If there is something he struggles with he re-reads that section from the book. Dallin felt that he performed well in the class and he received a final grade of A.

Justin. Justin is a sophomore with an undecided major. He plans to be podiatrist. He enjoyed science in high school, took quite a bit of it, and did very well. This is his first college level science class. He received mostly As (one B) in his college classes before this semester. He mainly achieved these grades by memorizing the material. He found that approach did not work in Biology 120 and explains that,

> It's been sort of a rough go for me. I definitely took the harder route. [Bell] kept telling us what to do to do well in the class but I wasn't doing it because I thought like I'll just do what I do in all my classes, keep on studying out of the book, memorizing the terms he wants us to know. I thought I would be fine but I was still doing horrible on all the assessments. And so about a month ago I went and saw [Bell] in his office and told him, "I'm studying a lot, I'm putting time in it but I'm still doing like 50% on every assessment." We talked about what I need to do. I need to improve the quality of my EQS. Cause my EQs weren't really… I was just doing them with some of my roommates. I would just sort of present it to

> them . . .like I need to talk to you for 15 minutes. Just listen and lets get this over with. And so he told me I needed to do a lot better on that. He actually started giving me an EQ and it was horribly embarrassing. He was asking me questions and I simply did not have the answers (on translation) . . .oh . . .so humiliating. So he said "I think we've definitely seen what you need to do better." And so I started meeting with Jen (a TA) a couple of times a week and an EQ study group formed and I started going to that and that was just great…helped out a lot. (Personal interview, March 2006)

He realized that he needed to change his approach to learning if he was going to succeed in the class so he moved away from a focus on memorizing and towards deeper learning techniques such as EQs. His understanding improved as he began to do EQs more effectively,

> It helps me understand what I already understand and helps me understand what I don't know. . . It helps me first of all remember what I am talking about because I am explaining it. It becomes more like a crystallized knowledge instead of just some abstract ideas that are wandering around. It is more structured because I have to structure it myself if I want to explain it to someone else. It takes all my random ideas and kind of sticks it together into more organized learning. (Personal interview, March 2006)

Justin gradually improved his performance on weekly assessments and received an A- in the course.

Research Question 3

Question 3 asks: In what ways do students improve or extend their biology-related knowledge and skills during the course? Data to answer this question came from a number of sources. On the class level, the most directly related data are student performance on the pretest and posttest and on the weekly assessments. In addition to this, the class responded to survey questions related to their progress in the courses and described their learning trajectories in their grade justification documents. On the case study level, students gave details about their progress in the course.

Class Level Data

Pretest and posttest. A direct measure of change in students' biology-related understanding or skill was their performance on the pretest and posttest (final exam). Students had the option of taking a pretest during the first two weeks of the course and the posttest (final exam) was given on the last day of class. One hundred and sixty-three students took both exams. Twenty-two of the items on the pretest were also included on the final exam. All items were dichotomously scored, selected-response format. Most of the items on the pretest and posttest were designed to assess more than simple recall. Students generally had to think with their knowledge and analyze authentic problems. Bell categorized each item by cognitive demand level based upon the revised version of Bloom's taxonomy of educational objectives (1956):

1. Knowledge: Recalls data or information
2. Comprehension: Understands the meaning, translation, interpolation, and interpretation of instructions and problems.
3. Application: Uses a concept in a new situation.

4. Analysis: Separates material or concepts into component parts so that its organizational structure may be understood. Distinguishes between facts and inferences.

Of the 22 items in common between the pretest and the posttest there were no items at the knowledge level, eight items at the comprehension level, eight items at the application level, and six items at the simple analysis level. Table 3 gives examples of items at each cognitive demand level. Item 2 required students to do more than recall facts about the Krebs cycle: They had to prove that they understood the concept by answering a relatively simple question that required them to think with their knowledge. When responding to item 10 students had to apply their understanding of genetics concepts and their skill in calculating probability to a novel situation. Item 26 presented a previously unencountered and somewhat complex scenario that required students to analyze the impact of cyanide on the electron transport chain.

Items were also categorized by topic. Topic subgroups were created based upon course objectives. According to the syllabus, students were to be able to explain the following concepts (Course syllabus, Biology 120, Section 1, Winter 2006):

1. Cell theory and biological compartments (Cell)
2. Chemistry of life (Central Dogma)
3. Bioenergetics (Respiration and photosynthesis)
4. Reproduction (Mitosis and meiosis)
5. Evolutionary theory (Populations; Genetics)
6. Experimental design and statistics (Experimental design)

Table 3

Examples of Pretest and Posttest items at Each Level of Cognitive Demand

Cognitive Demand	Pretest Item Number	Item
Comprehension	2	A glucose molecule enters the cell and becomes converted to pyruvate which is then transported into a mitochondrion and metabolized to form ATP. Which part of the original glucose molecule ends up in the ATP? A. electrons B. carbon C. oxygen D. phosphorus E. none of it
Application	10	The first child of a young couple (parents both normal) has cystic fibrosis, an autosomal recessive trait. What is the probability that both of the next two children, born 2 and 4 years later, respectively, will also have the disease? A. 1/16 (6.25%) B. 1/8 (12.5%) C. 1/4 (25%) D. 1/2 (50%) E. 3/4 (75%) F. 1 (100%)
Analysis	26	Cyanide is deadly because it poisons the electron transport chain thus preventing use of NADH. Cyanide is likely to A. decrease conversion of O_2 to CO_2. B. harm animals but not plants. C. increase H^+ inside mitochondria.

Most students experienced general improvement in their biology-related knowledge and skills, but gain in performance level per item varied for a number of reasons. In some cases the item was difficult on the pretest and, though students improved, it was still difficult on the posttest (see pretest item 7 in Table 4 for example). In other cases the item was relatively simple on the pretest and gain scores were thus limited by a ceiling effect (see pretest item 3 in Table 4 for example). The clearest indication of learning came when an item was difficult on the pretest and relatively easy on the posttest (see pretest item 1 in table 4 for example). These three gain conditions were coded as DD (difficult on pretest and posttest), DE (difficult on pretest and easy on posttest), or EE (easy on pretest and posttest). The cut-off point between easy and difficult items was a proportion correct of .70. Table 4 shows the pretest/posttest items categorized by topic, cognitive demand, and gain code. Seven items were difficult on both the pretest and the posttest, two items were relatively easy on both tests, and thirteen items changed from difficult on the pretest to easy on the posttest. This suggests that, based upon student performance on 13 of the 22 items, students experienced a noticeable gain in biology-related knowledge and skills. The number of items showing a difficult to easy shift varied within topic categories but all categories had at least one item showing a difficult to easy gain and one category, meiosis and mitosis, had all items showing this type of gain. Pretest Item 6 had a negative gain score. The item was briefly analyzed and it appears there is a problem was with one of the distracters with the wording of the stem.

Gain was also examined at the person level. On the pretest, students responded correctly to an average of 44.48% of the 22 items in common to both the tests (M = 9.79, SD = 3.27). Performance improved on the posttest to an average of 77.29% correct (M = 16.29, SD = 3.05) on those same items. A gain score was calculated for each student by subtracting the proportion correct on the pretest from the proportion correct on the posttest. The average gain score was .33 (*SD* = .16). Gain scores per student were examined qualitatively using the same system described above for items. The largest group, 113 students, improved from difficult to easy (below .70 to above .70 correct), 44 students performed at the difficult level on both sets of items, five students performed at the easy level on both sets of items, and one student decreased in performance from easy to difficult.

Table 4

Comparison Between Pretest and Posttest Performance by Item

Item Number			Proportion Correct				
Pretest	Posttest	Topic	Pretest	Posttest	Gain	Gain Coding	Cognitive Process
7	19	Central Dogma	.38	.57	.19	DD	Analysis
6	20	Central Dogma	.58	.51	-.07	DD	Application
9	22	Genetics	.34	.48	.14	DD	Comprehension
17	29	Experimental Design	.51	.66	.15	DD	Analysis
20	33	Experimental Design	.26	.59	.33	DD	Application
22	35	Experimental Design	.20	.56	.35	DD	Analysis
26	43	Respiration and photosynthesis	.34	.58	.25	DD	Analysis
1	8	Mitosis/meiosis	.33	.88	.55	DE	Comprehension
2	9	Respiration and photosynthesis	.21	.88	.67	DE	Comprehension
4	15	Mitosis/meiosis	.42	.80	.38	DE	Comprehension
5	17	Mitosis/meiosis	.61	.93	.32	DE	Comprehension
8	21	Genetics	.67	.94	.28	DE	Analysis
10	24	Genetics	.47	.72	.25	DE	Application
12	25	Central Dogma	.13	.76	.63	DE	Application
13	26	Genetics	.37	.78	.41	DE	Analysis
14	27	Evolutionary Theory	.64	.94	.29	DE	Application
18	30	Experimental Design	.63	.87	.24	DE	Application
19	31	Cell	.46	.88	.42	DE	Comprehension
21	34	Experimental Design	.33	.94	.62	DE	Application
25	36	Experimental Design	.33	.81	.48	DE	Application
3	10	Cell	.82	.99	.17	EE	Comprehension
24	37	Evolutionary Theory	.77	.92	.15	EE	Comprehension

Weekly assessments. Students' performance on the ten weekly assessments provides evidence for their development trajectories during the course. Unfortunately, the assessments varied each week and did not contain any repeated items so there is no stable measure of change in performance ability. It is possible to examine individual student performance levels in relation to the class average, but it is difficult to measure progress of the entire group against set criteria because there is no common metric from week to week. Average student performance per week was calculated and is displayed in Figure 1. There is no smooth upward trajectory.

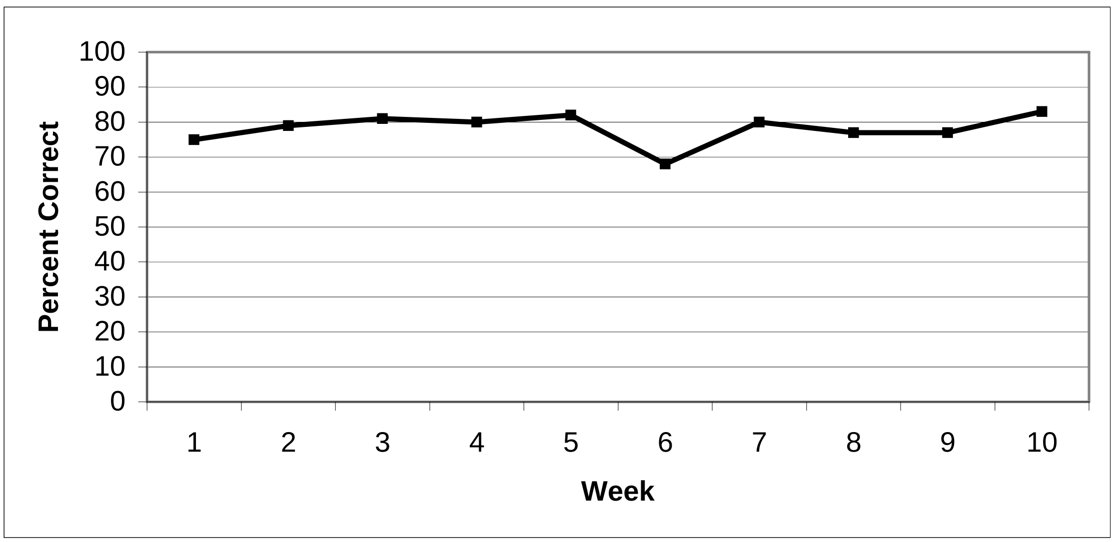

Figure 1. Average student performance on weekly assessments.

In order to decrease the impact of varying difficulty levels, assessments were examined at the item level and items were grouped into topic categories. Only the topic of experimental design had groups of items in multiple weekly assessments. Items were further grouped into subcategories of experimental design topics in an effort to examine groups of items of similar design and difficulty. Similar items from the pretest and posttest were included. There was only one item in each subcategory on each assessment.

Proportion of students responding correctly was calculated for each subcategory item. The trend in average student performance was generally upward as students progressed from the pretest, through the weekly assessments, and to the posttest (Table 5). Of course, there is still the confounding factor of item difficulty but this is minimized because items in each subcategory are similar. It is possible to see general improvement in student performance on these items indicative of general improvement in their understanding of experimental design.

Table 5

Average Student Proportion Correct on Experimental Design Items Across Assessments.

		Weekly Assessments						
Topic	Pretest	1	2	3	5	7	8	Final Exam
Negative Control		.80	.93	.88	.82		.90	
Positive Control	.33			.89	.87	.80		.94
Conclusion	.36	.74			.77	.81		.56
Null Hypothesis		.90		.82	.96	.96	.97	
Dependent Variable			.96	.88	.93			
Independent Variable	.85			.88	.90			
Dimension	.33					.68		.77

Course evaluation survey. Two items in the course evaluation survey provided information about students' learning experiences in the course (Table 6). Item 20 probed students progress in the course. Sixty-five percent of respondents selected response categories A and C indicating they had made progress but did not change in relative standing to the rest of the class. Twenty-three percent of respondents selected response category B indicating they had improved compared to others in the class. Most students (88%) selected one of those three response categories indicating they had improved in some way during the course. Item 27 asked if students had improved in their ability to think like scientists. All but two students (99%) indicated that experiences in the course had greatly or slightly enhanced that ability.

Table 6

Distribution of Responses to Course Evaluation Survey Items 20 and 27

Question	Frequency	Percent
20. Which of the following statements best describes your assessment of the progress you made in this course this semester?		
A. My skills and understanding of the course content were above average at the beginning of the course and still are. My relative standing in the class is still above average.	29	21.32
B. I have made significant improvement compared to others in the class. My relative standing in the class is higher than it was initially.	31	22.79
C. My skills and understanding of the course content have improved significantly. Since most of the other students in the course have made similar improvement, my relative standing in the class is about the same as before.	60	44.12
D. I really haven't improved much, although I have really tried hard.	10	7.35
E. I gave up and quit trying part way through the semester.	4	2.94
F. I never really tried.	2	1.47
27. Has your experience in this course enhanced or diminished your ability to think the way scientists think?		
A. Greatly enhanced	70	50.72
B. Slightly enhanced	66	47.83
C. Slightly diminished	2	1.45
D. Greatly diminished	0	0.00

Grade justification documents. Some students clearly described their learning progress in their grade justification documents. I read each proposal and noted when such a description occurred. Most students talked about their scores on the weekly assessments but fifteen students wrote a descriptive statement about their learning progress. I examined each of the statements and found that eight of the students indicated a steady learning gain. Sample descriptions include:

1. I never missed class, I did all of the readings, assignments and EQs and attended many of the review sessions, worked extremely hard and talked with both you and the TAs when I was confused to fix many of the misconceptions that I had. My grades and understanding of Biology consistently improved and I am peaking at the right time.

2. I honestly feel that throughout the entire semester, I have journeyed up the steady incline of improvement . . . I wasn't plateau-ed at a level of high performance, but I had to work for it.

3. As random as this may be, I feel my experience with the Friday assessments can be somewhat compared to learning to drive a manual car. Averaging 62% on my first three assessments was definitely like the first week with the stick shift. You kill it the first couple of times, but then you start to get the hang of it, and your ride becomes much smoother. After seeking the help I needed, my scores began to improve dramatically.

Six of the students reported that they struggled at first, made a change in their learning approach, and then improved after. Sample selections include:

1. In high school, I mastered the art of "regurgitation." I could read anything and spit out mindless facts that carried no value or meaning. Unfortunately I walked into Biology 120 with this same illogical way of thinking. I guess my

rude awakening happened during the first assessment when I was asked to *understand* what I learned. Unsurprisingly I failed. I got 36%. It was at that moment that I realized that something had to change – not my attitude, or time spent reading the material, but the way I made sense of the information. During the next week, I was much more active as I studied. I took notes, drew pictures, and matched the foreign concepts to things that I already understood. On assessment #2 I got a 97%. The first thing I thought when I saw my score was, “I understand 97% of the material – much better than last time.” From then on I did well on the rest of the assessments.

2. When the assessments became more comprehensive, I struggled and scored 54% and 40%. I started reviewing throughout the week and revamped my EQs, and my next three assessments showed marked improvements with scores going 60%, 81%, and final 89%. I really felt like I was getting the hang of the material in class since these were more comprehensive assessments.

3. I entered this class not really knowing what to expect as it was my first semester of college. However, I shortly found out that I needed to change the way I studied for this class. This is evident by my first two assessments on which I scored roughly 60% on both. I took seriously the part at the bottom of the syllabus that leaves room to write where improvement was needed on each assessment and decided if I were going to improve I needed to get some out of class help from the TAs. Not only did I go in to them with questions I had on lectures and assessments, but I also did some of my EQs with them which really helped me know what I understood and what I needed to work on. I

> quickly saw my assessment scores go up as the next 5 out of 6 assessments scored from 80-90%.

One student did not see any progress at all:

> I knew right away that this class would be difficult. I am not very smart and it is very hard for me to catch on to hard concepts and especially retain new information for long periods of time. Once I take a test or quiz all the information I just learned and studied leaves me. I got myself into the bad habit of studying by memorizing.

Case Studies

Julia. Julia's scores on the weekly assessments (she did not take Weekly Assessment 4) compared to class averages echo her comments described in the previous section (Figure 2). She started out scoring above the class average but then dipped during the third through sixth weeks of the course. That is when she met with Bell for help. After that, she finished above the class average on the final four assessments. In her grade justification Julia proposed an A- for the course and wrote:

> My performance on the assessments shows that I improved by the end of the semester. On the first few assessments I scored an 89% overall. The next few assessments show a definite decrease in understanding on my behalf. I averaged very low, about a 60% on these ones. It was at this point that I realized I did not understand the material. That is when I began to seek help. As a result of this my assessment scores began to steadily rise. . . . I think over the course of the semester, I have recognized my weakness and taken steps to fix these problems

and have come to perform, according to my latest assessments at an A- level in the class overall.

Julia scored 93% on the final exam and earned an A in the course.

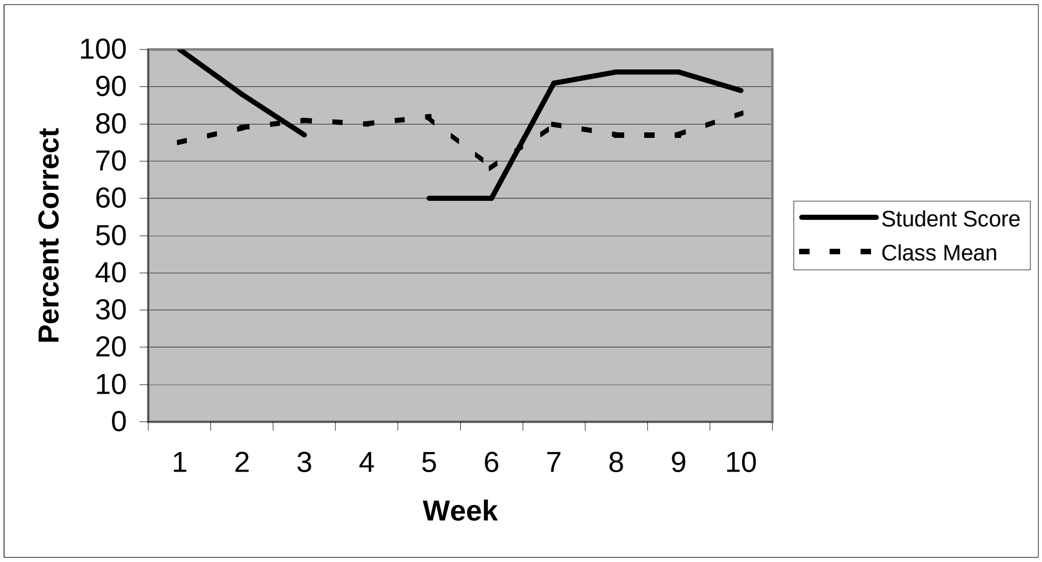

Figure 2. Julia's weekly assessment performance compared to the class average.

Dallin. Dallin came in to the class confident and was able to learn the material and perform well on most of the assessments. He proposed a grade of A- for the course and justified it by describing his learning trajectory.

In Biology 120, my assessment scores do not show any significant trends over the ten weeks we took them. Three of my lowest scores of 60, 61, and 73 percent were assessments that dealt with cellular respiration and photosynthesis. Taking Biology 100 last semester made this complicated for me because I felt like I knew the processes very well, but found out there is a big difference between application of the process and knowing exactly what molecule goes where next. I worked hard each week to try and understand my misconceptions by going back through the book and talking with classmates that performed much better than I did. I have prepared for the final even more by seeking help from the TAs and going to review sessions.

Dallin scored above the class average on six of the ten assessments and had perfect scores on three of them (Figure 3). His final exam score was 97.5 and he received and A in the course.

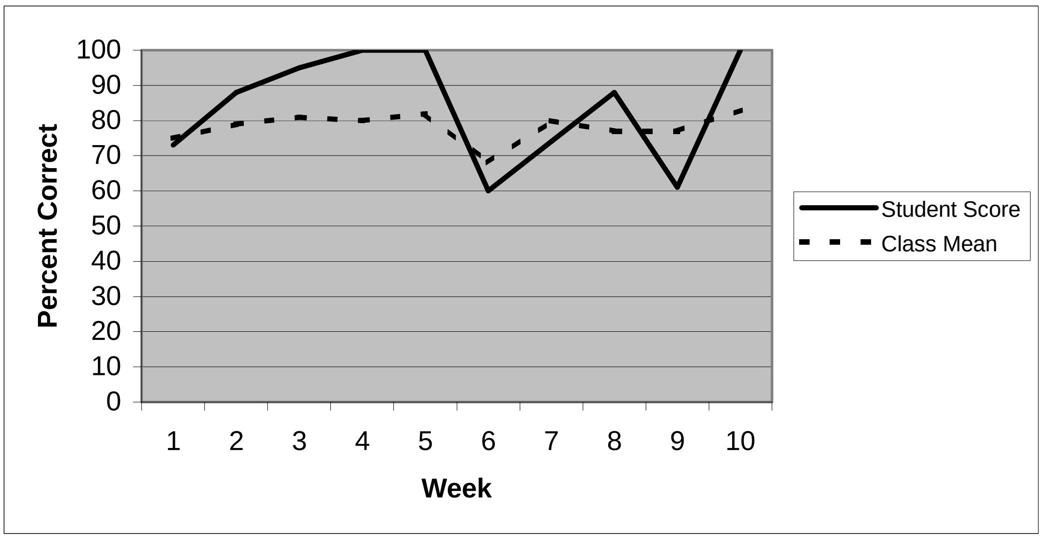

Figure 3. Dallin's weekly assessment performance compared to the class average.

Justin. Justin struggled with his learning during most of the semester. He summarized his learning trajectory in the course in his grade justification document:

My semester got off to a bad start. I thought this would be like any other class that I could breeze through with minimal studying of the notes. After the third assessment I realized that my plan was not working so I kicked it up a notch, and a few assessments later I realized that I needed help. I spoke with Dr. Bell and he gave me so good advice and I realized how bad I was doing and that it was my own fault. Low quality EQs proving to be my biggest problem. So I determined to do better. . . Soon I was giving a couple of EQs a week between Jen (TA), other students, my girlfriend, and my roommates. I saw great improvement from this getting 100% on assessment nine.

Based upon his assessment performance, Justin proposed a B- for his course grade. His assessment performance was erratic. He scored below the class average on seven of the nine assessments he took but scored 100% on assessment nine. He was able to score 91.8% on the final exam and because of that performance he earned a final course grade of A-.

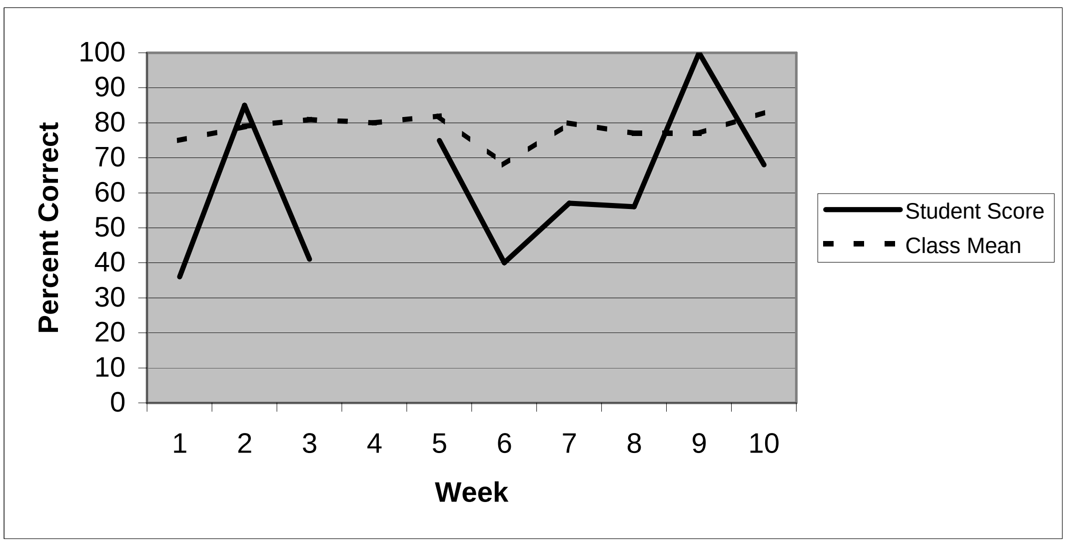

Figure 4. Justins's weekly assessment performance compared to the class average.

Research Question 4

Question 4 asks: According to students, what components of the course tend to foster this improvement (biology-related knowledge and skills), if any? On a class level, students responded to survey questions and to in-class questions related to this topic. On a case study level, students shared individual opinions regarding the effectiveness of various course components.

Class Level Results

Course evaluation survey. Two course evaluation survey items addressed the effectiveness of various aspects of the course (Table 7). Item 22 asked a general question about the entire course. Ninety-one students (66%) indicated that the learning activities and experiences in the course were extremely or quite meaningful. Item 29 asked more specifically about EQs. Sixty students (43%) indicated that EQs were very helpful in their learning and 59 (43%) found them somewhat helpful.

Table 7

Frequency Distribution for Course Evaluation Survey Items 22 and 29

Question	Frequency	Percent
22. To what extent were the learning activities and experiences in this course meaningful and relevant to you personally and to your goals for the future?		
A. Extremely meaningful and relevant	36	26.09
B. Quite meaningful and relevant	55	39.86
C. Moderately meaningful and relevant	37	26.81
D. Not very meaningful or relevant	9	6.52
E. Not at all meaningful or relevant	1	0.72
29. What influence did doing EQs have on your learning?		
A. They were very helpful in my learning	60	43.48
B. They were somewhat helpful in my learning	59	42.75
C. They didn't help very much	17	12.32
D. They were a waste of time	2	1.45

In-class questions. Two in-class questions probed students' thoughts on the value of course components. In-class Question 3 (given on March 3) is the most directly related. It asked: "Think about the new concepts you have learned. What activity in or out of class has helped the most with your learning?" The responses to this question were explored using a domain and componential analysis with a quantitative component (Table

8). First, domains or types of activities mentioned by the students were identified. Then the number of times that domain was mentioned was counted. Each time an activity was mentioned it was counted as one response in that domain category. Some students mentioned more than one learning activity per response.

The most frequently mentioned learning activity was EQs. Thirty-eight percent of respondents said EQs were helpful in their learning. Sample responses include (All comments in this section are from students' responses to In-class Question 3):

1. EQs rock.
2. I think that the most beneficial to me in this class is the EQs. I am forced to explain my understanding to someone else which really solidifies what I know as well as other concepts I am struggling with.
3. Probably the EQs. I thought they were irritating at the beginning of the course, but they more than anything help me fill in any major gaps in my learning.

Reading or doing reading summaries was mentioned by 15% of the students. Sample responses include:

1. What helps me the most is to skim the reading the night before class and to take notes on what Dr. Bell says in class. That way he is building on the basic knowledge I gained the night before and I can retain it.
2. Reading in general. I hate being assigned reading, but reading clearly presented material helps me most.
3. What I do to help myself study for this class? I will read the text, highlight it, write notes in the book as well as in a notebook. I write questions I have, then

try to answer them myself by referring back. Then I go horseback riding and think of the concepts I learned.

Fifteen percent of students mentioned that in-class explanations were helpful. Sample responses include:

1. What has really helped me learn the most is when Dr. Bell will take the time in class and lecture about the previous reading assignment. I know most people don't like lecturing, but the reading is really hard to understand and when he goes over it, I learn a lot.

2. What has helped the most has been the in class examples and the animations that Dr Bell shows us in class. I don't learn well when I just read the book.

A componential analysis was conducted on the domains identified from the responses to In-class Question 3 (Spradley, 1980). This involved determining and quantifying dimensions of contrast within each domain. The results of the analyses are presented in Tables 8 and 9. Three dimensions of contrast were identified among the domains: (a) location of the learning activity (location), (b) number of individuals involved (social condition), and (c) the individual directing the activity (locus of action). These dimensions were quantified by calculating the proportion of responses mentioning each dimension (Table 9). Helpful components of the course identified by students were about equally divided between an in-class location (46%) and an out-of-class location (54%). On the dimension of social condition, 26% of course components mentioned involved others, 29% were solitary, and 45% took place in the classroom. On the locus of action dimension, teaching assistants directed 6% of course components mentioned, the instructor generated 16%, and the students themselves generated 79%.

Table 8

Domain and Componential Analysis of In-class Question 3

Activity	Number of times mentioned	Percent	Location	Social Condition	Locus of Action
EQs	38	31.40	in class	classroom	student
In class explanations	15	12.40	in class	classroom	instructor
Reading	15	12.40	out of class	solitary	student
Talking to others out of class	11	9.09	out of class	with others	student
TA help	7	5.79	out of class	with others	TA
PowerPoints	6	4.96	out of class	solitary	student
Practice problems	6	4.96	out of class	solitary	student
Talking to others in class	6	4.96	in class	with others	student
Assessments	5	4.13	in class	solitary	student
Reading summaries	4	3.31	out of class	with others	student
Instructor help	3	2.48	out of class	with others	instructor
Reviewing notes or problems	2	1.65	out of class	solitary	student
Homework	1	0.83	out of class	solitary	student
Nothing	2	1.65			

Table 9

Proportion of Responses Within Contrast Categories for In-class Question 3

Domain	Dimension	Frequency	Percent
Location	In class	64	53.78
	Out of class	55	46.22
Social Condition	Large group	53	44.54
	Solitary	35	29.41
	With others	31	26.05
Locus of Action	Student	94	78.99
	TA	7	5.88
	Instructor	18	15.13

Students were asked specifically about their EQs through In-class Question 6 which posed two questions: How do you do your EQs? What impact have EQs had on your learning? It was given near the end of the semester on April 12 and 40 students responded. In describing their EQs, most respondents indicated that they explained concepts to a partner and then participated is some form of questioning. The following descriptions are typical (all comments from student responses to In-class Question 6):

1. Meet with another student and have a book handy. One explains the concept as the other questions. Any discrepancies are looked up in the book or lecture notes. Then we switch places.

2. My partner ([a classmate] and I always do ours together) and I randomly decide who goes first. One person presents, the other person asks questions as they think of them. Second person presents and the process of questions repeats. After, we talk about any questions we have, not just what the EQ was on.

3. I introduce the topic to the best of my abilities. I ask the person questions to see if he/she understands. He/she responds, asks more questions and when we get stuck or don't completely understand we go to the textbook.

4. I take the subject that is being taught and then teach it to someone as if they had absolutely no previous knowledge of the concept. Then I check for understanding through examples or problems and/or scenarios.

Eight students described poor quality EQs. Typical responses include,

1. I don't get much feedback from my partners. They don't ask good questions.

2. I talk someone through the material. But we don’t do al the steps that Dr Bell showed us. I should have done the EQs better

3. Sometimes, I just blather on about the material pointing out diagrams in the book. Twice, however, I shut the book and had my partner draw the diagrams as I teach how to draw them.

EQs, of course, are done with a partner. Of the 21 students who described their partner eight conducted them with roommates, seven with classmates, three with family members, two with friends, and one with a TA.

The second part of In-class Question 6 probed students’ opinions on the utility of their EQs. Nine of the 38 respondents commented directly on EQ utility. Five said they found them unhelpful, three did not like them, and one did not do them. Sample comments include,

1. I tried my best to make them effective, but I often found that they simply had us explain concepts while the assessments tested our ability to apply concepts. Therefore, I found homework problems in the packet more beneficial than the EQs. I just didn't feel that EQs prepared us for assessments.

2. My roommate rarely asked me questions so they weren't very helpful

3. Today it makes me feel like a complete loser.

Among the benefits mentioned were diagnostic feedback on student learning (11 comments), increased understanding (8 comments), and improved retention or transfer of knowledge (3 comments). Sample remarks include,

1. Even though they take an extra time, they helped me clarify some of the misunderstanding that I had on some subjects.
2. They have helped me to remember the material and have helped me to better be able to do problems I have not seen.
3. They have greatly helped me connect all the items together. I LOVE them!
4. I know what to study, what to improve, and what to master.
5. It really made a difference. I found if I couldn't explain it to someone else, I need to clarify things for myself as well to make sure that I understand the concepts.
6. They have helped me a lot in a class this size. It's really the only way for all people to be able to articulate what their learning
7. Huge. It is so much easier to internalize the information once I have taught it to another person. It helps bridge that ever elusive gap between short term memory and long term comprehension.

In-class Question 1a also gave information about components of the course that helped students learn. It asked: “How did you prepare for today’s assessment?” A domain analysis was conducted on students’ responses to this question (Table 10). The most frequently mentioned preparation category was reviewing materials (50%). Within that category looking over notes was the most commonly mentioned activity. Other frequently mentioned categories were doing assigned activities (21%) and studying with others (14%).

Table 10

Domain Analysis of In-class Question 1a

Category	Category Frequency	Category Percent of Total	Domain Subcategory	Subcategory Frequency	Subcategory Percent of Total
Reviewed materials	52	49.52	Reviewed reading	7	6.67
			Looked over notes	29	27.62
			Looked over/did practice problems	6	5.71
			Reviewed concepts	1	0.95
			Looked at PowerPoint	4	3.81
			Looked at packet	5	4.76
Did assigned or expected activities	22	20.95	Participated in class discussion	1	0.95
			Did reading	14	13.33
			Did homework	3	2.86
			Listened in class	4	3.81
Studied with others	15	14.29	Did EQ	5	4.76
			Studied with a peer	10	9.52
			Quizzed myself	1	0.95
					0.00
Created own learning activities	9	8.57	Visualized	1	0.95
			Wrote out concepts	1	0.95
			Took notes on reading	2	1.90
			Made note cards	2	1.90
			Drew concepts	1	0.95
			Talked out loud	1	0.95
Got help from TA or instructor	4	3.81	Got instructor help	1	0.95
			Got TA help	2	1.90
			Read instructor's email	1	0.95
Did nothing	3	2.86			

Case Studies

Julia. Julia said that the activity most helpful to her learning was visiting twice with Dr. Bell during his office hours. She was not benefiting from the textbook and her own efforts to understand class concepts. She also found it valuable to discuss concepts with other students while in class. She felt that the assessments helped her because they give her “a gauge of where I am in preparing for the final – where I need to study and focus” (Personal interview, March 2006). She rated the EQs as moderately helpful because they served more to reveal what she did not know than to help her learning directly.

Dallin. Dallin found that doing the reading, attending class, and doing practice problems was generally sufficient for his learning. He found talking to others in class and doing EQs only moderately helpful. He liked the way Bell inserted items in the weekly assessments that reviewed concepts from earlier in the course. “That makes me really think about that concept. I think that kind of keeps me on my toes” (Personal interview, March 2006).

Justin. The two things that helped Justin the most were EQs and getting help from the TAs. He did not feel that he was very good at understanding the readings on his own. He needed a conversation with someone else, particularly someone knowledgeable like a TA, to learn the concepts. He held his EQs in the TA lab with one or two other students and the TA. He described how he used that activity to learn about respiration:

> I talked to Jen (TA). I specifically told her that I had no idea about any of that stuff and I really need help with it. And so she gave me a pen and said start talking and pulled the whiteboard over. She told me to write down everything I

knew. Really the only thing I could do was draw a few things and I did that. She told me to start explaining what I was drawing and I started explaining it. . . . So I started drawing it and she would ask me questions. I would try to answer them. Sometimes it would involve a lot of guessing. Sometimes she would just tell me. Sometimes I would actually figure it out on my own. . . . And when we had done the whole thing through she would erase it and then tell me to start over again. And that would go much smoother. And then new questions would always arise the second time – questions that I wasn't quite at the point of asking or understanding the first time. (Personal interview, March 2006)

Because of the extended time it took him to grasp concepts, he did not find in-class interaction very helpful.

> I am more of a fan of having something explained to us and then we start interacting. Sometimes my partner doesn't know what he is doing and I don't know what I am doing so we all just sort of sit there until the class is ready. Sometimes we get help from the TA but sometimes there are so many hands up that the TAs can't get to everybody. (Personal interview, March 2006)

Justin struggled with the assessments, but found them valuable in diagnosing his learning.

Research Question 5

Question 5 asks: What opinions do students have about the advantages and disadvantages of the formative assessment pedagogy? The assessment system was unique to most students because of the lack of midterm exams. Most data used to answer this question was at the class level. Information came from class fieldnotes and student responses to five items on the affective survey and two in-class questions.

Class Level Results

Fieldnotes. In order to establish the context I will first describe a typical assessment day based upon class fieldnotes. The following account was taken from fieldnotes describing an assessment session that occurred on January 27, 2006.

Students file in as soon as the room begins to clear from the previous class. They are quieter and definitely more subdued that on non-assessment days. By 12:00 most seats are full and 80% of the students have their notes open. They seem to be reviewing them but not intensely. Some students are looking up at the board, gazing around, or chatting. I overheard a student say, “I was nervous studying last night.”

The bell rings and the instructor calls the class to order. He says that occasionally he will take a few minutes prior to the assessment to clarify concepts. He puts up some PowerPoint slides about an experiment he conducted during the last class session and reviews experimental design concepts.

The assessments are passed out at 12:14. The room gets very quiet and students work for about 20 minutes. At 12:35 about 20% of the students have stopped writing and Bell calls the class to order. He says, “The primary purpose of this experience is to help you discover where you are and make plans for improvement. He then uses PowerPoint slides to review each question with the class and give the correct answers. It appears almost all of the students are highly engaged in this process. Some are calling out answers and others are reacting verbally with cheers or groans as Bell reveals each correct answer. The students behind me are discussing concepts covered on the assessment.

At 12:47, three minutes before class ends, some students begin to file out and turn in their papers but others have their hands up with questions for the instructor or TAs. I overhear a student behind me saying she is worried that she will not get someone to answer her question about golgi apparatus before the class ends. When the bell rings, most students depart but about 20 students walk down to the front of the room and cluster around Bell and the TAs. For the most part, they ask questions about the concepts on the assessment. This continues for about ten minutes with students gradually departing as their questions are answered.

My impression of this process is that I have rarely seen students as engaged with their learning as they were during the past 60 minutes. First they were actively involved in solving problems during the assessment and then they were immediately and clearly shown where they stood in relation to the ideal. At this point, as they evaluated their own responses, they were motivated to bridge that gap. They were raising their hands, talking to neighbors, and carefully listening to the comments made by the instructor. After class there was almost a rush to the front of the room by a group of students still trying to improve their understanding.

Course evaluation survey. Items 23, 24, 33, and 38 in the course evaluation survey probed students' feelings about the impact of the assessment system on their learning. In all cases, the majority of students responded positively about the assessments. Table 11 summarizes the results from those items (see Appendix B for results from all items).

Table 11

Selected Course Evaluation Survey Items on Student Opinions of the Assessment System

Question	Frequency	Percent
23. How do you rate the fairness of the grading procedures and criteria used in this course?		
A. Completely fair	55	39.86
B. Quite fair	52	37.68
C. Moderately fair	30	21.74
D. Not very fair	1	0.72
E. Not fair at all	0	0.00
33. I prefer the grading scheme used in this course.		
A. Strongly Agree	48	34.78
B. Slightly Agree	37	26.81
C. Neither Agree nor Disagree	27	19.57
D. Slightly Disagree	19	13.77
E. Strongly Disagree	7	5.07
35. The assessment system enabled me to more effectively monitor my progress in achieving the course goals than a traditional exam system.		
A. Strongly Agree	51	36.96
B. Slightly Agree	47	34.06
C. Neither Agree nor Disagree	20	14.49
D. Slightly Disagree	18	13.04
E. Strongly Disagree	2	1.45
38. Overall, I have enjoyed the layout of this course and wish I could have more courses with a similar testing/grading format.		
A. Strongly Agree	63	46.32
B. Slightly Agree	36	26.47
C. Neither Agree nor Disagree	17	12.50
D. Slightly Disagree	14	10.29
E. Strongly Disagree	6	4.41

In-class questions. Students were asked early in the course after taking an assessment (Feb 17): "What benefit, if any, do you receive from this or these assessments" (In-class Question 2)? Their responses were explored though a taxonomic analysis (Table 12). Some students mentioned more than one category in their responses.

Table 12

Taxonomic Analysis of In-class Question 2

Domain	Domain Frequency	Percent	Sub-domain	Sub-domain Frequency	Percent
Provides feedback	74	55.64	Self diagnose learning	55	41.35
			Self diagnose study approach	10	7.52
			Verifies correct learning	9	6.77
Helps learning	25	18.80	Helps learn/understand material	9	6.77
			Gives view of how it all works together	2	1.50
			Practice	4	3.01
			Helps retention	3	2.26
			Chance to apply knowledge	7	5.26
Fosters success in the course (grade)	21	15.79	Helps see what I need to know	8	6.02
			Helps prepare for final	10	7.52
			Helps grade	3	2.26
Improves study skills	5	3.76	Encourages study	5	3.76
Negative view	5	3.76	Does not match what we learn	4	3.01
			Can't use assessment results because they are collected	1	0.75
Improves affect	3	2.26	Boosts self confidence	2	1.50
			Less stress/allows learning at own pace	1	0.75

Fifty-six percent of the respondents indicated that they benefited from the diagnostic feedback of the assessments. Students commented as follows (All comments in this section are from students' written responses to In-class Question 2):

1. Helps me know what I do not understand. At times I think I understand a concept but when I try to actually do it I can clearly see what I truly understand and do not.

2. The value of this assessment is that it helps me see if I truly understand what is being taught. I think I get the idea but if I can't apply it, I don't know if I truly understand.
3. I came because I needed to know my standing. It doesn't matter how well you can shoot free throws in your backyard, you need the pressure of an audience and game to really evaluate your skills.

Nineteen percent of the respondents felt that the assessment itself was a learning experience. Students commented:

1. This helps to apply the principles that we learned in class.
2. I feel that the assessments help me practice the concepts I learned that week in class and therefore help me remember.
3. It helped me with my critical thinking skills—to apply the skills I know to a question that was unfamiliar.

Sixteen percent of the respondents felt that the assessments helped foster success in the course, particularly in preparing for the final exam. The assessments helped students the level of understanding necessary to do well in the class. Students commented:

1. It evaluates if you really know the information not if you can memorize the facts.
2. The assessment was the reason that I came to class because I wanted to make sure that I understood the material to the level that the instructor expected. I felt that I understood it, but I wanted to make sure that it was to the level which he expected.

3. This assessment showed me what the professor is expecting me to know and what I should be getting out of class. It may help me study for the final and tell me what I need to work on and what concepts I may or may not understand.

Four percent of the respondents indicated the assessment system motivated them to change or improve their learning approach. Students commented:

1. It helped me see that I need to look at Blackboard and do the practice problems there.
2. It forces me to keep reviewing all info instead of forgetting it until I have to relearn for the final. Also shows how concepts from previous units work with current ones.

Four percent of the students did not like the assessment system. One student commented:

> The value is very little since it is not worth that many points and some questions I don't remember learning in class discussions or in the book.

A componential analysis was conducted on In-class Question 2. The dimension of contrast was diagnostic benefit from feedback versus direct learning benefit from taking the assessment itself. Each domain (type of benefit from assessment) was labeled as either diagnostic or learning. Seventy-four percent of the comments by students said that the assessments helped them diagnostically, 19% felt that the process of taking the assessments itself helped learning, and the rest of the comments were mixed. The set of comments mentioning the diagnostic value of the assessments was analyzed further to determine what components of learning were being affected by the diagnostic feedback.

Fifteen percent of respondents felt the assessments diagnosed their study skills in some way and 73% felt they diagnosed their learning.

A second question about the assessment system, In-class Question 5, was given towards the end of the course (March 31). It asked: “What is your opinion on the benefits and/or disadvantages of the assessment/grading structure of this course?” In contrast to the earlier questions, students were invited to comment on disadvantages. The responses were coded as positive (liked the assessment system), negative (did not like the assessment system), or mixed. Forty students responded to the question. Twenty-seven students (67%) had a positive view of the assessment system, two (5%) saw it negatively, and 11 (28%) had a mixed view. A taxonomic analysis was conducted to identify domains and sub-domains of students’ statements about the system (Table 13). The most commonly mentioned positive aspect of the assessment system was its diagnostic value (23%). Student comments were similar to those listed for in-class Question 2. Compared to responses to In-class Question 2, an increased percentage of students indicated the assessment system motivated them to increase their studying or improve their study skills (14%). Students commented:

1. The structure is awesome. It keeps me studying all semester. But the tests sure are tricky!
2. The benefits are there are no tests throughout semester in the testing center. It is more like an ongoing test that never stops. I study more for classes with tests. I like the feedback on the assessments. That is hard to do on tests. Overall, it does bring into your mind things to study and focus on.

Table 13

Taxonomic Analysis of In-class Question 5

Domain	Domain Frequency	Percent	Sub-domain	Sub-domain Frequency	Percent
			Positive		
Helps evaluate own learning	19	22.62	Diagnostic feedback	19	22.62
Assessment experience itself helps learning	14	16.67	Helps learning/understanding	9	10.71
			Good review	3	3.57
			Helps retention	3	3.57
Likes grading system	12	14.29	Likes "petitioning"/ good way to help grade	7	8.33
			Less likely for one grade to harm you	1	1.19
			Doesn't punish for individual learning curve	4	4.76
Helps study skills	12	14.29	Improves study habits	5	5.95
			Encourages more study	3	3.57
			Encourages review	1	1.19
			Encourages application	3	3.57
Likes process	6	7.14	Likes immediacy of feedback	2	2.38
			Low/more spread out stress	3	3.57
			Likes the novelty	1	1.19
Fosters Individual control	4	4.76	Likes self grading	2	2.38
			Likes control of own learning	2	2.38
Likes assessment itself	4	4.76	Truly tests what we have been learning	1	1.19
			Likes having no tests in testing center	1	1.19
			Likes comprehensive nature of assessments	2	2.38
Helps prepare for final	1	1.19	Good preparation for final	1	1.19
			Negative		
Grading system	4	4.76	Stress of too much weight on final	2	2.38
			Doesn’t like being graded on attendance/class is a waste of time	2	2.38
Format of test	4	4.76	Doesn't like test format/questions	4	4.76
Negative influence on study skills	4	4.76	Less motivation to study	4	4.76

There were also a number of students who said they liked the grading system (14%). Students commented:

1. The grading structure is extremely helpful and I think one of the best I've had in class. Even if you don't do so well on some of the assessments, you can still get a good grade by "petitioning" to only use some of the assessment grades and have the rest come from your exam. I tend to learn the material better after I've taken the assessments for some reason, so knowing I can pull my grade up based on my final exam score is actually very comforting.
2. I feel the grading structure in this course augments the learning experience. The weekly assessments do not necessarily affect your grade, and so you are not punished for your learning curve during the semester. However, if you score lower on the final, they will be used to boost your grade, giving you the best of both worlds. It is designed to help me learn, not hurt.

Case Studies

Julia. Julia thinks the assessment system is beneficial to her learning. She feels it takes into consideration a person’s effort. She likes the fact that the weekly assessments can contribute to the final grade (“in case you mess up on the final”) but that students are still held accountable for a certain level of performance. She particularly likes the way the assessment system allows students to learn at their own rates. She said, “Each person learns at a different rate, different level, and different way” (Personal interview, March 2006).

Dallin. The thing Dallin likes most about the assessments is their comprehensive nature. He said, “One thing that I do like is that he’ll go a couple weeks back and randomly pull out a question from a couple of weeks ago and that makes me really think about that concept. I guess that kind of keeps me on my toes" (Personal interview, March 2006). He finds the grading system "kind of different" and does not like the fact that the entire grade depends on final exam performance.

Justin. The assessment system is what motivated Justin to change his approach to the class and increase his level of effort. The greatest value for him was diagnostic. He said, "It definitely shows me where I am and shows me how well I understand the processes" (Personal interview, March 2006). He likes the grading system because it gives him a second chance. "If I can show on the final that I really have improved, then it will benefit me" (Personal interview, March 2006).

Research Question 6

Research Question 6 asks: How and to what extent do students' approaches to learning change during the course? Information to answer this question came from in-class question, the course evaluation survey, and the case studies.

Class Level Results

Course evaluation survey. Two items probing change in the quality of students' EQs provide a glimpse into changes in students' learning approach. Students were asked: What was the quality of your EQs during the first half of the semester (Item 30) and during the second half of the semester (Item 31)? The students' responses to Items 30 and 31 are crossclassified in Table 14 in order to reveal any changes in the self-ratings of the quality of their EQs from the first half of the semester to the second half. The column at the right of the table displays the distribution of the of EQ ratings during the first half of the course. Similarly, the bottom row of the table shows the distribution of the EQ ratings during the second half. Comparison of these row and column totals indicates that the number of students who rated their EQs to be of high quality increased from 25 (18.4%) to 48 (35.3%) while the number rating their EQs as moderate decreased from 88 (64.7%) to 67 (49.3%) and the number who assigned a poor rating decreased slightly from 23 (16.9%) to 21 (15.4%). However, relying solely on these marginal totals in Table 14 obscures changes in the responses of individual students. To better understand changes in the students' ratings, the reader needs to more closely examine the numbers in the body of the table.

The main diagonal in the body of Table 14 (from the upper left cell to the lower right cell) indicates the number of students who assigned the same rating to the quality of their EQs during first and second halves of the semester. The part of the main body of Table 14 that is below the diagonal summarizes the number of students who rated their EQs higher in the second half of the course, and the part of the table that is above the main diagonal summarizes the number of students who rated their EQs to be of lower quality during the second half of the term. A total of 54 students (39.7%) rated the quality of their EQs as being the same level of quality in the first and second halves of the semester, while 52 (38.2%) rated their EQs to be of higher quality during the second half of the term. Only 30 (22%) of the students rated their EQs to be of lower quality during the second half of the course.

Table 14

EQ Quality Across the Semester

	EQ Quality Second Half			
EQ Quality First Half	High	Moderate	Poor	Total
High	10	13	2	25
Moderate	33	40	15	88
Poor	5	14	4	23
Total	48	67	21	136

Pre/post-survey. Students responded to seven items (Items 12-18) on the pre/post survey designed to measure deep versus surface learning approaches. Responses were treated as scaled. After recoding negatively worded items, responses were averaged across the seven items to create a learning approach subscale value for each survey. Response levels range from 3 (highest endorsement of deep learning) to 0 (lowest endorsement of deep learning). Average values on the subscales were: 1.71 (SD = 0.37) on the pre-survey and 1.67 (SD = 0.40) on the post-survey. The difference in average subscale values was not statistically significant (*t* [99] = -0.95, p = .35). These survey results do not indicate a shift towards deeper learning approaches. However, qualitative evidence reported below suggests that at least some students felt that they had moved towards deeper learning approaches during the course. The absence of evidence from the pre/post survey may be due to lack of sensitivity in the instrument or the qualitative results may not be indicative of the majority of the class.

In-class questions. Students were asked directly about changes in their learning approach though In-class Question 4 given on March 24. It asked: “Has the way you approach your learning (the things you do to learn concepts or skills) changed because of this course? If so, how and why did you change?" A domain analysis was conducted on students' responses (Table 15).

Table 15

Domain Analysis of In-class Question 4

Change in Learning Approach	Frequency	Percent
EQs	35	31.53
Read better	11	9.91
Draw more	5	4.50
Focused more on understanding	4	3.60
Do things to diagnose learning	4	3.60
Group study	4	3.60
Apply concepts	4	3.60
Use TA/instructor help	3	2.70
Connect concepts	2	1.80
Take better notes	2	1.80
Less focus on grade	1	0.90
Focus on retention	1	0.90
Do more homework	1	0.90
No change	34	30.63

Of the 111 students who responded to the survey, 34 (28%) said they did not change anything. Comments included:

1. Truthfully I appreciate Dr. Bell's method of teaching however I don't think my approach has changed. It seems Dr. Bell wants a person to talk through the material to see if you understand it. That is what you do in study groups. If I have trouble in a class I go to study groups. If not having trouble there is no need to for I already knew the material.

2. Not really. Professor Bell has emphasized teaching and explaining to others in order to learn but I already believe that. I generally have done so to *myself* in the past and it has proven (for me) just as effective.

Thirty-two percent of the comments mentioned EQs. Comments included:

1. Yes. Before when trying to study and prepare I would just review the content. This resulted in me memorizing the material more than learning and understanding it. But now as I teach the information and try to explain it I am able to see what I know and do not know. With my old approach to learning there were many times when I was confused and grew in frustration. Not only because I could not remember and did not understand the material but also because I could not identify what I did and did not truly understand. I know it sounds strange but it is how it felt. But know I can clearly identify my strengths and weaknesses along with finding where my misconceptions lie. I am also able to better remember and understand the subject matter. It has helped me to learn how to enjoy learning.

2. Yes. I find myself explaining things a lot more, why things are they way they are. Not just in this class but in all of my classes. The EQs really help me to understand things myself. When I can answer and explain any question my wife asks me about a certain subject topic, then I know I know it.

3. Yes. I learned how to more effectively study my material because of the EQs. When I taught my roommate some of the concepts we were learning it helped me realize points of confusion for me. Even if she didn't ask certain questions on those topics I realized for myself what I still needed to go over and

understand. in the future I think it would be helpful to quiz myself by trying to explain things without looking at the book.

4. Yes. Through the EQs I actually started to know how to explain concepts. This gave me a deeper understanding of those same concepts. I have applied this technique to other classes as well.

Nine percent of comments mentioned that students had learned to read better. Comments included:

1. The EQs have changed the way I use my textbook—both the way I read it and how I refer back to it. I have started to go through and explain diagrams and concepts from the textbook to myself and others if there is a concept I am unclear on. I have started to do it in my other classes too. that way I can obtain my own understanding of a concept instead of limiting myself to the words the textbook uses.

2. Yes. I do more reading in general and while I read I try to organize in one whole picture and the key concepts that would fit into the big picture

3. Reading with a purpose—there needs to be questions answered to focus the mind into learning. Dr Bell is good at this and is on to a mind breaking discovery.

4. It has changed the way I treat my reading assignments in other classes. I actively read, highlight, and note take.

The other responses, ranging from four to one percent of total comments, were: focus more on understanding, do things to diagnose own learning, group study, apply concepts, utilize TA or instructor help, connect concepts, take better notes, and less focus on the grade. Sample comments include:

1. Yes. Before taking this class I just focused on memorizing concepts but I started to apply concepts because of this course. It is very good because I will not forget what I learn by applying it.
2. It has helped me understand better how to do well in a class. Primarily to not stress so much as to the actual grade I have but rather to focus and really understand the material. Not only is one more likely to do better in the class but to remember the material in the future.
3. Yes. I really have recognized the value of group study sessions. I am looking for big ideas and focusing less on details in my other classes. Understanding processes is huge. In some classes, however some teachers test on details that don't reflect understanding or competence. Dr. Bell is a master at teaching clearly and then asking questions that reflect levels of understanding and misconception.

Some students mentioned a trend towards deeper learning approaches and increased effort:

1. At the beginning of class I thought I knew most of the material in biology as I took it last semester. However, after the pretest and some of the other Friday tests, I realized that I actually needed to study. Some things have helped tremendously such as reviewing old material and the EQs and obviously it has paid off. My scores have been on the upward trend.

2. Yes I used to consume myself with memorizing facts for a certain class but in this class I cannot do that. I actually have to study and practice the material. I cannot get by doing nothing.

In-class Question 1b, given on January 27, also gives evidence about learning change. The first part of the question, discussed earlier, was: “How did you prepare for today’s assessment?” The second part of the question provides indirect evidence for changes in learning approach. It asked: “What do you plan to do differently as you prepare for next week’s assessment?” The responses to this question were evaluated using a taxonomic analysis (Table 16).

Forty-three percent of respondents indicated they were planning to improve the quality of their study activities. Comments included:

1. I will cover it more in depth, study earlier, and make sure I can apply it.
2. Try to better understand concepts that are cloudy. This time I ignorantly ignored the fact that I didn't understand diffusion.
3. If I don't understand a concept completely, well don’t be too shy to ask about it.
4. I will make sure I know the names and functions better. Relate things to the whole.
5. I’ll think more of concepts instead of just focusing on definitions.
6. To prepare for next week's assessment I will try and go through or make my own “real life” or practical examples so that I can know how to better apply concepts that are taught.

Table 16

Taxonomic Analysis of In-class Question 1b

Domain	Domain Frequency	Percent	Sub-domain	Sub-domain Frequency	Percent
Improve quality of study activities	27	42.86	Review more thoroughly	10	15.87
			Read more carefully	5	7.94
			Do practice problems	4	6.35
			Focus on whole	2	3.17
			Work to understand	1	1.59
			Memorize better	1	1.59
			More effort on homework	1	1.59
			Summarize concepts	1	1.59
			Make sure I can apply	1	1.59
			Make own examples	1	1.59
Manage study time better	17	26.98	Study more	13	20.63
			Study earlier or more consistently	4	6.35
Get help from others	6	9.52	Get TA help	4	6.35
			Do better EQs	2	3.17
Better test taking	4	6.35	More care taking the test	3	4.76
			More savvy about what teacher wants	1	1.59
Improve behavior in class	4	6.35	Do not miss class	2	3.17
			Concentrate better in class	1	1.59
			Take better notes	1	1.59
Change nothing	5	7.94	Change nothing	5	7.94

Twenty-seven percent of the respondents said they would manage their time better by studying earlier or more consistently. Comments included:

1. Study more and explain concepts I have trouble with to other people.
2. Review earlier so I can practice the things I'm not solid on.
3. Take more time to study and study throughout the week not just right before.

Other changes mentioned were to get help from others (10%) or to generally do better at test taking (6%).

A componential analysis was conducted on a subsection of student responses to In-class Question 1b (Table 17). The dimension of contrast was changing learning strategies versus increasing the intensity or amount of existing learning strategies.

Table 17

Componential Analysis of In-class Question 1b

Domain	Frequency	Percent of Total
Create New Learning Strategy		
Focus on whole	2	5.0
Work to understand	1	2.5
Summarize concepts	1	2.5
Make sure I can apply	2	5.0
Subcategory Total	6	27.5
Modify Existing Learning Strategy		
Study more	13	32.5
Review more thoroughly	10	25.0
Read more carefully	5	12.5
Do more practice problems	4	10.0
Memorize better	1	2.5
More effort on homework	1	2.5
Subcategory Total	34	72.5

Case Studies

Julia. As mentioned in an earlier section, Julia had difficulty on the assessments and found she needed to change her approach to learning. She chose to get help from the instructor and then take his advice in seeking for deeper, more holistic understanding.

So I think meeting with Dr Bell really helped that because I had all these pieces and I didn't know how to connect them. I didn't have the entire overall picture and how the process and the concept was from start to finish. (Personal interview, March 2006)

Dallin. Dallin came into the course with definite ideas on how to manage his learning and did not make any major changes but there is a hint that he made a slight change in his learning approach. He said that he made over 100 note cards for a previous biology class and when asked if he made cards for the Biology 120 class he said, "I don't know what to make them on" (Personal interview, March 2006).

Justin. Justin made the most dramatic change out of the three students who served as case studies. His high performance in previous classes fostered an attitude of confidence in his abilities and learning approach as he began the Biology 120 class, but because of his poor performance on the assessments, he quickly realized that his learning approach of reading and memorizing was not sufficient (Personal interview, March 2006).

> At the time what I was doing was note cards. So I think note cards are way better for strict memorization but not for conceptual type of things. . . . When it comes to conceptual they don't really help me at all. I really need to do what they have shown us in this class, explain it to someone else, have them correct me, have them ask me questions, I ask them questions. That helps me so much. That is a

> completely different kind of learning than I am used to. (Personal interview, March 2006)

By the end of the course he had made significant changes in his approach to learning.

> It is definitely a lot deeper in this class. It's more than superficial reading over notes and then recognizing things when you take the test. Because a lot of tests you can just study and then you might not know about something but because you recognize a lot of things. Recognizing is totally different than knowing. In this class it really teaches you to know the material rather then recognize it. And I think that I was just expecting to recognize things when I started taking the assessments and I kept thinking ok just study a little harder and it will get better. And it really never get better until I really did the EQs with more quality. You really have to know the material deeper in this class. And it's really not that hard if you do it right. That is another thing I realized: I'm spending just as much time on it now, a little more actually, and I understand everything 20 more times than I did. (Personal interview, March 2006)

He also indicated that he began to feel more personal responsibility for and control of his learning.

> I think I look at learning with more personal responsibility now. At first I was thinking: this is a class for kids who know what they are doing…and I do think those kids do have a bit of an upper hand on me because a lot of this stuff, like stuff about the cells, I am learning that from scratch because I have completely forgotten everything since my sophomore year in high school when I learned about cells and organelles. But I realize now I could be getting better scores than

> they are. I just have to put the time in….there is nothing more the teacher could do. He has told us a thousand times what we need to do and I just wasn't doing it effectively. I really do understand that it has a lot more to do with me. There may be exclusive, seldom cases where it does have more to do with a bad professor or bad TAs...the majority it is really is my fault if whether do well or do bad. I also know that when it comes to studying I also need to focus on quality rather then quantity because if I study for four hours but it is less effective then it is not getting me anywhere. But if I study for one hour having good conversation with someone, explain to them, they ask me questions, explain it to me, I ask them questions. That is *so* much better than 3 hours with a book. (Personal interview, March 2006)

Research Question 7

Research question 7 asks: How and to what extent do students' attitudes towards learning change during the course? The particular focus of this question was to evaluate whether students changed in their orientation towards grades as opposed to learning for understanding and retention and to evaluate any change in their interest in learning biology but other issues arose during the research. Data to answer this question came from the pre/post-survey, course evaluation survey, and from class fieldnotes.

Class Level Results

Pre/post survey. Items 6 to 11 on the pre/post survey were designed to measure change in students' orientation towards grades versus learning. The items were combined into subscales. Response levels ranged from 3 (highest orientation towards learning) to 0 (highest orientation towards grades). Average values on the subscales were: 1.29 (SD =

0.50) on the pre-survey and 1.38 (SD = 0.47) on the post-survey. The difference in average subscale values was statistically significant (t [103] = 2.15, p = .03) but the effect size (d = .17) was small (complete survey responses are in Appendix A). These survey results alone do not signify a clear shift away from orientation towards grades during the course but they tend to support the results from other data sources described below.

Course evaluation survey. Students were asked directly about any changes in grade versus learning orientation in Item 34 of the course evaluation survey (Table 18). Sixty-four percent of respondents strongly or slightly agreed that the course had helped them focus more attention on their learning with less worry about grades. Students were also asked in Items 25 and 26 about any changes in interest towards learning biology or conducting research (Table 18). Eighty-six percent of respondents felt the course greatly or slightly enhanced their interest in studying biology further and 83% of respondents felt the course greatly or slightly enhanced their interest in designing or conducting research.

Fieldnotes. A student talked to me about his learning orientation after class on January 20, 2006. At that early point in the course he had already experienced a shift in away from grade orientation. The following is a recreation of what he said:

> My attitude has changed. I had anatomy and physiology in Idaho (a different university). There was so much force-feeding of facts and this caused lots of anxiety. It was a distraction – hard to focus. I was more focused on grades than on learning. In this class I am more focused on absorbing. I don’t even think about my grade. When [Bell] showed that picture of the flounder (PowerPoint slide of a fish adapting to background color) I was so excited that I went on Google and started looking up stuff. (Field notes, January 20, 2006)

Table 18

Course Evaluation Survey Items 25, 26 and 34

Question	Frequency	Percent
25. Has your experience in this course enhanced or diminished your interest in studying biology further?		
A. Greatly enhanced	56	40.58
B. Slightly enhanced	65	47.10
C. Slightly diminished	14	10.14
D. Greatly diminished	3	2.17
26. Has your experience in this course enhanced or diminished your interest in the possibility of designing and conducting research in an area of interest to you?		
A. Greatly enhanced	26	18.84
B. Slightly enhanced	89	64.49
C. Slightly diminished	21	15.22
D. Greatly diminished	2	1.45
34. In this system I have been able to focus my attention more on learning and worry less about my grade.		
A. Strongly Agree	51	36.96
B. Slightly Agree	38	27.54
C. Neither Agree nor Disagree	15	10.87
D. Slightly Disagree	23	16.67
E. Strongly Disagree	11	7.97

Research Question 8

Research Question 8 asks: How and to what extent does students' self-efficacy towards studying and learning biology change during the course? This topic was explored through items on the pre/post survey and the course evaluation survey as well as through the case studies.

Class Level Results

Pre/post survey. Items 1-5 of the pre/post survey were designed to measure changes in students' self-efficacy towards learning biology. Response levels ranged from 3 (highest self-efficacy) to 0 (lowest self-efficacy). A self-efficacy subscale was created by calculating an average of each student's responses to the five items. Average values on the subscales for the 104 students who took both the pre and the post survey were: 2.05 (SD = 0.53) on the pre-survey and 2.02 (SD = 0.58) on the post-survey. The difference was not significant (t [103] = .63, p = .53) (complete survey responses are in Appendix A). These results may be due to lack of change in self-efficacy levels or they may be due to insensitivity of the instrument. The subscale items were relatively easy to endorse. At the beginning of the course most students indicated high levels of self-efficacy towards learning biology. In responses to Pre-survey Items 2 and 5 given on the first day of class, close to 90% of the 216 students who took the pre-survey agreed or somewhat agreed that they were confident they could explain biology concepts (88%) or understand biology topics (93%)(Table 19).

Table 19

Pre-survey Items 2 and 5

Question	Frequency	Percent
2. I am confident I could explain something learned in biology classes to another person.		
A. Agree	95	43.98
B. Agree somewhat	95	43.98
C. Disagree somewhat	20	9.26
D. Disagree	6	2.78
5. I am confident that I can understand topics in biology classes.		
A. Agree	121	56.02
B. Agree somewhat	80	37.04
C. Disagree somewhat	14	6.48
D. Disagree	1	0.46

Responses to Item 3 from the self-efficacy subscale reveal an interesting pattern of change. Students responded to the statement “Biology is difficult for me” by selecting a level of endorsement ranging from A (*agree*) to D (*disagree*). Because the item was given at the beginning and the end of the course it is possible to examine change in the distribution of students’ endorsement levels. Table 20 summarizes the distribution of responses to this item on the pre and post-surveys. Of the 104 students who took both surveys, 45 (43%) did not change in their endorsement level of this item but 30 (29%) of respondents increased and 29 (28%) of respondents decreased their level of endorsement. The shift was towards a flattening out of the frequency distribution. It appears that some students felt that Biology was less difficult for them after taking the course but almost an equal number of students felt that biology was more difficult for them at the end of the course. These results may be partially due to a change in students’ definition of what it means to learn biology. Evidence from interviews and question responses suggests that some students began the class thinking they could succeed by relying on surface learning approaches. As they attended Bell's classes and took his challenging weekly assessments their perspective may have shifted from a reliance on memorization to a realization of the importance of developing the ability to understand and think with their knowledge. This more demanding mode of learning may have caused students to reevaluate their conceptualization of what it meant to learn biology and perhaps to decrease in their feelings of self-efficacy towards that more rigorous definition of learning.

Table 20

Bivariate Frequency Distribution for Item 3 on the Pre and Post Survey

	Post-survey Responses				
Pre-survey Responses	Agree	Agree Somewhat	Disagree Somewhat	Disagree	Total
Agree	1	2	0	0	3
Agree Somewhat	5	10	11	0	26
Disagree Somewhat	6	9	19	16	50
Disagree	0	3	7	15	25
Total	12	24	37	31	104

Course evaluation survey. Two items in the course evaluation survey were related to self-efficacy. Items 27 and 28 in the course evaluation survey probed whether students thought that the course had helped them become better at thinking like a scientist or at learning biology (Table 21). An impressive 98% of students who responded to the survey indicated that their experiences in the course had greatly or slightly enhanced their ability to think like scientists and 88% of students thought the course had greatly or slightly enhanced their ability to learn biology.

Table 21

Course Evaluation Survey Items 27-28

Question		Frequency	Percent
27. Has your experience in this course enhanced or diminished your ability to think the way scientists think?			
	A. Greatly enhanced	70	50.72
	B. Slightly enhanced	66	47.83
	C. Slightly diminished	2	1.45
	D. Greatly diminished	0	0.00
28. Has your experience in this course enhanced or diminished your confidence in your ability to learn biology?			
	A. Greatly enhanced	54	39.13
	B. Slightly enhanced	67	48.55
	C. Slightly diminished	13	9.42
	D. Greatly diminished	4	2.90

Case Studies

I asked each of the case study students if they had experienced any change in confidence in their ability to learn biology. Julia said there was no change because she was confident coming into the course. Dallin also maintained a high level of confidence before, during, and after the class. Justin experienced a fluctuation in his level of self-efficacy towards learning biology. He actually began the course thinking he would do well, but early in the course he experienced a dip in self-efficacy towards learning biology:

> In the beginning I was thinking well maybe I just suck at this and it is not something I can do but when you realize you are in control, that really adds a lot to what you think your ability is because you think even though I may not be good at this right now, there is nothing that says by the end of this semester I can’t be

just as good as anyone in this class if not better. And I definitely don't think I am better than hardly any of the kids in this class but I have definitely made improvement. And if I would have just done what he was telling us to do at the beginning of the semester it would have made a world of differences. (Personal interview, March 2006)

Research Question 9

Research Question 9 asks: In what ways do the responses to the above questions vary by individual students or subgroups of students? I first examined the demographic variables of gender and year in college (Table 22). A two-way analysis of variance yielded a main effect for year in school ($F(3, 249) = 4.43$, $p < .01$). Performance tended to increase as year in school increased. The main effect for gender was non-significant ($F(1, 249) = 0.97$, $p = .32$) and the interaction effect between year in school and gender was non-significant ($F(3, 249) = 1.32$, $p = .27$).

Table 22

Final Exam Total Points by Gender and Year in College

	Gender		
Year	Males	Females	Total
Freshman	45.44	40.23	43.60
Sophomore	46.98	43.50	45.89
Junior	49.13	47.29	48.84
Senior	47.54	51.80	48.87
Total	46.92	42.88	

In order to explore subgroups and their relation to each of the research questions I selected a at least one quantitative measure representative of important variables referred to in the research questions and created a correlation matrix for each of those measures. Table 23 lists the quantitative measures used for each variable.

The relationships of most interest were between the two performance variables (final exam and gain) and the other variables in the matrix. As would be expected, final exam scores were positively correlated with all of the effort variables: number of weekly assessments taken (r [249] = .407, $p < .01$), attendance (r [247] = .365, $p < .01$), homework completion (r [245] = .261, $p < .01$), and reading completion (r [247] = .242, $p < .01$). Concerning affective variables, the self-efficacy post-survey subscale scores correlated positively with final exam scores (r [114] = .423, $p < .01$), with self-efficacy gain (r [105] = .493, $p < .01$), and with learning approach (r [136] = .313, $p < .01$).

Gain, the other measure of performance, only correlated positively with three of the effort variables: weekly assessments taken (r [159] = .265, $p < .01$), attendance (r [159 = .243, $p < .01$), and reading (r [159] = .182, $p = .02$). There were no significant correlations between gain scores and any of the affective measures. This may be partially due to the fact that correlations between performance gain scores and affective subscale gain scores were limited to responses from students who took both tests and both surveys. Consequently, the number of usable responses was low (n = 84 to 86). However, the correlation between gain and learning approach gain approached significance (r [84] = .199, $p = .07$).

Table 23

Quantitative Measures for Exploration of Subgroups

Variable	Quantitative Measure
Performance	Final Exam: Posttest total points
Performance	Gain: Posttest total of 22 matched items – pretest total of 22 matched items
Effort	Weekly Assessments: Number of weekly assessments taken
Effort	Attendance: Number of days attending class
Effort	Reading: Number of reading assignments completed
Effort	Homework: Number of homework assignments completed
Self-efficacy	Self-efficacy: Post-survey self-efficacy subscale score
Learning orientation	Learning orientation: Post-survey learning orientation subscale score
Learning approach	Learning approach: Post-survey learning approach subscale score
Self-efficacy	Self-efficacy gain: Post-survey self-efficacy subscale score – pre-survey self-efficacy subscale score
Learning orientation	Learning orientation gain: Post-survey learning orientation subscale score – pre-survey learning orientation subscale score
Learning approach	Learning approach gain: Post-survey learning approach subscale score – pre-survey learning approach subscale score
EQs	Elaborative questioning: Responses top course evaluation survey item 29: What influence did EQs have on your learning
Feedback	Feedback: Responses to course evaluation survey item 35: The assessment system enabled me to more effectively monitor my progress in achieving course goals than a traditional exam system.

The EQ and the feedback variables were highly correlated with one another (*r* [137] = .925, $p < .01$) and their pattern of significant correlations with other variables was identical. Both variables were positively correlated with learning orientation (EQ: *r* [137] = .635, $p < .01$, Feedback:(*r* [137] = .587, $p < .01$), learning approach (EQ: *r* [136] = .874, $p < .01$, Feedback: (*r* [136] = .853, $p < .01$), and learning orientation gain (EQ: *r* [105] = .731, $p < .0$, Feedback: (*r* [105] = .689, $p < .01$).

The following results are suggested by this correlational analysis:

1. Final exam performance is positively correlated with effort. For example, the number of weekly assessments taken accounts for approximately 16% of the variance in final exam scores.

2. Gain in performance as measured by scores on the 22 items in common to the pretest and posttest is positively correlated with the number of weekly assessments taken and class attendance.

3. The degree of self-efficacy towards learning biology is positively correlated with final exam performance.

4. Increases in levels of self-efficacy and learning approach (towards deeper learning strategies) are positively correlated with final exam performance.

5. The level of endorsement of both EQs and formative feedback is positively correlated with the end-of-course level of orientation towards learning (as opposed to grades) as well as gain in that level from the beginning to the end of the course.

Chapter 5: Discussion and Conclusions

I admire the writings of Elliot Eisner. He examines the diverse and colorful world of education through the eyes of an artist and recognizes that there are

> No near certain answers or foolproof methods, but a sensitivity to context, an appreciation for nuance, a set of skills that one can use with both virtuosity and flexibility, and a variety of intellectual frameworks that allows one to see the situation from different perspectives. (Eisner, 1985, p. 2)

He suggests that in education we need to "pay attention not simply to the score, but to the ways the game is played" (p. 6). This is the place to summarize and speculate on how the "game" was played. It is important to discuss answers to each research question, limitations, contributions to theory, and implications for future research. These topics will be covered in this chapter, but the focus will be on integrating the diverse findings discussed in Chapter 4 into a lucid and meaningful representation of student's experiences in the Biology 120 class. Each theme that emerged during this research will be discussed in its own section.

Themes

Two Hundred and Sixty-Three Active Learners

Standing at the front of a stadium style classroom overflowing with students can be a daunting experience. It is tempting to conclude that the only possible way to teach so many students at once is by lecturing. However, Bell, the instructor of the Biology 120 class I observed, has a different opinion. Early in his career he realized that planning what *he* would do in the classroom was far less important than planning what his *students* would do. He created, adopted, and adapted numerous techniques for keeping students actively involved in their own learning. In of all the classes I observed, there was only one segment with more than ten minutes of straight lecturing. Based upon the sample of class fieldnotes I examined, student-centered learning activities occurred almost 40% of the time (23% in student-centered learning activities and 17% in students questioning the instructor) (see Table 2) and activities changed every two to three minutes. Even when he was lecturing, Bell often employed a question and answer (class chant) technique. It was a rare student who was able to doze in the back of the classroom. Activities varied, but generally they emphasized problem solving and discussion in pairs. Bell encouraged students to talk about, vote on, draw, list, shout or solve.

Clone the Teacher

One instructor to 263 students is a frightening ratio. How can any one person address the individual learning needs of that many students? A solution used in Biology 120 was to "clone the teacher." First of all, Bell selected three excellent teaching assistants (TAs). They did much more than just grade papers—they were actively involved in daily classroom activities. When students were working on problems or discussing concepts with their neighbors, there were many more hands in the air than could be attended to by the instructor alone so the TAs would rove through the classroom and assist students. After class, students would often descend upon the instructor and TAs seeking more specialized attention. It would sometimes be 20 minutes before the room cleared and the TAs could leave. TAs also held regular office hours and conducted help sessions. One TA assisted a group of struggling students almost daily with their EQs and homework problems. I observed her on the final exam day worriedly watch some of her charges as they worked long hours to complete their exams. A number of students benefited significantly from TA help ("What has helped me the most is going in for TA hours and doing my EQs there. When I go there and do the practice problems the TA gives me or discuss the important things with them, then the principles of the course are solidified for me" [Students comments on In-class Question 3]).

The elaborative questioning component of the course is another way Bell cloned the professor. As students worked together in pairs teaching and questioning one another they received personalized help on their learning. When the EQ system works properly, each student has his or her own personal teacher ("I think he was trying to teach us to learn together and so now we are at a point where we kind of do it automatically. I can't explain it. It is just amazing" [Student comments on In-class Question 6]).

A more subtle way Bell cloned the professor was to encourage students to take charge of their own learning. He structured activities in the course that compelled them to address their biology shortcomings and motivated them to organize or seek the help they needed. In a sense, they became their own teachers. There was a general theme that I noticed after reading numerous student comments: The class is tough but the resources are in place for success and I just need to take advantage of them. In some classes students arrive expecting to *be taught* something and that is the instructor's responsibility. In Bell's class students quickly realized that they were there to *learn* something and it was their own responsibility. Justin clearly expressed the idea of feeling control:

> I think I look at learning with more personal responsibility now. . .in the beginning I was thinking well maybe I just suck at this and it is not something I can do but when you realize you are in control, that really adds a lot to what you

think your ability is because you think even though I may not be good at this right now, there is nothing that says by the end of this semester I can't be just as good as anyone in this class if not better. And I definitely don't think I am better than hardly any of the kids in this class but I have definitely made improvement. And if I would have just done what he was telling us to do at the beginning of the semester it would have made a world of difference. (Personal interview, March 2006)

Personal Connection

Related to the problems associated with a large lecture class and the need to clone the teacher is the issue of connection between the instructor and individual students. Bell told me that in a class of fewer than 100 students he is able to learn their names and connect in some way with each one individually; however in larger classes he feels frustrated because he is unable to make that connection and give students the individual help they need. He feels there just is not time talk to each student ("I have a hard time talking to Dr bell after class. There is always a line to see him" [Personal interview, March 2006]).

Bell made an effort in Biology 120 to connect with as many students as possible, but in the end there were students who got lost. Out of the 263 students in the class, 13 (5% of the class) registered for the course, did not take the final exam, and received an E as a final grade. Eighteen students took fewer than five weekly assessments and five students did not take any at all. These students got lost in the crowd and were not identified until the final performance data was compiled and by then it was too late. I do not know the stories of these students so I cannot comment on the factors that led to their poor performance, but Bell is convinced that if he would have had at least one personal contact with them he could have kept most of them on a better learning track.

Time is a limiting factor in adequately connecting with a large group of students. Bell was able to devote a reasonable amount of time to his students. He was fortunate to teach only Biology 120 during Winter 2006 but he had to balance teaching with his personal research and his administrative duties as an associate dean. He held office hours during the hour before class each day (three times per week). One or two students attended on most days but up to 15 students came on the days before assessments. The students who attended found them extremely helpful ("He made me think through things. Because I was actually the one doing it and not being a spectator I actually learned it because I am a hands on learner" [Personal interview, March 2006]). He also scheduled eight review sessions scattered throughout the three weeks before the final exam. About 50 students attended each of these sessions. He felt that these types of activities allowed him to connect with at least some of his students. Students seemed to agree,

> I have been very impressed with the way he has made himself available to the students who are willing to put forth the effort to take advantage of that. I know a lot of teachers that are helpful but don't put forth that effort. I think that is effective because it lets students know that he is genuinely concerned in how they do and really does want them to learn the material and do well. That, at least for me has helped me to want to do better because I feel I can go and talk to him if I need to. (Personal interview, March 2006)

There are methods other than meeting in person that may foster a feeling of connection. E-mail is one of them. Bell sent the entire class nine e-mails during the semester on a variety of subjects. The following are two examples:

1. Now you know what an assessment is like (January 27): Remember, the main purpose of the assessments is to help you learn and improve. Ordinarily, there will be more time for feedback at the end than there was today. I realize that many of you did not get your questions answered today. I urge you to write to me or come see me if that is the case so that we can get the matter resolved . . . The assessment is not very helpful if we don't do this follow-up.
2. What if I'm feeling frustrated (February 11): We are now a month into Biol 120. We've had three assessments and sufficient time to become quite familiar with the layout of the course. I know that many of you are pleased with what has been happening, and I'm glad for that. Some of you are undoubtedly frustrated. You may feel that you are not performing as well as you prefer on assessments. You may feel that the style of teaching being used is not effective for you. You may have additional frustrations. I want this class to be the most positive experience it can possibly be for every individual. This is a challenge in a large class because my only option for class time is to do what works best for the largest percentage of students. However, not everyone learns best by the same method. I am anxious to individualize this course as much as possible. I can be much more creative than you imagine. If you are feeling frustrated with your experience for any reason, please write to me or come see me as soon as possible. There is time to make personalized

adjustments that will help you succeed. Obviously, I can't do that if I don't know you and your needs. It doesn't matter whether your needs relate to lack of understanding, too little information, mismatch between your learning and my teaching style, etc. All of these are things we can deal with and adjust for you so that your experience is premium.

Bell also unconsciously employed a less tangible method for fostering a feeling of connection. The students I interviewed almost universally mentioned that they were convinced that Bell cared about their learning. Justin described an incident that particularly impressed him. He was struggling and needed help so he set up a personal appointment with Bell,

> [Bell] was totally willing to set up a time with me and it was a time right after he was getting out of an appointment with the Dean. So he even told me, "I'll have to leave my appointment with the Dean a little early. Just make sure the receptionist knows you are there and thy will pull me out." So he was willing to get out of an appointment with the Dean to meet with me and *that meant a lot that he actually cared for how I did*. He wanted me to do well and he actually showed that. I think that, seeing he felt responsible for a lot of things made me feel personally responsible for a lot of things. That is huge. (Personal interview, 2006 emphasis added)

Other students mentioned similar sentiments:

1. Just the way we present ourselves make people respond differently and that has been the biggest impact on me from Dr bell – seeing his commitment to the students and to the class, without holding expectations over my head

without holding homework over my head, it makes me want to be better because of who he is, because of what he is giving, because of the appreciation he gives. (Personal interview, March 2006)

2. I have been very impressed with the way he has made himself available to the students who are willing to put forth the effort to take advantage of that. . . .I think that is effective because it lets students know that he is genuinely concerned with how they do and really does want them to learn the material and do well. That, at least for me has helped me to want to do better because I feel I can go and talk to him if I need to. (Personal interview, March 2006)

There was also an atmosphere of talking with and questioning the instructor during the class. This may have stemmed from the active nature of the in-class activities and well as Bell's constant encouragement to "expose yourself." Students seemed to feel a personal connection, if not directly with the instructor, at least with other struggling students,

1. He actually encouraged talking in class! It was very helpful. I always felt comfortable in class because I didn't feel alone. I could always turn and get help from somebody. (Personal interview, March 2006)
2. It might just be the class – but I think it is also professor. It looks as though people feel comfortable asking questions. A lot of time you are in such a big class and it's like – I'm not going to ask that. Like even today, the guy sitting behind me was like. "Hey wait a second can we go over that problem?" I thought it was good that he felt comfortable enough to blurt it out. Because I was kind of wanting to go over it too but it was like—do I say anything?—and

a couple of people were nodding their heads. (Personal interview, March 2006)

A final connecting component of the Biology 120 class cannot be taught or transferred. It was Bell's individual manner of communicating ("'Folks, now listen up, this one is table worthy.' Bell climbs up and stands on the lab table at the front of the room" [Class fieldnotes, March 31, 2006]) and his unique brand of humor ("An allele is a version of a gene. We don't have different genes. If we had different genes you would be a cow, or a manta ray or a lilac" [Class fieldnotes, March 15, 2006]). Students mentioned that they enjoyed his humor and classroom antics ("It has just really helped me a lot to see someone so excited about what they do" [Personal interview, March 2006]).

Digest First, Then Come to Class

Bell required students to read and digest textbook material before coming to class. Students were assigned to write a summary sentence on their reading, a paragraph or diagram illustrating main concepts, and a list of questions. He enforced that activity by factoring reading assignment completion into the final class grade. In his opinion, textbooks are generally a high quality, peer-reviewed source of information and instructors do not need to redeliver that information during class time. I have heard Bell describe his approach as a paradigm shift in teaching. Generally, students expect to learn concepts in the classroom and then do something with those concepts (homework) on their own. Just the opposite occurred in Biology 120. Students were expected to come to class with at least a rudimentary understanding of the concepts. Then they actively worked with those concepts in the classroom.

One of the in-class questions asked students what components of the course tended to foster their learning. Fifteen percent of the respondents mentioned the importance of reading ("That way he is building on the basic knowledge I gained the night before and I can retain it"[Student responses to In-class Question 3, 2006]). Students also mentioned improved or more active reading in response to an in-class question about change in their learning approach ("I do more reading in general and while I read I try to organize in one whole picture and the key concepts that would fit into the big picture" [Student responses to In-class Question 4, 2006]). Apparently, while experiencing the Biology 120 pedagogy students came to realize the importance of working to understand the concepts before coming to class. In some cases, this new approach transferred ("It has changed the way I treat my reading assignments in other classes. I actively read, highlight, and note take" [Student responses to In-class Question 4]).

Expose Yourself

From the very first day, Bell established the class theme: "expose yourself." He explained to students that, in order to learn biology, they would need to work to discover their misconceptions. The thrust of classroom activities was to compel students to reify their knowledge. Bell engineered ways for students to make their abstract ideas concrete in order to expose and examine them. This required students to accept the possibility that they might make and reveal mistakes. In a typical class Bell would engineer six to eight "expose yourself" occasions by doing activities such as explain a concept to a partner, raise hands to vote on a correct answer, draw a concept, write (not just think) what will happen next, or solve a problem.

Of course, exposure by itself can be demoralizing. To be effective in promoting learning it must be paired with useful feedback. According to Black and Wiliam,

> When anyone is trying to learn, feedback about the effort has three elements: recognition of the desired goal, evidence about present position, and some understanding of a way to close the gap between the two. All three must be understood to some degree by anyone before he or she can take action to improve learning. (1998b)

Black and Wiliam's principle at work can be seen in the following description of a typical expose/feedback activity from my February 8th fieldnotes:

> Bell asks the class to draw a DNA and an RNA molecule and illustrate the concepts of five prime, three prime, anti-parallel, base paring, number of strands, and where there are hydrogen bonds. Student react with sighs and it is obvious many of them are not sure how to include all those concepts. Bell notices and says, "If you are confused, raise hands and let us come help. We are underemployed here." Immediately five or six hands shoot up so the TAs and Bell rove the room helping students. The students sitting around me are hard at work. One is stuck so he is watching his neighbor draw and asking her questions. Another student has his hand up. Eventually Bell comes over and explains five prime and three prime to him. Three students are working together. Two of them are explaining base parings to one who seems confused. After six minutes Bell calls the class to order and says, "We gave you a good chance to find out what you do and don't know. Now you are ready to hear an explanation. Your

> responsibility is to find out what you don't understand." He goes on to share his diagram and explain the concepts. (2006)

By the end of this activity students have completed two of Black and Wiliam's three elements of feedback: recognition of the desired goal and evidence of their desired position. The third element, how to close the gap, is less defined. Bell frequently tells students that they must decide what they are going to do to solidify their understanding and he will often give them suggestions on how to do it (EQs, practice problems, draw), but students have complete control of that process. My March 22 fieldnotes have an example of a "close the gap" activity.

> It is the beginning of class. Bell asks students to take out a clean sheet of paper and tells them they will be turning it in. He says, "You have had seven assessments now. There are three left. You need to make a decision on how you are doing. I know many of you have come and seen me. For many of you that is not the case. I apologize for this but I don't know how to fix it." He then tells them to describe how they are doing and gives them three choices of what to write:
>
> 1. Fine, thanks for asking.
> 2. Not too good, but I know what to do.
> 3. Help!
>
> Students are asked to fold the paper and pass it in. Later that day he emailed all students who wrote "Help!" asking them to respond to the email or come see him to set up a plan for how they were going to get the help they needed. (2006)

Exposure was actualized for an entire class period approximately once per week on assessment days. Students worked authentic challenging problems in a test-like atmosphere, shared their answers with classmates, and then compared them to Bell's correct answers. The assessments were difficult enough to challenge students and some of the item distracters were designed to catch common misconceptions (see Appendix H for a sample weekly assessment). Many students recognized the value of this process. In response to In-class Question 2 about the value of the assessment system, 56% of respondents said they benefited from the diagnostic feedback. Sample comments include (Student responses to In-class Question 2):

1. The assessment helps me see where I am in biology right now. Sometimes it can be frustrating because I think I know a concept and then realize I did not know it as well as I thought.
2. It evaluates if you really know the information not if you can memorize the facts.
3. The value of this assessment helps me see what I didn't understand or study enough. It shows me that I need to do more practice problems. It also gives me confidence in some of the concepts. I can apply my knowledge.

Docemur Docendo

The Latin phrase *Docemur Docendo* means he who teaches, learns. This is one of the strongest themes that arose from my exploration of the Biology 120 class. A quote by Joseph Jourbet, an early 19th-century philosopher, is prominently displayed on a door leading into the BYU science building. It says: "To teach is to learn twice over." Bell embraces that philosophy and he required the Biology 120 students to teach one another.

He did this through assigned EQs (elaborative questioning). After reading about a concept and then working with it in class, students were to find a partner and explain that concept from memory. The partner was to follow up with questions beginning with the word “why” or “how.” If students did not know the answers they were to turn to their textbook or get help from the instructor or a TA. Students were to do at least 13 EQs during the course and completion was recorded as part of the 19 homework assignments. Students reported an average of 17 homework assignments completed, so it appears they were diligent in doing their EQs. One student sent me an email describing his last-minute race to complete his EQ on time:

> On the fifteenth of March I realized that I had not completed the EQ that was suppose to be done for class that day. I went to the biology lab in 436 WIDB and could not find anyone who would listen to me. Everyone looked so busy and enthralled in their own work. I even asked someone who looked like he might have some time, but was rejected. I decided then to check out the Wilkinson Center (student center) because I knew there were always people who were sitting at tables just passing the time and relaxing. Upon arriving at the Wilk I found someone who fit that description and asked him if he would be willing to listen to me. His name is Peter and it was fun to approach him because he was thrown off at my randomness, which was helpful because it diffused my anxieties. It was fun to get to know him and we had a pleasant conversation as I taught him about the process of meiosis. It was very helpful for me to teach someone who did not know anything about the process because he asked questions about DNA replication so I had to back up and teach about that first. Teaching someone in the most basic way

I knew how was beneficial for me because it helped to solidify what we had been learning in class. I know that I got much more out of our conversation than he did, in terms of learning about meiosis. Although this is the case, it is fun when I see him around campus because we always smile and have a quick conversation. I made a new friend out of the experience. (Personal communication, April 2006)

Most students appreciated the EQs. In response to a question from the course evaluation survey (Item 29), 86% of students indicated that EQs were very or somewhat helpful in their learning. Responses to two other questions (Items 31 and 32) from that same survey suggest that EQs improved somewhat during the course. Only 20% of students said their EQs were high quality during the first half of the course and that percentage rose to 36% for the second half of the course. When students were asked what components of the class helped most with their learning (In-class Question 3), 37% mentioned EQs. They indicated that EQs helped them both diagnose their learning and improve the quality of their understanding with statements like the following (Student responses to In-class Question 3, 2006):

1. I thought they were irritating at the beginning of the course, but they more than anything help me fill in any major gaps in my learning.
2. The EQs are probably the most time-effective learning that I do.
3. I always do better when I talk about the concepts more.
4. I think that the most beneficial to me in this class is the EQs. I am forced to explain my understanding to someone else which really solidifies what I know as well as other concepts I am struggling with.

5. Talking/explaining forces me to confront weaknesses.

6. If I don't understand it as I teach, I realize what I need to learn so I can ask questions about it.

In addition to the required EQs, Bell often asked students who were struggling with a concept to go and explain it to others a specified number of times before meeting with him again. As I observed Bell's office hours on February 27 I wrote the following:

> Bell is teaching a female student about standard error of measurement and hypothesis testing. He writes out a problem on a piece of paper and has her explain things to him in a question and answer format. He says, "I think if we are honest here, things are a little fuzzy." She agrees. He than says, "If you want to be a doctor someday I can't emphasize how important it is that you are not fuzzy. You may never be exposed to this again. What are you going to do to remove the fuzziness?" She replied that it is explained in the back of the book and she will read that. Bell agrees and then says, "Come back and see me next Monday and what I want you to do in the meantime is the following: read the part in the book and then find five different people and explain this concept to them. I am going to be mean. You can only use my example for one of the five. Make up new examples for the others. When you come back next Monday do two things: report on what happened and show me a list of the questions you generated. I promise that if you do this you will be a lot closer to being an expert than you are today. Are you willing to do that?" The student answered, "yes." (2006)

That same student actually came to me later that day and tried to explain an example she had generated illustrating standard error of measurement.

Not all students found the EQs helpful. The case study students were mixed in their opinions. Julia felt they were only moderately helpful but they did serve to reveal what she did not know. Dallin agreed. Justin found them essential and ended up doing them with TAs far more often then assigned. I talked to a small group of students directly about their EQs and it seems that students who have a good knowledgeable EQ partner, particularly someone from the class, tend to find them more valuable. Students who only go through the motions receive fewer benefits. Students said (Personal interviews, March 2006):

1. Some conversations help a lot because we both learn but other times it is just roommates listing off questions and not really caring.
2. Because I haven't chosen the most optimal partner I am not getting as much out of them I could have.

No Carbon Copies

It is possible to describe the Biology 120 students' learning experiences with the following statements:

1. Students scored an average of 76% (SD = 15) on the final exam.
2. Average performance on the 22 matched pretest/posttest items improved from 44% to 74%.
3. Average performance on the first assessment was 74.77%.
4. Average performance on the last assessment was 82.86%.
5. Thirty-one percent of students said EQs were the most helpful component of the course.

These statements are all correct however, they obscure the experiences of individual students. Julia, who thought EQs were only moderately helpful, scored 100% on the first assessment, 89% on the last assessment, struggled in between, and finished with a 95% on the final. Dallin, who did not think EQs were helpful at all, scored 73% on the first assessment, 100% on the last assessment, sailed through the course, and finished with a 90% on the final. Finally, Justin, who loved the EQs, scored 36% on the first assessment, 68% on the last assessment, struggled through most of the course, but was able to finish with 88% on the final exam. The point is that each student is an individual and each has his or her own learning path and needs. Looking only at class-level data can obscure that important fact. Perhaps the most definitive statement I can make about effective teaching and learning based upon this research is that every student, every instructor, and every classroom is unique and it is the intertwining of those threads that constitutes each individual's learning experience.

Diversity among students causes problems for instructors who seek to meet the needs of all students. In a large class like Biology 120 this is impossible. While students' opinions on Bell's class were overwhelmingly positive, some students just did not like his approach (Student comments from BYU Student Ratings Survey, 2006):

1. I thought that his "innovative teaching processes" were not very effective and wasted quite a bit of time.
2. I had a really hard time learning from him. I felt like he didn't teach anything he just told us what to do but never really explained HOW to do it. If he taught what we needed to learn I would've understood a lot more.

One student perceptively pointed out the variation in student attitudes:

> I would be curious to see how polarized the class was. I think it was organized so that you could easily do well if you did the work, but would fail miserably if you didn't, and since all the work wasn't graded, I imagine there was a big gap between those who really wanted to learn, and those who wanted the grade. I didn't see it that way during the class, but it is really amazing how he accomplished that goal. It is set up perfectly to make you learn to love learning, if you don't, you'll fail, even if you are smart. (Personal interview, March 2006)

The challenge for Bell was to balance concern for individual students with what he felt were the best teaching methods for the entire class.

It Takes a Village

According to an African proverb, "It takes a village to raise a child." Likewise, it takes an entire array of learning activities to teach a student biology. Each student learns differently and thus benefits from multiple options to reach the same goal. Some students need to have repeated and varied exposure to a concept in order to grasp it:

> When I learn something I need to be exposed to it a couple of times. Reading kind of gave the first dose of what we were learning. In class would kind of elaborate on what was discussed in the reading because the reading really was a lot of information to take in at once and I honestly didn't get a whole lot out of it. In class when he would go over it, the information would be presented again and I would get kind of an elaboration of it but I still wouldn't get it. I would need to go over my notes and study it, I need to connect things for me to actually learn concepts—how this concepts fits with this concept—and how everything plays together. So I think meeting with Dr. Bell really helped that because I had all

> these pieces and I didn't know how to connect them. I didn't have the entire overall picture and how the process and the concept were from start to finish. (Personal interview, March 2006)

Other students do just fine sitting alone in a quiet room reading the text:

> I like to read to learn. I learn best, not through any set method but when it interests me. For me, I hate being told what to do. Before school I started reading my biology book. It was so fascinating I read half the book. Ideal learning for me would be to read a book and then sit and discuss it with a teacher. (Personal interview, March 2006)

The point is that there is no one single path to learning that fits all students.

Bell has thought about the idea of multiple intelligences and varied learning styles and he feels that neither the instructor nor students, particularly freshman, can always categorize the way they learn best. Because of this he fostered or created a variety of activities for students to learn biology. Examples include

1. Reading assignments
2. EQs
3. Formative assessments
4. Problem solving
5. Help sessions
6. Office hours
7. Study groups

8. Lectures

9. PowerPoint presentations

10. Animations

11. Demonstrations

12. Metaphors

13. Class activities

Bell feels that being exposed to numerous learning activities does not harm students, but that they can be harmed if deprived of variety. He does not mind pushing students to do things for their learning that they may find annoying at first because he feels that may help them come to understand something about their own learning paths. That is why EQs were required. Not many students had experienced teaching to learn and perhaps not all students benefited from it, however, Bell felt that the potential for good far outweighed any annoyances students experienced. Some students did come to understand themselves better by being forced to try novel approaches to learning. Lisa is a good example. She explains that,

> What would have helped me more in this class would be making more use of the EQs. . . The night before the final, I reserved a room in the library where three other girls on my hall who are also in Bio 120 and I could study together. We used a whiteboard to work problems. The time that I studied with them was most valuable. We asked questions and fixed misconceptions. What was different about that EQ and the EQs that I had been doing all semester was that the night before the final, I had reviewed sufficiently before I had tried discussing it with

someone else. Typically, I'd come to an EQ with the expectation to be learning, not reviewing and teaching. But on the night before the final, I was teaching and explaining and drawing and reviewing. Also, for me at least, it was helpful to have a group to study with instead of just one person. It seemed like more of a valuable discussion instead of staring blankly at someone's face trying to think of what to explain next. I feel that if I had done this, on a smaller scale, in preparation for the assessments I would have performed much better in the class. I also wish that I hadn't been as casual about the assessments. I was so frustrated with my performance on them, but then realized that it was how I approached them that were the problem. I wish that I had treated them as mini finals. I didn't realize until the very end, that they were tools to help me. I'm sorry if what I've said doesn't make much sense. But what I've meant to say is that I wish I had taken the EQs and assessments more seriously. In retrospect, I can see that they were tools to help me understand and improve. Oh well... Bio 120 is over and it's too late to implement that strategy for that class. At least, *I now know how to study*, and that will help me immensely in the future (Personal interview, March 2006, emphasis added).

A few students noticed Bell's efforts to meet their varied learning needs. One student told me that,

> He's pretty effective because each person learns at a different rate, different level, and different way. He is pretty effective at providing resources in order to accommodate that. (Personal interview, March 2006)

Another student wrote in an e-mail

> He was very good at helping everyone learn in their own way. I was very surprised at how much trust he placed in the students. He always gave us the benefit of the doubt. His willingness to respond to different needs helped me feel like he knew me and was teaching me. It made the large lecture a small group. (Personal e-mail communication, 2006)

Students Can Think

Students in Bell's Biology 120 class realized from the first week that they would need to do more than memorize and recall information to succeed ("I used to consume myself with memorizing facts for a certain class but in this class I cannot do that. I actually have to study and practice the material" [Student responses to In-class Question 4, 2006]). Because students tend to align their effort with assessments, Bell early and consistently exposed students to items demanding comprehension, application, or analysis of concepts. There were no items at the knowledge or recall level on the pretest (given during the first two weeks of class) or on the weekly assessments. This directed students learning firmly towards higher levels of cognition.

Most students experienced a significant gain in their ability to understand, apply, and analyze with concepts. The average proportion of students responding correctly to items at those three cognitive levels increased from .44 on the pretest to .77 on the posttest (based on students who took both tests) (see Table 4 for a comparison between pretest and posttest performance by item). An example of an item that illustrates analytical thinking is the following (Pretest Item 13, 2006):

> A life cycle that alternates between diploid (2n) and haploid (n) phases benefits organisms in all of the following ways EXCEPT:

A. It provides a mechanism for re-assorting of genetic information across generations.
B. It provides a mechanism for sexual reproduction.
C. Evolution could not occur without it.
D. It prevents doubling of the chromosome number from generation to generation during sexual reproduction.

The percentage of students who answered that item correctly increased from 37% on the pretest to 78% on the posttest. Even greater gain was made on the following application item (Pretest Item 12, 2006):

> A certain protein consisting of a single polypeptide chain has a molecular weight of approximately 31,000. What is the best estimate for the minimum molecular weight of the gene (the double-stranded segment of DNA) which programs the synthesis of this protein? The molecular weight of an average amino acid is 120 g/mol, and the average nucleotide molecular weight is 310 g/mol.

A. 72,000	D. 188,000	G. 480,000	J. 717,000
B. 96,000	E. 236,000	H. 558,000	
C. 124,000	F. 393,000	I. 603,000	

The percentage of students responding correctly to this item increased from 13% on the pretest to 76% in the posttest.

Most students did indeed learn to think with their knowledge ("Before taking this class I just focused on memorizing concepts but I started to apply concepts because of this course. It is very good because I will not forget what I learn by applying it" [Personal interview, March 2006]). Students were challenged from the beginning to think, apply, and analyze; they received frequent feedback on their status; and they proved their gain by performance on the posttest.

Summary of Results by Research Question

The topics described above represent what I feel are the most important themes that emerged from this research. However, in order to address the research questions directly, a brief answer to each one will be given in this section. Evidence supporting these answers in the form of data, results of analyses, and interpretations of data has already been presented in Chapter 4.

Question 1: What is the nature of the formative format pedagogy and its context in the Biology 120 course taught at BYU winter term 2006?

The Biology 120 formative format pedagogy was mostly active and student-centered. Bell provided students with a variety of learning activities both in and out of class. Students worked problems, learned with peers, made their learning concrete in a variety of ways, and received frequent formative feedback. Students were expected to develop the ability to think and reason with a set of basic biology concepts and this level of cognition was clearly and recurrently communicated to students through the assessment items.

Question 2: What is the nature of students' learning experiences in this course?

Students began their learning before class by actively reading their text. In class they participated in activities that enhanced that preliminary understanding. They were given frequent opportunities to make abstract concepts concrete coupled with clear feedback on their understanding and skill level in relation to the ideal. Students continued learning outside of class with homework problems and EQs. On assessment days students applied their understanding to authentic problems and received feedback on their performance.

Most, but not all, students enjoyed their experience in Biology 120. They rated the course highly on surveys and many students expressed positive feelings in interviews and responses to questions. Class attendance and homework completion levels were high. A number of students expressed that they worked hard in the course and some indicated that they had to change their approach to learning in order to succeed. A small group of students felt the course moved too slow or was too easy and some felt that it was too hard.

Question 3: In what ways do students improve or extend their biology-related knowledge and skills during the course?

Most students improved in their ability to comprehend, apply, and analyze with biology concepts. Average student scores on the set of items common to the pretest and posttest increased significantly. There were only 9 students out of 263 who stayed the same or decreased in performance. Students improved in all topics and cognitive demand categories.

It was difficult to track student performance across the weekly assessments because of differing assessment difficulty levels; however, in their grade justification documents most students mentioned improvement as they progressed through the semester even though many experienced challenging periods.

Question 4: According to students, what components of the course tend to foster this improvement (biology-related knowledge and skills), if any?

When asked what components of the course were most helpful to their learning, students most frequently mentioned EQs or some form of working with other students outside of class. A number of students also talked about reading assignments and Bell's in-class explanations. The small group of students who, because of difficulties in the class, worked with TAs or attended Bell's help sessions found those experiences extremely valuable.

Question 5: What opinions do students have about the advantages and disadvantages of the formative assessment pedagogy?

Students generally had a positive (67%) or partially positive (28%) view of the formative assessment system. A majority of students felt the assessment and grading system was fair (76%) and useful in monitoring progress (70%). The greatest benefit students identified from the system was diagnostic. Most students felt they received ongoing clear feedback about their progress in the course. Assessment items gave students a clear picture of the level of understanding and skill they were expected to attain in order to do well in the class. Because students were expected to be able to do more than simply recall their knowledge, clear and precise feedback about the more complex processes of comprehension, application, and analysis was important. Students also mentioned that the process of taking the weekly assessments was a useful learning experience because it helped them practice their learning by applying or thinking analytically with concepts. Some students found the assessments difficult. Though this spurred many to change their learning approach in some way, it caused a few of them to get discouraged.

Question 6: How and to what extent do students' approaches to learning change during the course?

Most students (66%) changed their learning approach in some way in response to the demands of the Biology 120 course. The greatest change for many students was to begin using EQs and students seemed to improve the quality of their EQs across the semester. Some students also indicated they improved or changed their method of reading. Bell's assignment to summarize and write questions helped them to read more actively. There also appeared to be a shift during the course for many students from a surface learning approach based on memorizing to a deeper approach based on understanding.

Question 7: How and to what extent do students' attitudes towards learning change during the course?

Most students strongly (36%) or slightly (27%) agreed that the course helped them focus more attention on learning and worry less about grades. The majority of students also felt that their experiences in the course had enhanced their interest in studying biology (86%) or in doing research (82%). Students tended to become more oriented towards learning as opposed to grades during the course.

Question 8: How and to what extent does students' self-efficacy towards studying and learning biology change during the course?

Many students began the Biology 120 course with high levels of self-efficacy towards learning biology and most felt the course greatly (39%) or slightly (48%)

enhanced that level of confidence. However, there were individuals such as Justin who experienced fluctuations in confidence levels during the course due to the difficulty of the weekly assessments.

Question 9: In what ways do the responses to the above questions vary by individual students or subgroups of students?

Males tended to score better on the final exam than females and as year in school increased, so did final exam score. Students who attended class, did homework and reading assignments, and took most of the weekly assessments tended to score higher on the final exam. Also, higher scores on the final exam were associated with students who increased in the self-efficacy towards learning biology and students who deepened their learning approach during the course (based on survey responses).

Limitations

As with all research, there are limitations that must be acknowledged when considering results. The exploratory nature and qualitative emphasis of this study yielded the benefits of openness and depth but also incurred certain problems. The main limitations of this study stem two forms of bias: self-selection bias and researcher bias. Steps were taken to control both of these problems.

Self-selection bias is a potentially serious limitation. Because of IRB requirements, individual data could only be collected from the 222 out of 263 students who gave consent. I was able to examine aggregate data from the entire class but could not look at individual information from non-consenting students. Thus, the individual learning experiences of those 41 students are unexpressed in this research. Selection bias was further incurred because participation in the research was entirely voluntary.

Students were not given incentives to complete surveys or respond to in-class questions. The number of students responding to data collection instruments ranged from 40 to 126. The sample of students who chose to respond may have been skewed towards those who felt positively towards the course. There was also a subgroup of students who chose to participate minimally or not at all in the class and thus were poorly represented in data collection. Nothing can be said about this important subgroup of students who did not express their opinions.

Measures were taken to counteract the problem of self-selection bias. Class level data was reported when possible to provide a more inclusive picture of students' experiences. This balanced the more limited data from interviews and question responses. When interview subjects were selected, I particularly sought out students who were experiencing difficulties with the course. I also searched for and reported negative interview comments and negative responses to in-class questions. It may be the case that the results of this research are primarily representative of students who were willing participants and perhaps had relatively positive views of the course. It is important to consider that there may have been additional or alternative results that are not reported here.

A second, inevitable, source of bias was researcher bias. I chose Bell's biology 120 class as the case for this research because I was familiar with his teaching practices and saw value in his approach. I expected to find positive student outcomes. My history with Bell's pedagogy increased personal connection with the students and enhanced my understanding. However, it also had the potential to obscure findings contrary to expectations. I took measures to limit this potential problem through peer review, member checking, and the search for negative cases.

Contributions to Theory

This research contributes to theory in a number of ways. First, and most practically, it illustrates the application of certain theoretical principles to a real classroom. Students in Biology 120 were asked to do something with abstract biology concepts by using them in authentic problem-solving situations. Similarly, Bell did something with abstract learning theories by applying them to a real classroom situation. The results of that effort, reported here, contribute to an understanding of how and why certain instructional strategies work.

Second, a number of the theories that Bell applied in his classroom are of current interest in educational research. While this research is not a systematic study of teaching practices, it can provide evidence, based on students' opinions, to support or contradict those theories. One such theory is the value of formative feedback. Black and Wiliam and others suggested that increasing the quality and amount of formative feedback is one of the most important things an instructor can do to improve learning (Black, 1995; Black & Wiliam, 1998a; Brookhart, 1997a; Stiggins, 2002). This seemed to be the case in Bell's classroom. Most students felt they benefited from the focus on feedback. The opportunity to frequently diagnose their own learning led some students to take control of their learning and work to fix misconceptions. The nature of the classroom and assessment tasks seems also to have challenged students to increase effort and in some cases change the way they approached their learning (Black & Wiliam, 1998a; Brookhart, 1997a).

Another theory of interest is problem solving or problem-based learning. Bell illustrated a way to integrate authentic problems (Wiggins, 1993) into classroom activities and assessments. This focus on problems seems to have deepened learning approaches (Doyle, 1983) and promoted high level cognitive outcomes (Allen et al., 1996; Bransford & Schwartz, 1997).

Student experiences with Bell's efforts to encourage them to teach to learn contributes to literature on cooperative learning (O'Donnell & Dansereau, 1992) and teaching to learn (Cooper & Robinson, 2000). The value of teaching to learn may be one of the most significant contributions of this research. Many students thought that Bell's innovative EQs had the greatest impact on their learning. Students learned as they taught (Gunter et al., 1999; O'Donnell & Dansereau, 1992) and learned differently because they were planning to teach (Annis, 1983; Benware & Deci, 1984).

Contributions to Practice

A stated objective of this research was to examine results in light of current theory. Equally important, in my opinion, are contributions that can be made directly to practice. This study was designed with an audience of practitioners in mind. Of course, the unique classroom context of the BYU Biology 120 class (instructor personality, subject matter, set of students, etc.) cannot be duplicated, but the teaching practices presented here may be transferable to other contexts. The themes described above represent the most significant findings of this research. In addition, there are a few specific recommendations for classroom practice that were revealed by this research.

First, one of the most important practices instructors can enhance is the variety, degree, and quality of feedback provided in their classes. There are three general categories of instructional feedback: (a) feedback that aids in judging learning, (b) feedback that provides information for instructors so that they can better meet the needs of students, and (c) feedback that provides information to students so that they can diagnose and improve their own learning. Each type of feedback is necessary but the third category, student-centered feedback, is often overlooked. If students are expected to perform beyond the simple recall of facts and learn to think with their knowledge it is essential that they have the means to examine and improve upon the complex process of gaining that ability.

Feedback is often equated with test results. Consequently, instructors often focus on improving assessments in order to improve feedback. This is a valuable effort and Bell's innovative weekly assessment system illustrates the importance of that focus. His system was an essential component of the course because it provided frequent, timely, and relatively non-threatening feedback to students. However, assessments were not the sole source of student-centered feedback: There were numerous feedback occasions scattered throughout classroom and homework activities. Students were continuously asked to expose themselves in order to make their learning concrete by writing, drawing, voting, solving, teaching, and numerous other activities. As they exposed their learning they, in turn, received essential diagnostic feedback that provided information needed for improvement and fostered personal ownership of the learning process. I would encourage teachers to creatively examine their unique situations and look for ways to incorporate more student-directed feedback into their classrooms.

Second, teaching to learn is a practice that may be a straightforward way to improve student learning. Evidence for its value is limited but the results of this research suggest that it is a practice worthy of consideration. When teaching to learn, students are forced to organize, synthesize, and articulate their ideas. This may improve the structure and clarity of their knowledge and foster retrieval. In addition, students have the opportunity to clearly diagnose the state of their learning as they attempt to teach and respond to challenging questions. This is when misconceptions may be uncovered and gaps in learning revealed. Students seem to study and prepare differently, perhaps more actively, when they know that they will be teaching. Teaching to learn can take place in the classroom through paired or small group activities as well as outside of the classroom as a specific homework assignment.

The third suggestion for practice is directed at those involved with large enrollment classes. There are unique and rigorous challenges associated with teaching these classes but instructors can creatively think about alternatives to lecture-based instruction. This research has illustrated that high enrollment does not necessarily proscribe active student-centered learning. Students can solve problems, talk to peers, respond to and ask questions, vote, or participate in other beneficial learning activities in the context of a large enrollment class. Instructors, as they plan, should consider what students will do to enhance their learning during each class period. Also, deep and active learning strategies outside of the classroom could be encouraged by assigning activities such as reading summaries, group work, teaching to learn, or problem solving.

While each of the three topics discussed above has the potential to improve learning in general, this study also served to highlight individual differences and direct attention towards subgroups of students who may be overlooked in large classes. The wide variety of student responses to Bell's pedagogy is a clear reminder that it is impossible to declare a teaching strategy successful. There are only approaches that benefit some students some of the time.

Suggestions for Future Research

I see the building of learning theory as an iterative progression incorporating both inductive and deductive phases. Exploratory studies such as this one contribute through their openness to emerging ideas. Experimental studies contribute by examining more controlled slices of learning. Both approaches can work together to enhance teaching and learning. Based upon the inductive results from this research, it would be helpful to evaluate some of Bell's teaching strategies in a more controlled setting or through additional exploratory, ethnographic, or design-based research. The following questions could be addressed:

1. Does the formative assessment system improve cognitive achievement or increase levels of positive affect compared to a traditional assessment system?
2. Do EQs promote improve cognitive achievement or increase levels of positive affect?
3. Is there an interaction between the benefit of formative feedback and the level of cognition demanded by the instruction?
4. How do formative feedback and problem solving interact?
5. How do students do EQs?
6. Are there qualities in EQs that increase their benefit?
7. Are there subgroups of students who react in different ways to EQs or to formative feedback?

8. What are the common characteristics and experiences of students who perform poorly in large enrollment classes?

Many of the strategies Bell employed could be examined further using different methods or set in different contexts. This would contribute to the generalizability of the findings reported here.

References

Ackerman, J. M. (1993). The promise of writing to learn. *Written Communication*, *10*(3), 334-370.

Albanese, M. A. (1993). Problem-based learning: A review of literature on its outcomes and implementation issues. *Academic Medicine*, *68*(1), 52-81.

Albanese, M. A. (2003). Problem-based learning: Why curricula are likely to show little effect on knowledge and clinical skill. *Medical Education*, *34*, 729-738.

Allen, D. E., Duch, B. J., & Groh, S. E. (1996). The power of problem-based learning in teaching introductory science courses. In L. Wilkerson & W. H. Gijselaers (Eds.), *Bringing problem-based learning to higher education: Theory and practice* (Vol. 68, pp. 43-52). San Francisco: Jossey-Bass Publishers.

Ambron, J. (1987). Writing to improve learning in biology. *Journal of College Science Teaching*, *16*, 263-266.

Ames, C. (1992). Classrooms: Goals, structures, and student motivation. *Journal of Educational Psychology*, *84*(3), 261-271.

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and Assessing: A revision of Bloom's taxonomy of educational objectives*. New York: Longman.

Annis, L. F. (1983). The processes and effects of peer tutoring. *Human Learning: Journal of Practical Research and Applications*, *2*(1), 39-47.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychology Review*, *84*, 191-215.

Bandura, A. (1995). *Self-efficacy in changing societies.* Cambridge: Cambridge University Press.

Bandura, A. (1997). *Self-efficacy: The exercise of control.* New York: W.H. Freeman and Company.

Bass, K. M., & Glaser, R. (2004*). Developing assessments to inform teaching and learning.* University of Pittsburgh: CREST/ Learning Research and Development Center.

Beghetto, Ronald A. (2004). Toward a more complete picture of student learning: assessing students' motivational beliefs. *Practical Assessment, Research & Evaluation*, 9(15). Retrieved May 22, 2006 from http://PAREonline.net/getvn.asp?v=9&n=15

Benware, C. A., & Deci, E. L. (1984). Quality of learning with an active versus a passive motivational set. *American Educational Research Journal*, *21*, 755-765.

Berkson, L. (1993). Problem-based learning: Have the expectations been met? *Academic Medicine*, *68*(10), 79-88.

Black, P. (1995). Assessment and feedback in science education. *Studies in Educational Evaluation*, *21*, 257-279.

Black, P., & Wiliam, D. (1998a). Assessment and classroom learning. *Assessment in Education: Principles, Policy & Practice*, *5*(1), 7-75.

Black, P., & Wiliam, D. (1998b). Inside the black box: Raising standards through classroom assessment. *Phi Delta Kappan*, *80*(2), 139-148.

Bloom, B., Englehart, M. Furst, E., Hill, W., & Krathwohl, D. (1956). *Taxonomy of educational objectives: The classification of educational goals.* White Plains, NY: Longman.

Bransford, J. D., & Schwartz, D. L. (1997). Rethinking transfer: A simple proposal with multiple implications. In W. K. Cummings & N. F. McGinn (Eds.), *International handbook of education and development: Preparing schools and nations for the twenty-first century* (pp. 61-100). Oxford: Pergamon.

Bridges, E. M., & Hallinger, P. (1996). Problem-based learning in leadership education. In L. Wilkerson & Gijselaers, W. H. (Eds.), *Bringing problem-based learning to higher education: Theory and practice* (vol. 68, pp. 101-104). San Francisco: Jossey-Bass Publishers.

Brookhart, S. M. (1997a). Effects of the classroom assessment environment on mathematics and science achievement. *Journal of Educational Research, 90*(6), 323-330.

Brookhart, S. M. (1997b). A theoretical framework for the role of classroom assessment in motivating student effort and achievement. *Applied Measurement in Education*, *10*(2), 161-180.

Brown, J., Collins, S., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42.

Butler, R. (1987). Task-involving and ego-involving properties of evaluation: Effects of different feedback conditions on motivational perceptions, interest, and performance. *Journal of Educational Psychology*, *79*, 474-482.

Butler, R., & Nisan, M. (1986). Effects of no feedback, task-related comments, and grades on intrinsic motivation and performance. *Journal of Educational Psychology*, *78*, 210-216.

Carbone, E., & Greenberg, J. (1998). Teaching large classes: Unpacking the problem and responding creatively. In M. Kaplin (Ed.), *To improve the academy* (pp. 311-326). Stillwater, Oklahoma: New Fortune Press.

Chase, W. G., & Chi, M. T. H. (1981). Cognitive skill: Implications for spatial skill in large-scale environments. In J. Harvey (Ed.), *Cognition, social behaviors, and the environment* (pp. 111-136). Hillsdale, NJ: Erlbaum.

Chin, C. (1993). Towards a problem-solving approach in teaching and learning science. *Journal of Science and Mathematics Education in S.E. Asia, XVI*(2), 22-27.

Colliver, J. A. (2000). Effectiveness of problem-based learning curricula: Research and theory. *Academic Medicine*, *75*(3), 259-266.

Cooper, J. L., & Robinson, P. (2000). The argument for making large classes seem small. *New Directions for Teaching and Learning*, *81*, 5-16.

Creswell, J. W., Goodchild, L. F., & Turner, P. P. (1996). Integrated qualitative and quantitative research: Epistemology, history, and designs. In J. C. Smart (Ed.), *Higher Education: Handbook of Theory and Research* (vol. XI, pp. 90-136). New York: Agathon Press.

Crotty, M. J. (1998). *Foundations of social research: Meaning and perspective in the research process*. London: Sage Publications.

Davidson, N. (1994). Cooperative and collaborative learning: An integrative perspective. In J. S. Thousand, R. A. Villa & A. I. Neven (Eds.), *Creativity and collaborative learning: A practical guide to empowering students and their teachers* (pp. 13-30). Baltimore: Paul H Brookes Publishing Company.

DeGroot, A., & Gobet, F. (1996). *Perception and memory in chess: Heuristics of the professional eye.* Holland: Van Gorcum.

Delquadri, J. C., Greenwood, C. R., Stretton, K., & Hall, R. V. (1983). The peer tutoring spelling game: A classroom procedure for increasing opportunity to respond and spelling performance. *Education and Treatment of Children*, *6*(3), 225-239.

Delucchi, M. (2006). The efficacy of collaborative learning groups in an undergraduate statistics course. *College Teaching, 54*(2), 244-248.

Distlehorst, L. H. (1994). Problem-based learning: Have the expectations been met? Comment. *Academic Medicine*, *69*(6), 471-472.

Dochy, F., Segers, M., Van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: A meta-analysis. *Learning and Instruction, 13*(5), 533-568.

Donovan, M. S., Bransford, J. D., & Pellegrino, J. W. (1999). *How people learn: Bridging research and practice.* Washington, D.C.: National Research Council.

Donovan, M. S., Bransford, J. D., & Pellegrino, J. W. (Eds.). (2000). *How people learn: Brain, mind, experience, and school.* Washington D.C.: National Academy Press.

Doyle, W. (1983). Academic work. *Review of Educational Research, 53*, 159-199.

Dweck, C. S., Mangels, J. A., & Good, C. (2004). Motivational effects on attention, cognition, and performance. In Y. Dai & R. J. Sternberg (Eds.), *Motivation, Emotion and Cognition* (pp. 41-56). Mahwah, NJ. Erlbaum.

Earl, L. (2003). *Assessment as learning.* Thousand Oaks: Corwin Press.

Eison, J. A. (1981). A new instrument for assessing students' orientation towards grades and learning. *Psychological Reports*, *48*, 919-924.

Entwistle, N. (2000). Approaches to studying and levels of understanding: The influences of teaching and assessment. In J. C. Smart & W. G. Tierney (Eds.), *Higher education: Handbook of theory and research* (vol. 15, pp. 72-101). New York: Agathon Press.

Entwistle, N. (2000b). *Promoting deep learning through teaching and assessment: Conceptual frameworks and educational contexts.* Paper presented at the Teaching and Learning Research Programme Conference, Leicester, England.

Entwistle, N., McCune, V., & Hounsell, D. (2002). *Approaches to studying and perceptions of university teaching-learning environments: Concepts, measures and preliminary findings*: ETL Project. Retrieved May 22, 2006, from http://www.ed.ac.uk/etl/publications.html

Entwistle, N., & Tait, H. (1993). *Approaches to studying and preferences for teaching in higher education: Implications for student ratings.* Paper presented at the annual meeting of the American Educational Research Association, Atlanta, GA.

Ericsson, K. A., & Hastie, R. (1994). Contemporary approaches to the study of thinking and problem solving. In R. J. Sternberg (Ed.), *Thinking and problem solving* (pp. 37-79). New York: Academic Press.

Farrow, R., & Norman, G. R. (2003). The Effectiveness of PBL: The debate continues. *Medical Education*, *37*, 1129-1130.

Fink, L. D. (2003). *Creating significant learning experience*. San Francisco: Jossey-Bass.

Foyle, H. C. (1995). *Interactive learning in the higher education classroom: Cooperative, collaborative, and active learning strategies*. Washington, D C: National Education Association.

Geske, J. (1992). Overcoming the drawbacks of the large lecture class. *College Teaching*, *40*(4), 151-154.

Gijbels, D., Dochy, F., Van den Bossce, P., & Segers, M. (2005). Effects of problem-based learning: A meta-analysis from the angle of assessment. *Review of Educational Research, 75*, 27-61.

Gijselaers, W. H. (1996). Connecting problem-based practices with educational theory. In Wilkerson, L., & Gijselaers, W. H. (Eds.). *Bringing Problem-Based Learning to Higher Education: Theory and Practice,* (vol. 68, pp. 13-21). San Francisco: Jossey-Bass.

Glaser, R. (1992). Expert knowledge and processes of thinking. In D. Halpern (Ed.), *Enhancing thinking skills in the sciences and mathematics* (pp. 63-75). Hillsdale, NJ: Erlbaum.

Greeno, J. (1992). Mathematical and scientific thinking in the classroom and other situations. In D. Halpern (Ed.), *Enhancing thinking skills in the sciences and mathematics* (pp. 39-61). Hillsdale, NJ: Erlbaum.

Gunter, M. A., Estes, T. H., & Schwab, J. H. (1999). *Instruction: A models approach* (3rd ed.). Boston: Allyn & Bacon.

Halpern, D. (1992). *Enhancing thinking skills in the sciences and mathematics*. Hillsdale, NJ: Erlbaum.

Hartner, S. (1978). Pleasure derived from challenge and the effects of receiving grades on children's difficulty level choices. *Child Development, 49*, 788-799.

Hensley, T. R., & Oakley, M. (1998). The challenge of the large lecture class: Making it more like a small seminar. *Political Science & Politics, 31*(1), 47-51.

Hom, H. L., Jr., & Murphy, M. D. (1983). Low achiever's performance: The positive impact of a self-directed goal. *Personality and Social Psychology Bulletin, 11*, 275-285.

Hounsell, D., & McCune, V. (2002). *Teaching-learning environments in undergraduate biology: Initial perspectives and findings* (Occasional Report 2): ETL Project. Retrieved May 22, 2006, from http://www.ed.ac.uk/etl/publications.html

Hughes, B., Sullivan, H. J., & Mosley, M. L. External evaluation, task difficulty, and continuing motivation. *Journal of Educational Research, 78*(4), 210-215.

Johnson, R. T., & Johnson, D. W. (1986). Action research: Cooperative learning in the science classroom. *Science and Children, 24*, 31-32.

Jones, B. F., Valdez, G., Nowakowski, J., & Rasumussen, C. (1995). *Plugging in: Choosing and using educational technology*. Retrieved May 12, 2006, 2006, from http://www.ncrel.org/sdrs/edtalk/toc.htm

Kelly, G. A. (1955). *A theory of personality: The psychology of personal constructs*. New York: Norton.

Kitchen, E., King, S. H., Robison, D. F., Sudweeks, R. R., Bradshaw, W. S., & Bell, J. D. (in press). Rethinking exams and letter grades: How much can teachers delegate to students? *Cell Biology Education.*

Kluger, A. N., & DeNisi, A. (1996). The effects of feedback interventions: A historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychological Bulletin, 119*(2), 254-284.

Kohn, A. (2004). *What does it mean to be well educated?* Boston, Mass.: Beacon Press.

Krumboltz, J. D., & Yeh, C. J. (1996). *Competitive grading sabotages good teaching. Phi Delta Kappan, 78*(4). Retrieved May 22, 2006, from http://www.pdkintl.org/kappan/krumbol.htm

Kuhn, D., Amsel, E., & O'Loughlin, M. (1988). *The development of scientific thinking skills.* San Diego, CA: Academic Press.

Leonard, W. H. (2000). How do college students best learn science? *Journal of College Science Teaching*, *29*(6), 385-388.

Lewis, K. G., & Woodward, P. J. (1984). What really happens in large university classes. ERIC Document Reproduction Service No. ED245590).

Lincoln, Y., & Guba, E. G. (1985). *Naturalistic inquiry*. Beverly Hills, CA: Sage Publications.

Lincoln, Y., & Guba, E. G. (1989). *Fourth generation evaluation:* Beverly Hills, CA: Sage Publications.

Linnenbrink, E. A., & Pintrich, P. R. (2004). Role of affect in cognitive processing in academic contexts. In Y. Dai & R. J. Sternberg (Eds.), *Motivation, emotion and cognition* (pp. 57-87). Mahwah, NJ: Erlbaum.

Lyle, K. S., & Robinson, W. R. (2001). Teaching science problem solving: An overview of experimental work. *Chemical Education Today*, *78*(9), 1162-1163.

Martino, G., & Sala, F. (1996). Engaging students in large lecture classes. Paper presented at the *Annual Conference on Undergraduate Teaching of Psychology*, Ellenville, New York.

Mayer, R. E. (1992). Teaching of thinking skills in the sciences and mathematics. In D. Halpern (Ed.), *Expert knowledge and processes of thinking* (pp. 95-115). Hillsdale, NJ: Erlbaum.

Merriam, S. B. (1988). *Case study research in education: A qualitative approach*. San Francisco: Jossey-Bass.

Mintzes, J., & Wandersee, J. (1998). Research in science teaching and learning: A human constructivist view. In J. J. Mintzes, J. H. Wandersee & J. D. Novak (Eds.), *Teaching science for understanding: A human constructivist view* (pp. 59-92). San Diego, CA: Academic Press.

Mintzes, J., Wandersee, J., & Novak, J. (Eds.) (1998). *Assessing science understanding: A human constructivist view*. San Diego, CA: Academic Press.

Moore, R. (1992). *Writing to learn biology*. Philadelphia: Saunders College Pub.

Multon, K. D., Brown, S. D., & Lent, R. W. (1991). Relation of self-efficacy beliefs to academic outcomes: A meta-analytic investigation. *Journal of Counseling Psychology*, *38*(1), 30-38.

Newman, M. (2003). A Pilot systematic review and meta-analysis on the effectiveness of problem based learning. Campbell Collaboration Systematic Review Group on the Effectiveness of Problem Based Learning. Retrieved May 22, 2006, from http://www.hebes.mdx.ac.uk/teaching/Research/PEPBL/PSR-PBL.pdf

Nichols, J. (1984). Conceptions of ability and achievement motivation. In R. Ames & C. Ames (Eds.), *Research on motivation in education* (vol. 1, pp. 39-73). New York: Academy Press.

Nickerson, R. S. (1995). The teaching of thinking and problem solving. In R. J. Sternberg (Ed.), *Thinking and Problem Solving* (pp. 409-449). San Diego, CA: Academic Press.

O'Donnell, A. M., & Dansereau, D. F. (1992). Scripted cooperation in student dyads: A method for analyzing and enhancing academic learning and performance. In Hertz-Lazarowitz & N. Miller (Eds.), *Interaction in cooperative groups: The theoretical anatomy of group learning* (pp. 120-141). Cambridge: Cambridge University Press.

O'Donnell, A. M., Dansereau, D. F., Hall, R. H., & Rocklin, T. R. (1987). Cognitive, social/affective, and metacognitive outcomes of scripted cooperative learning. *Journal of Educational Psychology*, *79*(4), 431-437.

Owen, E., & Sweller, J. (1985). What do students learn while solving mathematics problems? *Journal of Educational Psychology*, *77*(3), 272-284.

Pajeres, F. (1995, April 18-22). Role of self-efficacy and general math ability in mathematical problem solving: A path analysis. Paper presented at the *American Educational Research Association*, San Francisco, CA.

Pajeres, F. (1996). Mathematics self-efficacy and mathematical problem solving: Implications of using different forms of assessment. *Journal of Experimental Education*, *65*, 213-228.

Patton, M. Q. (2002). *Qualitative research & evaluation methods* (3 ed.). Thousand Oaks, CA: Sage Publications.

Piaget, J. (1959). *The language and thought of the child*. London: Routledge.

Perkins, D. N., & Salomon, G. (1989). Are cognitive skills context bound? *Educational Researcher*, *18*(1), 16-25.

Piburn, M. D. (1993, April 15-18). Evidence from meta-analysis for an expertise model of achievement in science. Paper presented at the *Annual Meeting of the National Association for Research in Science Teaching*, Atlanta, GA.

Pintrich, P. R., & Zusho, A. (2000). Student motivation and self-regulated learning in the college classroom. In J. C. Smart & W. G. Tierney (Eds.), *Higher education:*

handbook of theory and research (vol. 15, pp. 55-128). New York: Agathon Press.

Pithers, R. T. (2000). Critical thinking in education: A review. *Educational Research, 42*(3), 237-249.

Polya, G. (1973). *How to solve it*. Princeton: Princeton University Press.

Programs that work: Peer-assisted learning strategies. (2006). Retrieved May 13, 2006, from http://www.promisingpractices.net/program.asp?programid=143

Salili, F., Maehr, M. L., Sorensen, R. L., & Fyans, L. J. (1976). A further consideration of the effects of evaluation on motivation. *American Educational Research Journal*, *12*, 85-102.

Schoenfeld, A. H. (1985). *Mathematical problem solving*. Orlando, FL: Academic Press.

Seegers, G., Cornelis, M. P., & Cornelis, J. B. (2002). Goal orientation, perceived task outcome and task demands in mathematics tasks: Effects on students' attitude in actual task settings. *British Journal of Educational Psychology*, *72*, 365-384.

Seltzer, S., Hilbert, S., Maceli, J., & Robinson, D. S. (1996). An active approach to calculus. *New Directions for Teaching and Learning*, *68*, 83-90.

Silver, E. A., & Marshall, S. P. (1990). Mathematical and scientific problem solving: Findings, issues, and instructional implications. In L. I. Beau Fly Jones (Ed.*)*, *Dimensions of thinking and cognitive instruction* (pp. 265-285). Elmhurst, IL: North Central Regional Educational Laboratory.

Simon, D. P., & Simon, H. A. (1978). *Children's thinking: What develops*? Hillsdale, NJ: Erlbaum.

Slife, B. D., & Williams, R. N. (1995). *What's behind the research? Discovering hidden assumptions in the behavioral Sciences*: Beverly Hills, CA: Sage Publications.

Spradley, J. P. (1979). *The ethnographic interview*. New York: Holt, Rinehart, and Winston.

Spradley, J. P. (1980). Participant observation. New York: Holt, Rinehart and Winston.

Stake, R. E. (1995). *The art of case study research.* Beverly Hills, CA: Sage Publications.

Stewart, J., & Hafner, R. (1994). Research on problem solving: Genetics. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 284-300). New York: MacMillan Publishing Company.

Stiggins, R. J. (2002). Assessment crisis: The absence of assessment for learning. *Phi Delta Kappan*, *83*(10), 758-765.

Stinson, J. E., & Milter, R. G. (1996). Problem-based learning in business education: Curriculum designs and implementation Issues. In Wilkerson, L., & Gijselaers, W. H. (Eds.). *Bringing problem-based learning to higher education: Theory and practice* (pp. 33-42). San Francisco: Jossey-Bass.

Stuessy, C. (1984). *Correlates of scientific reasoning in adolescents: Experience, locus of control, age, field dependence-independence, rigidity/flexibility, IQ, and gender.* Columbus, OH: Doctoral dissertation, Ohio State University (Eric Document Reproduction Service No. ED244834).

Sugrue, B. (1995). A Theory-based framework for assessing domain-specific problem-solving Ability. *Educational Measurement: Issues and Practices*, 29-35.

Taconis, R., Ferguson-Hessler, M. G. M., & Broekkamp, H. (2001). Teaching science problem solving: An overview of experimental work. *Journal of Research on Science Teaching, 38*(4), 442-468.

Tierney, B., & Dorroh, J. (2004). *How to write to learn science* (2nd ed.). Arlington, VA: National Science Teachers Association Press.

Topping, K. J. (2005). Developments in educational psychology: How far have we come in 25 years? *Educational Psychology, 25*(6), 631-645.

Totten, S., Sills, T., Digby, A., & Russ, P. (1991). *Cooperative learning: A guide to research*. New York: Garland.

Vazin, T. (2006). Collaborative learning: Maximizing students' potential for success. In W. Buskist & S. F. Davis (Eds.), *Handbook of the teaching of psychology* (pp. 65 -69). Malden, MA: Blackwell Publishing.

Vernon, T. A., & Blake, R. L. (1993). Does problem-based learning work? A meta-analysis of evaluative research. *Academic Medicine, 68*(7), 550-563.

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes*. Cambridge: Harvard University Press.

Webb, D. T., Campbell, R. D., & Schwartz, L. (1966). *Unobtrusive measures*. Chicago: Rand McNally.

Wiggins, G. (1993). Assessment: Authenticity, context, and validity. *Phi Delta Kappan, 75*(3), 200-214.

Wilkerson, L., & Gijselaers, W. H. (Eds.). (1996). *Bringing problem-based learning to higher education: Theory and practice* (vol. 68). San Francisco: Jossey-Bass.

Witt-Rose, D. L. (2003). Student self-efficacy in college science: An investigation of gender, age, and academic achievement. Unpublished Master's Degree Project, University of Wisconsin-Stout.

Woods, D. R. (1996). Problem-based learning for large classes in chemical engineering. *New Directions for Teaching and Learning*, *68,* 91-99. San Francisco: Jossey-Bass.

Wulff, D. H., Nyquist, J. D., & Abbott, R. D. (1987). Students' perceptions of large classes. *New Directions for Teaching and Learning*, *32*, 17-31. San Francisco: Jossey-Bass.

Yanchar, S. C. (in press). On the possibility of contextual-quantitative inquiry. *New Ideas in Psychology*.

Yin, R. K. (2002). *Case study research: Design and methods*: Beverly Hills, CA: Sage Publications.

Appendix A: Pre Post-survey Results

Subscales

1. Self-efficacy towards learning biology: Items 1-5

2. Learning orientation: Items 6-11

3. Learning approach: Items 12-18

Question	Pre-survey Frequency	Post-survey Frequency
1. I am usually at ease during biology tests.		
A. Agree	23	24
B. Agree somewhat	53	46
C. Disagree somewhat	22	25
D. Disagree	5	8
2. I am confident I could explain something learned in biology classes to another person.		
A. Agree	51	57
B. Agree somewhat	43	42
C. Disagree somewhat	6	4
D. Disagree	3	0
3. Biology is difficult for me.		
A. Agree	3	12
B. Agree somewhat	22	23
C. Disagree somewhat	52	37
D. Disagree	26	31
4. I get anxious about doing biology assignments when I know they will be graded.		
A. Agree	12	23
B. Agree somewhat	41	32
C. Disagree somewhat	29	33
D. Disagree	21	15

Question	Pre-survey Frequency	Post-survey Frequency
5. I am confident that I can understand topics in biology classes.		
A. Agree	55	64
B. Agree somewhat	42	33
C. Disagree somewhat	6	6
D. Disagree	0	0
7. I dislike courses in which a lot of material is presented in class or in readings that does not appear on the exam.		
A. Agree	13	25
B. Agree somewhat	55	32
C. Disagree somewhat	24	30
D. Disagree	11	16
8. I think I would rather take a small discussion group class rather than a large lecture even if it would require me to work harder.		
A. Agree	27	37
B. Agree somewhat	32	36
C. Disagree somewhat	29	24
D. Disagree	15	6
9. I care much more about what I learn in a class than about what grade I get.		
A. Agree	7	5
B. Agree somewhat	43	48
C. Disagree somewhat	38	38
D. Disagree	15	12
10. My goal is to understand and retain what I have learned regardless of how well I do on the tests.		
A. Agree	30	17
B. Agree somewhat	31	48
C. Disagree somewhat	35	33
D. Disagree	7	5
11. I don't mind courses that require a lot of work as long as I know that if I do the work, I will get a good grade.		
A. Agree	54	53
B. Agree somewhat	36	37
C. Disagree somewhat	11	11
D. Disagree	2	2

Question	Pre-survey Frequency	Post-survey Frequency
12. I concentrate more on remembering what my instructors say than on developing my own interpretations of course materials.		
A. Agree	9	6
B. Agree somewhat	55	41
C. Disagree somewhat	30	46
D. Disagree	9	9
13. Ideas I come across in my academic reading often set me off on long chains of thought.		
A. Agree	19	21
B. Agree somewhat	55	53
C. Disagree somewhat	27	21
D. Disagree	2	8
14. Much of what I learn seems no more than disconnected bits and pieces of information in my mind.		
A. Agree	3	3
B. Agree somewhat	14	17
C. Disagree somewhat	44	40
D. Disagree	42	42
15. Because of time limitations, I often resort to memorizing what I need to know for a test rather then spending the time and effort to really understand the subject.		
A. Agree	18	17
B. Agree somewhat	58	50
C. Disagree somewhat	21	26
D. Disagree	6	10
16. I tend to read very little beyond what is actually required to pass.		
A. Agree	18	11
B. Agree somewhat	32	21
C. Disagree somewhat	34	41
D. Disagree	19	30

Question	Pre-survey Frequency	Post-survey Frequency
17. I discuss interesting material that I've learned with my friends or family.		
A. Agree	57	57
B. Agree somewhat	39	40
C. Disagree somewhat	5	5
D. Disagree	2	1
18. I get annoyed when lectures or class presentations are only rehashes of easy reading assignments.		
A. Agree	24	32
B. Agree somewhat	39	35
C. Disagree somewhat	26	26
D. Disagree	11	10

Appendix B: Course Evaluation Survey Results

Question	Frequency	Percent
19. When you consider what you learned in this course (new knowledge, skills, attitudes, and perspectives, etc.) in light of what it cost in terms of personal study time and effort, was what you learned worth the effort you invested?		
A. Definitely yes	82	59.42
B. Probably yes	40	28.99
C. Probably not	10	7.25
D. Definitely not	2	1.45
E. I'm not sure.	4	2.90
20. Which of the following statements best describes your assessment of the progress you made in this course this semester?		
A. My skills and understanding of the course content were above average at the beginning of the course and still are. My relative standing in the class is still above average.	29	21.32
B. I have made significant improvement compared to others in the class. My relative standing in the class is higher than it was initially.	31	22.79
C. My skills and understanding of the course content have improved significantly. Since most of the other students in the course have made similar improvement, my relative standing in the class is about the same as before.	60	44.12
D. I really haven't improved much, although I have really tried hard.	10	7.35
E. I gave up and quit trying part way through the semester.	4	2.94
F. I never really tried.	2	1.47
21. Given the objectives of this course, how appropriate was the workload in this class?	3	2.14
A. Much more demanding than necessary	8	0.06
B. Too demanding	111	0.82
C. About right	12	0.09
D. Not demanding enough	4	0.03
E. Much less demanding than it should have been	0	0.00

Question	Frequency	Percent
22. To what extent were the learning activities and experiences in this course meaningful and relevant to you personally and to your goals for the future?		
A. Extremely meaningful and relevant	36	26.09
B. Quite meaningful and relevant	55	39.86
C. Moderately meaningful and relevant	37	26.81
D. Not very meaningful or relevant	9	6.52
E. Not at all meaningful or relevant	1	0.72
23. How do you rate the fairness of the grading procedures and criteria used in this course?		
A. Completely fair	55	39.86
B. Quite fair	52	37.68
C. Moderately fair	30	21.74
D. Not very fair	1	0.72
E. Not fair at all	0	
24. If you are planning to take a biology course next semester (e.g. Physiology), which course format would you prefer?		
A. The same course format that was used during this current semester	82	0.61
B. A more conventional format consisting of traditional lectures accompanied by tests focused on recall of information taught in the text and in the lectures	32	0.24
C. Other	21	0.16
25. Has your experience in this course enhanced or diminished your interest in studying biology further?		
A. Greatly enhanced	56	40.00
B. Slightly enhanced	65	46.43
C. Slightly diminished	14	10.00
D. Greatly diminished	3	2.14

Question	Frequency	Percent
26. Has your experience in this course enhanced or diminished your interest in the possibility of designing and conducting research in an area of interest to you?		
A. Greatly enhanced	26	18.84
B. Slightly enhanced	89	64.49
C. Slightly diminished	21	15.22
D. Greatly diminished	2	1.45
27. Has your experience in this course enhanced or diminished your ability to think the way scientists think?		
A. Greatly enhanced	70	50.72
B. Slightly enhanced	66	47.83
C. Slightly diminished	2	1.45
D. Greatly diminished	0	0.00
28. Has your experience in this course enhanced or diminished your confidence in your ability to learn biology?		
A. Greatly enhanced	54	39.13
B. Slightly enhanced	67	48.55
C. Slightly diminished	13	9.42
D. Greatly diminished	4	2.90
29. What influence did doing EQs have on your learning?		
A. They were very helpful in my learning	60	43.48
B. They were somewhat helpful in my learning	59	42.75
C. They didn't help very much	17	12.32
D. They were a waste of time	2	1.45
30. What was the quality of your EQs during the first half of the semester?		
A. High quality	27	19.71
B. Moderate quality	88	64.23
C. Poor quality	22	16.06
31. What was the quality of your EQs during the second half of the semester?		
A. High quality	50	36.50
B. Moderate quality	67	48.91
C. Poor quality	20	14.60

Question	Frequency	Percent
32. How often did you attend one of Dr. Bell's eight final exam preparation help sessions?		
A. 0 times	32	23.36
B. 1-2 times	49	35.77
C. 3-4 times	41	29.93
D. 5-6 times	10	7.30
E. 7-8 times	5	3.65
33. I prefer the grading scheme used in this course.		
A. Strongly Agree	48	34.78
B. Slightly Agree	37	26.81
C. Neither Agree nor Disagree	27	19.57
D. Slightly Disagree	19	13.77
E. Strongly Disagree	7	5.07
34. In this system I have been able to focus my attention more on learning and worry less about my grade.		
A. Strongly Agree	51	36.96
B. Slightly Agree	38	27.54
C. Neither Agree nor Disagree	15	10.87
D. Slightly Disagree	23	16.67
E. Strongly Disagree	11	7.97
35. The assessment system enabled me to more effectively monitor my progress in achieving the course goals than a traditional exam system.		
A. Strongly Agree	51	36.96
B. Slightly Agree	47	34.06
C. Neither Agree nor Disagree	20	14.49
D. Slightly Disagree	18	13.04
E. Strongly Disagree	2	1.45

Question	Frequency	Percent
36. How do you assess the quality of feedback (knowing what I did well and what needed improvement) you have received during each assessment session?		
A. I received higher quality feedback than I usually get with a traditional TA/Professor graded exam	92	66.67
B. I received poorer feedback than I usually get with a traditional TA/Professor graded exam.	11	7.97
C. The quality of feedback I have received has been comparable to what I have received with a traditional TA/Professor graded exam.	35	25.36
37. Through the course of the semester, do you believe you have become more accurate and realistic in critiquing your own work?		
A. Definitely yes	35	25.55
B. Probably yes	73	53.28
C. Probably not	20	14.60
D. Definitely not	0	0.00
E. I'm not sure	9	6.57
38. Overall, I have enjoyed the layout of this course and wish I could have more courses with a similar testing/grading format.		
A. Strongly Agree	63	46.32
B. Slightly Agree	36	26.47
C. Neither Agree nor Disagree	17	12.50
D. Slightly Disagree	14	10.29
E. Strongly Disagree	6	4.41

Appendix C: In-class Questions

1. Jan 27: How did you prepare for today's assessment? What do plan to do differently as you prepare for next week's assessment?
2. Feb 17: What benefit, if any, do you receive from this or these assessments?
3. March 3: Think about the new concepts you have learned. What activity in or out of class has helped the most with your learning?
4. March 24: Has the way you approach your learning (the things you do to learn concepts or skills) changed because of this course? If so, how and why did you change?
5. March 31: What is your opinion on the benefits and/or disadvantages of the assessment/grading structure of this course?
6. April 12: How do you do your EQs? What impact have EQs had on your learning?

Appendix D: Student Self-report Form

Date	Topic	Attend? (you initial)	Reading Assignment (partner initials box)	Homework (partner initials box)
	Unit I: The Science of Biology			
Jan 9	**First day of class**			
11	**Course mechanics (How to get an A!)**			
13	**Concept 1:** Critical thinking, questions		A27–42	
16	**HOLIDAY**			
18	**Concept 2:** Membranes		6.1–6.3	
20	**Concept 3:** Cells		7.1	EQ Con 2
23	**Quant. Analysis 1:** Making observations		1.4, A9–17	EQ Con 3
25	**Quant. Analysis 2:** Displaying results		A19–26	
27	**Assessment #1**			
	Score (% correct):			
	Strengths:			
	Area(s) that need(s) improvement:			
	Plan to improve:			
30	**Practice**			
Feb 1	**Practice**			Packet 7–14
3	**Assessment #2**			Packet 20–23
	Score (% correct):			
	Strengths:			
	Area(s) that need(s) improvement:			
	Plan to improve:			
	Unit II: The Biochemical Unity of Life			
6	**Concept 1:** Biological molecules		2.2, 2.3, 3.2, 3.3, 4.1–4.3, 5.1, 5.2	
8	**Concept 2:** DNA, replication		14.1–14.3	EQ Con 1
10	**Assessment #3**			EQ Con 2
	Score (% correct):			
	Strengths:			
	Area(s) that need(s) improvement:			
	Plan to improve:			
13	**Concept 3:** RNA, protein synthesis		15.1–15.3	
15	**Concept 3 cont:**		16.1, 16.3–16.5	
17	**Assessment #4**			EQ Con 3

Score (% correct):

Strengths:

Area(s) that need(s) improvement:

Plan to improve:

20	**HOLIDAY**		
21	**Quant. Analysis:** Probability		
22	**History:** Breaking the genetic code	15.2, A6–7	
24	**Assessment #5**		Packet 29–31

Score (% correct):

Strengths:

Area(s) that need(s) improvement:

Plan to improve:

	Unit III: Energy is Essential for Life		
27	**Concept 1:** Life transforms energy	9.1, 10.1	
Mar 1	**Concept 2:** Respiration, photosynthesis		EQ Con 1
3	**Assessment #6**		EQ Con 2

Score (% correct):

Strengths:

Area(s) that need(s) improvement:

Plan to improve:

6	**Practice**		
8	**Quant. Analysis:** Relationships among variables		
10	**Assessment #7**		Packet 36–38

Score (% correct):

Strengths:

Area(s) that need(s) improvement:

Plan to improve:

	Unit IV: Life Reproduces		
13	**Concept 1:** Chromosomes, cell cycle, mitosis	11.1, 11.2	
15	**Concept 2:** Meiosis	12.1–12.3	EQ Con 1
17	**Practice**		EQ Con 2

Appendix E: Brigham Young University Student Ratings Survey

Comparing this course with other university courses you have taken, please indicate an OVERALL rating for the following:

Course:

Very Poor	Good
Poor	Very Good
Somewhat Poor	Excellent
Fair	Exceptional

Instructor:

Very Poor	Good
Poor	Very Good
Somewhat Poor	Excellent
Fair	Exceptional

Please respond to each of the following items regarding this course:

Response categories:

Very Strongly Disagree	Somewhat Agree
Strongly Disagree	Agree
Disagree	Strongly Agree
Somewhat Disagree	Very Strongly Agree

I learned a great deal in this course.

Course materials and learning activities were effective in helping students learn.

This course was well organized.

Evaluations of students' work (e.g., exams, graded assignments and activities) were good measures of what students learned in the course.

Course grading procedures were fair.

This course helped me develop intellectual skills (such as critical thinking, analytical reasoning, integration of knowledge).

This course provided knowledge and experiences that helped strengthen my testimony of the Gospel of Jesus Christ.

For this course, about how many hours per week did you spend in class?
(e.g. 2, 2.5)

What percentage of the time you spent in class was valuable to your learning?
% 0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

For this course, about how many hours per week did you spend out of class (doing assignments, readings, etc.)?
(e.g. 4, 4.5)

What percentage of the time you spent out of class was valuable to your learning (as opposed to just busy work)?
% 0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Please respond to each of the following statements regarding this instructor:

Response categories:

Very Strongly Disagree
Strongly Disagree
Disagree
Somewhat Disagree
Somewhat Agree
Agree
Strongly Agree
Very Strongly Agree

Showed genuine interest in students and their learning.

Provided opportunities for students to get help when they needed it.

Provided opportunities for students to become actively involved in the learning process.

Gave students prompt feedback on their work.

Provided students useful feedback on their work.

Responded respectfully to students' questions and viewpoints.

Was effective in explaining difficult concepts and ideas.

This instructor and course contributed to the Mission and Aims of a BYU Education (i.e., Spiritually Strengthening, Intellectually Enlarging, Character Building, Leading to Lifelong Learning and Service).

Please add any comments or suggestions you have about your learning experience in this course with this instructor.

Appendix F: Research Questions, Data Sources, and Analyses

Question	Data Source	Data Analysis
What is the nature of the formative format pedagogy and its context in the Biology 120 course taught at BYU winter term, 2006?	Class observations, student interviews, instructor interviews, course documents	Ethnographic analysis
What is the nature of students' learning experiences in this course?	Class observations, student interviews, responses to questions, performance data	Ethnographic analysis, descriptive statistics
In what ways do students improve or extend their biology-related knowledge and skills during the course?	Class observations, student interviews, performance data, surveys	Ethnographic analysis, CTT, descriptive statistics
According to students, what components of the course tend to foster this improvement, if any?	Class observations, student interviews, responses to questions, surveys	Ethnographic analysis, descriptive statistics
What opinions do students have about the advantages and disadvantages of the formative assessment pedagogy?	Class observations, student interviews, responses to questions, surveys	Ethnographic analysis, descriptive statistics
How and to what extent do students' approaches to learning change during the course?	Pre/post survey, interviews, responses to questions	Ethnographic analysis, descriptive statistics
How and to what extent do students' attitudes towards learning change during the course?	Pre/post survey, interviews, responses to questions	Ethnographic analysis, descriptive statistics
How and to what extent does students' self-efficacy towards studying and learning biology change during the course?	Pre/post survey, interviews, responses to questions	Ethnographic analysis, descriptive statistics
In what ways do the responses to the above questions vary by individual students or subgroups of students?	All data	Excel spreadsheet exploration, correlation, regression

Appendix G: Componential Analysis Worksheet

In-class Question 3			Dimensions of Contrast		
Activity	Number of times mentioned	Percent	Location	Social Condition	Locus of Action
EQs	38	31.40	in class	classroom	student
In class explanations	15	12.40	in class	classroom	instructor
Reading	15	12.40	out of class	solitary	student
Talking to others out of class	11	9.09	out of class	with others	student
TA help	7	5.79	out of class	with others	TA
PowerPoints	6	4.96	out of class	solitary	student
Practice problems	6	4.96	out of class	solitary	student
Talking to others in class	6	4.96	in class	with others	student
Assessments	5	4.13	in class	solitary	student
Reading summaries	4	3.31	out of class	with others	student
Instructor help	3	2.48	out of class	with others	instructor
Reviewing notes or problems	2	1.65	out of class	solitary	student
Homework	1	0.83	out of class	solitary	student
Nothing	2	1.65			
Total	121				

Weekly Assessment 4

A transfer RNA has the anticodon sequence AUG. What is the correct triplet of nucleotide bases in DNA that acts as template for the production of the codon to which this tRNA will bind during translation (all sequences are 5' on the left)?

a. AUG
b. TTC
c. TAC
d. ATG
e. AAG
f. UAC

What is the best estimate for the molecular weight of the protein, consisting of a single polypeptide chain, encoded by a gene (a double-stranded segment of DNA) having a molecular weight of 1,125,500 g/mole? Assume that the average molecular weight of an amino acid is 120 g/mole and that the average weight of a single nucleotide in DNA is about 310 g/mole.

a. 1,210
b. 1,565
c. 3,125
d. 9,380
e. 36,305
f. 72,610
g. 145,225
h. 435,680
i. 484,590
j. 969,182

In 1955, E. Chargaff isolated and purified DNA from yeast, and determined that it contained 18% cytosine. Yeast DNA contains what percent adenine?

a. 9
b. 18
c. 24
d. 32
e. 36
f. 48
g. 64
h. 82

Which of the following aspects of molecular genetics is possible in prokaryotes but impossible in eukaryotes?

a. Only one of the two complementary strands of a gene is transcribed by RNA polymerase.
b. The nucleotide base sequence in the 5' to 3' direction on one strand of DNA is different from the 5' to 3' sequence on the complementary strand.
c. An mRNA could be translated at the same time as it is being synthesized. (prokaryotes have no nuclear membrane to separate transcription and translation)
d. The tRNAs are located in the cytoplasm of the cell.
e. Three nucleotides in an mRNA program the addition of one amino acid to a growing protein.

In a few sentences, explain the role of tRNA and why a cell needs many different species of tRNA. You may include a simple diagram to help answer this question. A quality answer will tell what tRNA does, describe briefly how it works, and use the correct vocabulary.

Appendix I: Brigham Young University Student Ratings Results

Responses ranged from 1 (lowest level of endorsement) to 8 (highest level of endorsement).

Question	Mean Response
Comparing this course with other university courses you have taken, please indicate an overall rating for the following:	
Course	6.6
Instructor	7.3
Please respond to each of the following items regarding this course:	
I learned a great deal in this course.	6.6
Course materials were effective in helping students learn.	6.8
The course was well organized.	7.0
Evaluations of students' work (e.g., graded assignments and activities) were good measures of what students learned in the course.	6.7
Course grading procedures were fair.	6.9
This course helped me develop intellectual skills (such as critical thinking, analytical reasoning, integration of knowledge).	6.9
Please respond to each of the following items regarding this instructor:	
The instructor showed genuine interest in students and their learning.	7.8
The instructor provided adequate opportunities for students to get help when they needed it.	7.7
The instructor provided opportunities for students to become actively involved in the learning process.	7.6
The instructor gave students prompt feedback on their work.	7.2
The instructor provided students useful feedback on their work.	7.0
The instructor responded respectfully to students' questions viewpoints.	7.5
The instructor was effective in explaining difficult concepts and ideas.	7.1

Appendix J: Subgroups Correlation Matrix

		FE	GA	WA	AT	RE	HW	SE	LO	LA	SEG	LOG	LAG	EQ	FB
FE	r	1.001	**.446**	**.407**	**.365**	**.242**	**.261**	**.423**	-.039	.128	**.312**	-.052	**.252**	.012	.007
	p		.001	.001	.001	.001	.001	.001	.682	.176	.001	.599	.010	.895	.941
	n	249	159	249	247	247	245	114	114	113	105	105	103	114	114
GA	r	.446	1.000	**.265**	**.243**	**.182**	.135	-.196	.067	.054	.004	.091	.199	.021	.056
	p	.001		.001	.002	.022	.090	.064	.529	.613	.968	.406	.069	.842	.603
	n	159	159	159	159	159	158	90	90	89	86	86	84	90	90
WA	r	.407	.265	1.000	**.141**	**-.227**	**.420**	-.071	-.094	-.023	-.046	.024	-.098	.012	-.006
	p	.001	.001		.026	.001	.001	.444	.311	.807	.641	.811	.327	.897	.947
	n	249	159	267	251	251	248	118	118	117	105	105	103	118	118
AT	r	.365	.243	.141	1.000	**.370**	**.574**	-.146	-.042	-.053	.002	.046	-.005	-.012	.053
	p	.001	.002	.026		.001	.001	.112	.649	.564	.986	.646	.958	.894	.562
	n	247	159	251	254	253	247	120	120	119	104	104	102	120	120
RE	r	.242	.182	-.227	.370	1.000	**.708**	.089	.099	.034	.127	-.061	.143	.029	-.023
	p	.001	.022	.001	.001		.001	.330	.281	.711	.199	.536	.152	.749	.799
	n	247	159	251	253	255	247	121	121	120	104	104	102	121	121
HW	r	.261	.135	.420	.574	.708	1.000	-.020	-.165	-.109	.075	**-.225**	.127	-.166	-.104
	p	.001	.090	.001	.001	.001		.836	.080	.251	.452	.022	.204	.078	.269
	n	245	158	248	247	247	248	114	114	113	103	103	101	114	114
SE	r	.423	-.196	-.071	-.146	.089	-.020	1.000	.138	**.313**	**.493**	.031	.154	.145	.089
	p	.001	.064	.444	.112	.330	.836		.109	.001	.001	.751	.121	.091	.300
	n	114	90	118	120	121	114	137	137	136	105	105	103	137	137
LO	r	-.039	.067	-.094	-.042	.099	-.165	.138	1.000	**.700**	.008	**.735**	.074	**.635**	**.587**
	p	.682	.529	.311	.649	.281	.080	.109		.001	.937	.001	.461	.001	.001
	n	114	90	118	120	121	114	137	137	136	105	105	103	137	137
LA	r	.128	.054	-.023	-.053	.034	-.109	.313	.700	1.000	**.240**	**.687**	**.573**	**.874**	**.853**
	p	.176	.613	.807	.564	.711	.251	.001	.001		.014	.001	.001	.001	.001
	n	113	89	117	119	120	113	136	136	136	104	104	103	136	136
SEG	r	.312	.004	-.046	.002	.127	.075	.493	.008	.240	1.000	-.013	**.223**	.165	.150
	p	.001	.968	.641	.986	.199	.452	.001	.937	.014		.895	.024	.093	.127
	n	105	86	105	104	104	103	105	105	104	105	105	103	105	105
LOG	r	-.052	.091	.024	.046	-.061	-.225	.031	.735	.687	-.013	1.000	-.042	**.731**	**.689**
	p	.599	.406	.811	.646	.536	.022	.751	.001	.001	.895		.673	.001	.001
	n	105	86	105	104	104	103	105	105	104	105	105	103	105	105
LAG	r	.252	.199	-.098	-.005	.143	.127	.154	.074	.573	.223	-.042	1.000	-.075	.043
	p	.010	.069	.327	.958	.152	.204	.121	.461	.001	.024	.673		.451	.670
	n	103	84	103	102	102	101	103	103	103	103	103	103	103	103
EQ	r	.012	.021	.012	-.012	.029	-.166	.145	.635	.874	.165	.731	-.075	1.000	**.925**
	p	.895	.842	.897	.894	.749	.078	.091	.001	.001	.093	.001	.451		.001
	n	114	90	118	120	121	114	137	137	136	105	105	103	137	137
FB	r	.007	.056	-.006	.053	-.023	-.104	.089	.587	.853	.150	.689	.043	.925	1.000
	p	.941	.603	.947	.562	.799	.269	.300	.001	.001	.127	.001	.670	.001	
	n	114	90	118	120	121	114	137	137	136	105	105	103	137	137

Bolded values = significant at .05 alpha level

Key to labels:

FE Final Exam: Posttest total points

GA Gain: Posttest total of 22 matched items – pretest total of 22 matched items

WA Weekly Assessments: Number of weekly assessments taken

AT Attendance: Number of days attending class

RE Reading: Number of reading assignments completed

HW Homework: Number of homework assignments completed

SE Self-efficacy: Post-survey self-efficacy subscale score

LO Learning orientation: Post-survey learning orientation subscale score

LA Learning approach: Post-survey learning approach subscale score

SEG Self-efficacy gain: Post-survey self-efficacy subscale score – pre-survey self-efficacy subscale score

LOG Learning orientation gain: Post-survey learning orientation subscale score – pre-survey learning orientation subscale score

LAG Learning approach gain: Post-survey learning approach subscale score – pre-survey learning approach subscale score

EQ Elaborative questioning: Response top course evaluation survey item 29: What influence did EQs have on your learning

FB Feedback: Response to course evaluation survey item 35: The assessment system enabled me to more effectively monitor my progress in achieving course goals than a traditional exam system.