ABSTRACT

GALLUCCI, KATHLEEN K. The Case Method of Instruction, Conceptual Change, and Student Attitude. (Under the direction of Glenda S. Carter.)

The purpose of this study was to investigate the effect of the case method of instruction (CMI) on conceptual change in students’ understanding of genes, biodiversity, and evolution topics, and to investigate the effect of learning with CMI on student attitude regarding the discipline of science, and learning about science. The study also investigated students’ perceptions of their learning gains based on CMI.

This was a mixed-methods action research study that used a quasi-experimental design. The study participants were enrolled in three sections \( (n_1 = 20, n_2 = 16, n_3 = 30) \) of the same introductory biology course during the spring of 2006 at a small, private university in the southeastern United States.

At the beginning of the semester, students completed a pretest composed of six open-ended questions (two on each topic) to uncover their alternative conceptions – or lack of them, and after instruction using CMI, students answered the same questions as a post-test on two hourly class exams. The answers were scored with original rubrics and the differences between the scores were analyzed using the Student’s paired \( t \)-Test.

In addition, twelve student volunteers were interviewed twice, once after each exam, by an independent interviewer, to elicit their understanding about the method of CMI, their understanding of the topics from the recent exam, and their attitudes about science and learning about science. The interviews were audio taped and transcribed, and analyzed for themes and comments about conceptual understanding and learning about science.
Students also completed two instruments anonymously: the Science Attitude Inventory (SAI II) and the Student Assessment of Learning Gains (SALG). The SAI II was completed on the first and the last day of the semester to assess change in student attitude about science and the pretest and posttest scores were analyzed for significant differences. Students completed the SALG online immediately before the course final exam to provide their opinion on learning science with CMI and their perception of learning gains made by using CMI. Student responses in each of 5 categories were studied and written comments were analyzed.

According to the interview data, CMI presented a new learning paradigm for students and many agreed that the method made learning more interesting, motivating, and relevant, and as a consequence they learned more and expect to retain knowledge longer. Based on the pretest answers, many students had alternative conceptions, but some responses indicated a lack of preconceptions altogether. All classes showed an increase in conceptual learning of all three topics, based on the analysis of the posttest rubric scores, with evolution concepts showing the largest increase. CMI appears to have a no effect on student attitude toward science, according to the SAI II data, it but does affect student attitude about learning science, based on the interview data. CMI appears to be a teaching strategy that can promote student engagement in learning science and may help students to make progress toward conceptual change.
The Case Method of Instruction, 
Conceptual Change, and 
Student Attitude

by
Kathleen K. Gallucci

A dissertation submitted to the Graduate Faculty of 
North Carolina State University 
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Doctor of Philosophy

Science Education

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DEDICATION

This dissertation is dedicated to my family:

my husband, Jim,

and my children, Mario, and Madeline,

for their unending encouragement, support, and love,

without which I could not have persevered.
BIOGRAPHY

Kathy Kubicki Gallucci was born on May 28, 1951, the fourth of six children born to Chester and Irene Kubicki in Buffalo, New York. She has always had a keen interest in science and nature, and this curiosity was kindled by her early outdoor experiences, particularly those as a Girl Scout. In high school at Villa Maria Academy, Kathy was an active participant in the science club and competed in local and regional science fairs, with the compassionate guidance of her early mentor, Ms. Georgianna McCoy. In 1973, she graduated from LeMoyne College in Syracuse, NY, with a Bachelor of Science in Biology, and after getting married that year, taught biology at Bishop Grimes High School in Syracuse. Kathy then moved in 1976 with her husband to Huntsville, AL, where she worked as a veterinary technician, and later as a research assistant for a physician. When her husband obtained a job in Greensboro, NC, she worked there as a chemical analyst for Pfizer, Inc., before returning to graduate school in Marine Sciences at the University of North Carolina, Chapel Hill. She obtained her Master of Science in 1981, for her research on the bacterial symbionts associated with the algal blooms on the Chowan River, NC. Her son, Mario, was born right after she completed her M.S.

In 1984, Kathy became a faculty member at Elon University, NC, where she has revised the introductory laboratory program for biology students and has written three laboratory manuals for the biology department. She teaches introductory courses and labs, special topics courses, and has co-taught some study abroad courses. Her interest in understanding how students learn biological concepts compelled her to seek a degree in science education.

Kathy currently resides in Greensboro, NC, with her husband, Jim, and daughter, Madeline. She enjoys travel, theater, and camping, and is still a Girl Scout.
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My department chair, Dr. Michael Kingston, helped to arrange my teaching schedule to allow the timely completion of this study.

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Chapter One
Introduction

Reform in Higher Education

Efforts aimed at improving the quality of K-12 science education have recently been expanded to include reforms for improving the quality of higher education. State legislatures, national commissions, the corporate world, and the public have insisted that post-secondary institutions be accountable for the education they provide (National Research Council [NRC], 2003; National Science Foundation [NSF], 1996). The demand for change has also emerged within academia, with many reforms recommending a shift to learner-centered pedagogies. But teachers in higher education have lagged behind their K-12 colleagues in implementing recent constructivist approaches. This is due, in part, to the fact that university professors typically have little formal training in pedagogy, and in particular, training in learner-centered techniques and assessment, with few rewards offered for improvement, especially at research institutions (NRC, 1997, 2003; NSF, 1996).

The need for reform in higher education is especially acute in introductory large-enrollment courses – the very environment where students often develop their interest, or disinterest, in science – which are often taught by less experienced and/or research-focused instructors (Sunal, Wright, & Day, 2004). But tenure-seeking professors are already overwhelmed with multiple claims on their time, including grant-writing and service responsibilities, in addition to teaching classes and mentoring students (Howard Hughes Medical Institute [HHMI], 1996). At the same time, teaching excellence is often undervalued by the
institution (Kreber, 2002), professors are typically unfamiliar with the educational research literature, and have few incentives to learn how to improve or assess their teaching (NRC, 2003).

Since Boyer’s (1990) seminal work on the scholarship of teaching and learning, efforts to improve the quality of teaching in higher education have received more attention and respect (Kreber, 2002). One study of 47 instructors found that many faculty members are now approaching teaching as an investigative process, in the same manner as they approach research in their discipline (Cottrell & Jones, 2003). The drive to improve teaching in higher education is continuing to build momentum (Association of American Colleges & Universities [AAC&U], 2007; U.S. Department of Education, 2006).

Theoretical Perspectives

Undergraduate Education

Undergraduate biology education serves future scientists and science-literate world citizens. Moreover, it must also educate preservice teachers, who will impact student learning and understanding of science in grades K-12 (American Association for the Advancement of Science [AAAS], 1993; National Academy of Sciences [NAS], 1996; NRC, 1997). Many science education reforms recommend constructivist pedagogies, including inquiry methods (NRC, 2005) to promote conceptual learning of the nature of science, rather than factual knowledge (NRC, 1997; NSF 1996; Sunal et al., 2004). Moreover, students who are engaged with collaborative and group work not only learn science, but also higher-order thinking skills (AAAS, 1990; NRC, 2005).
Reforms emphasize construction of knowledge through inquiry, hands-on activities and technology, cooperative learning, and a focus on problems (Sunal et al., 2004; Udovic, Morris, Dickman, Postlethwait, & Wetherwax, 2002). According to Shulman (2000), the essence of pedagogy is “putting the inside out, working on it together while it is out, and then putting the outside back in” (p. 133). In other words, teachers must first assess students’ prior knowledge, students construct knowledge together in groups, and then students reflect on their new knowledge as part of a meaningful whole. These essential ingredients of constructivism rely on active learning, rather than the traditional learning characteristic of many post-secondary science lecture halls. Without an active-learning environment, students may never achieve science-literacy, shake their negative beliefs about science, or realize the importance of science in their lives.

For non-science majors, a required general studies course is likely to be their last formal experience with science (Boyer Commission on Educating Undergraduates in the Research University, 1998; NSF, 1996; Tobias, 1992). But students often say that general education science courses are not relevant to them. They are turned off by the lecture approach, content-dense texts, and a sense of disconnect with the subject matter (Seymour & Hewitt, 1997; Tobias, 1992). Still, they have low expectations and little motivation to learn about a subject outside of their chosen field (Tobias, 1992). Even with constructivist learning experiences in secondary school, students often expect a passive-learning environment in post-secondary education and may even resist active-learning techniques at the college level (Qualters, 2001; Watters & Watters, 2007). However, a change in pedagogy could effect change in this view of learning.
One meta-analysis pointed out that a student’s approach to education and the professor’s pedagogy have the greatest effect on learning (Springer, Stanne, & Donovan, 1997).

One constructivist strategy, the “learning cycle,” uses the ideas of “exploration,” “concept introduction,” and “concept application” (Allard & Barman, 1994). Although initially introduced as a pedagogy for elementary and middle school science classrooms, some educators have found the learning cycle to be effective in the post-secondary classroom as well (Allard & Barman, 1994; Lawson, 2001; Lawson & Thompson, 1988). Students in a constructivist biology classroom (using the learning cycle methodology) did significantly better than those in a traditional classroom, where students “downloaded” factual information during lecture (Lord, 1997).

The Case Study Method of Instruction (CMI)

Another, perhaps more adaptable constructivist strategy that has many of the elements of the learning cycle is the case method of instruction. The case study method of instruction, or CMI, is a pedagogical strategy that can address some of the problems encountered in higher education.

The case study method has been used for years in many business, law, and medical schools across North America. Cases require students to analyze and consider solutions, and possible consequences, of dilemmas. While working on cases, students develop higher-order thinking skills, learn teamwork, and internalize learning. Case studies also have a strong appeal for students who dislike lecture and factual learning (Herreid, 1994).

Cases are stories or narratives used in the classroom or laboratory to engage and motivate students to take charge of their own learning. A good case tells a story, focuses on an interest-
arousing issue, and is relevant to the reader (Herreid, 1997). Case studies also give students the opportunity to practice the inquiry method, uncover their own alternative conceptions, and help them recognize the relevance of course material (Herreid, 1994). While working on a case study, students typically collaborate with others so their learning becomes self-directed and student-centered. In this environment, students can “construct” their own knowledge.

It is important to distinguish between a teaching case study and a research case study, although research case studies may be used in the science classroom. A teaching case study has no “right” answer and no correct solution, and thus requires students to think critically (Wood & Anderson, 2001). A good teaching case has ambiguities and results in different class discussions each time (Herreid, 1997). This use of cases for teaching is known as CMI. In contrast, a research case analyzes a phenomenon in its authentic context and is usually presented with a complete analysis (Lynn, 1999).

Cases are often used in teacher education to promote the development of pedagogical content knowledge (PCK) for pre-service teachers (Lundeberg, Levin, & Harrington, 1999), but until recently, the use of cases was rare in the science curriculum (Gabel, 1999). However, a growing number of university educators have turned to the case study method to enhance student engagement in their classrooms (Herreid, 1994). The case study method is not the same as Problem Based Learning (PBL), but the two approaches do overlap, as both methods are inductive. A problem is a type of case, but a case is not necessarily a problem (Herreid, 1997). In its simplest form, a case is a story with a learning message, such as a conversation, newspaper clipping, or a courtroom scene. But a case can also be as complex as a problem used in PBL that requires longer periods of time to investigate, often over the course of entire semester (Herreid, 1997).
Inductive approaches such as CMI or PBL have typically received positive evaluations from both teachers and students, but studies on the formal assessment of CMI and how it affects learning have been sparse (Lundeberg, et al., 1999). One study by Lieux (1996) at the University of Delaware, used standard research methods to compare the effectiveness of student learning with PBL and the lecture method in two classes with the same instructor. From traditional student assessments the study concluded that students learned concepts equally well with both the lecture and PBL methods but in PBL, the students rated themselves higher in their development of problem solving skills. Interestingly, the students rated themselves lower on how well they learned content knowledge with PBL, even though this supposition was not supported by the final assessment (Lieux, 1996).

Data from medical schools across the globe showed PBL methods were rated significantly more superior on students’ program evaluations and, at the same time, PBL showed no difference in content test scores compared to traditional pedagogies (Vernon & Blake, 1993). Faculty surveys from US business schools also point to the effectiveness of the case study method, but they admit that its effectiveness is hard to assess (Michlitsch & Sidle, 2002).

CMI is a “new” teaching strategy that can address reform issues in higher education science teaching. But, implementation of new teaching strategies requires the application of the instructor’s PCK, a combination of general pedagogical content knowledge and subject matter knowledge (Gess-Newsome, 1999; Wandersee, Mintzes, & Novak, 1994). Even though case study teachers are motivated by a desire to bring learning excitement to their classroom, most lack formal pedagogical training and their own PCK (NRC, 2003). The case method of instruction is a teaching strategy that draws on a professor’s own expertise to help them develop
PCK – the content knowledge of their discipline. Moreover, Shulman (1986) described case knowledge (such as illustrations, parables, and examples) as one of the three main types of PCK that can be used to address student misconceptions and promote understanding.

Conceptual Change

The National Research Council’s (NRC, 2000, 2005) meta-analysis of current research in cognitive science concluded that there are three established principles about learning that can be used to drive educational reform. First, students come to the classroom with preconceptions that are highly resistant to change which are based on their prior knowledge. Second, development of competency in a discipline requires a deep foundation of factual knowledge that is organized in a conceptual framework. Third, students can learn to take control of their own learning through metacognitive approaches that define their learning goals and help them assess their progress (NRC 2000; NRC 2005). The first principle of the NRC was explored in this study.

The term “preconception” in the first principle has also been variously described as “alternative conception,” or “preconception,” or “misconception,” often without a clear-cut distinction among the three terms. Wandersee, Mintzes, and Novak (1994) recommended the use of the term “alternative conception” as a more appropriate constructivist descriptor that acknowledges the positive aspects of prior conceptions for learning, such as a basis for comparison. This idea aligns with the view that alternative conceptions not only promote conceptual conflict but may also help the learner build upon existing ideas in her conceptual ecology (Scott, Asoko, & Leach, 2007). Duit & Treagust (2003) contended that conceptual change is more than “conceptual,” but may also be “intentional,” by connecting motivation for learning with cognition. They described three broad views of conceptual change: first, as “weak
knowledge restructuring,” in which conceptual “capture” promotes assimilation, second, “strong or radical restructuring” in which accommodation results in conceptual exchange,” and third, knowledge “accretion” rather than assimilation or accommodation.

Knowledge accretion is similar to the “incremental” conceptual change proposed as one of four patterns by Demastes, Good, and Peebles (1996), who also described “cascade,” “wholesale,” and “dual constructions.” They proposed that conceptual change theory might be over-applied in describing students’ conceptual restructuring. By using repeat interviews of several subjects, they described two patterns of thinking that are examples of true conceptual change, which they refer to as “cascade” and “wholesale,” and two patterns that they do not consider to be true conceptual change, which they refer to as “incremental” and “dual.”

“Cascade” conceptual change refers to a sequence of conceptual changes that are free to occur once the controlling conception is overturned. For example, once students change their conception that change in evolution is not driven by need but by mutation, they can change their conception about how selection, and thereby evolution occurs. In “wholesale” conceptual change, the alternative conception is completely replaced by the scientific conception. For example, if students do not see the plausibility of cave salamander blindness caused by disuse, they are more likely to replace it with the scientific conception of selection for the random blindness mutation. The “wholesale” change occurs because of a rational assessment of the evidence. “Incremental change” can occur as a student methodically works through the meaning behind scientific conceptions, for example, by coming to grips with the role of mutation in evolution. Finally, “dual” constructions occur when a student accepts two incompatible conceptions, for example, applying need as a basis for mutation in one population and randomness in another.
Scott et al. (2007) explained that misconceptions might be spontaneously generated from within a mental framework developed from childhood presuppositions. They described conceptual change as not only the replacement of an alternative conception, but that it may also result from connecting fragmented conceptions, or conceptual addition, or even replacement of conceptions. Finally, students may lack any preconception when confronted with new scientific conceptions. This was the basis for Geraedts and Boersma’s (2006) “guided reinvention” strategy for teaching natural selection, which is described in Chapter 2.

In this study, the term “alternative conception” will be used to refer to prior knowledge that a student believes is an acceptable explanation for an observation. Students’ alternative conceptions are highly resistant to change with traditional teaching methods (Alters & Nelson, 2002; NRC, 2000; NRC, 2005). Some alternative conceptions in biology originate from the unique nature of the discipline – its continuous change, its conflict with students’ belief systems (such as creationism), its contradictory meanings for common biological terms (e.g., “dominant”), and its “errors resulting from ‘historical baggage’” such as the various definitions of a chromosome (Fisher, et al., 1986). Case studies used in introductory classes for non-majors can focus on these unique problems of biology.

Alternative conceptions can be addressed directly by teaching strategies. Students replace or reorganize concepts through a process known as accommodation (Posner, Strike, Hewson, & Gertzog, 1982). The conditions for accommodation are: dissatisfaction with the existing conceptions (known as dissonance), and the intelligibility, plausibility, and fruitfulness of the new conception. Posner and his colleagues included anomalies, analogies, and metaphors as part of student conceptual ecologies (i.e., concepts that govern conceptual change). Case
studies can be used to highlight conceptual ecologies and create the dissatisfaction required to illustrate the intelligibility, plausibility, and fruitfulness of a new conception. With appropriate case study selection by the instructor, accommodation may be promoted in the biology classroom. Indeed, Palmer (2003) found that students experienced accommodation of scientific concepts in a context-based conceptual change intervention study.

Undergraduate students often have alternative conceptions in biology, particularly in such topics as evolution, biodiversity, and genes (Bishop & Anderson, 1990; Ferrari & Chi, 1998; Fisher, Lipson, Hildebrand, Miguel, Schoenberg, & Porter, 1986; Lawson & Thompson, 1988; Lewis & Kattman, 2004; Lewis & Wood-Robinson, 2000; Marbach-Ad, 2001; Wandersee, Mintzes, & Novak, 1994). Recent reform pedagogies that have been successful in addressing these alternative conceptions include inductive techniques (Jensen & Finley, 1996).

Student Attitudes

CMI can also be used to improve or enhance student attitude toward learning because it is student-centered and collaborative. One student survey reported that positive student attitudes can be fostered by hands-on activities, inquiry, laboratory work, group work, open-ended questions, and teaching for understanding (Piburn, 1993). CMI can address the negative influences students reported on their attitude such as ambiguity, risk-taking, complexity of subject, lack of student involvement, isolation, repetition, and lack of relevance (Piburn, 1993). Moreover, Sundberg, et al. (1994) reported that non-science majors’ attitude and achievement both improved with a decline in coverage of content, another characteristic of CMI (Herreid, 2005).
Myers and Fouts (1992) did a cluster analysis of a stratified random sample of high school students using two different instruments and found that classroom environment was the best predictor of student attitude. They found that classes with a high level of student involvement, an array of relevant topics, cooperative learning, diverse teaching strategies, an organized classroom, and low level of teacher control, also produced positive student attitudes. McMillan and May (1979) found that class formats stressing active involvement and experiences, experiments, and investigations have a positive effect on student attitude. Significant research questions in science education deal with an understanding of attitude and the promotion of a positive attitude to improve the quality of science education (Myers & Fouts, 1992).

Addressing problems with student attitude would help to address some of the national problems in education, such as, loss of interest in science, low achievement, and declining enrollment in science classes (Simpson & Oliver, 1990). Student motivation and attitude can be improved by changing the classroom environment, banishing memorization, and using open-ended problems (Herreid, 2005; Moravcsik, 1981). If students have a better attitude and become more engaged in their science classes, they may feel empowered and experience increased success. Furthermore, they may retain their positive attitude about science, as they become adults.

Statement of the Problem

Cases have been promoted as a technique to improve learning outcomes in the classroom, but there are few studies on collaborative learning on the college level (NRC, 1997). Though
widely advocated, CMI and PBL both lack significant research studies that statistically evaluate science teaching outcomes with these methods. This is largely due to the difficulty in assessing student learning through PBL. Lundeberg, et al. (1999) reported that CMI lacks empirical research in teacher education. Michlitsch and Sidle (2002) reported that teachers admit it is harder to assess student learning with PBL compared to assessments from traditional tests and examinations. Research-based reasons for promotion of PBL include improving reasoning ability, critical thinking, concept application, as a model for real-life problem solving, and acquisition of problem-solving skills (Barell, 1998). Since there is little research on the effectiveness of case studies in post-secondary education, this study may provide important insights into the effect that case studies have on these skills. Furthermore case study teaching may be viewed as a useful constructivist pedagogy that may offer post-secondary instructors an opportunity to pursue the scholarship of teaching and learning and reflection on practice (Kreber, 2002).

Importance of the Topic and Contributions to Knowledge

Students possess alternative conceptions that are highly resistant to change with traditional teaching methods. CMI is a constructivist technique designed to effect conceptual change in students’ understanding of science concepts. Case studies also give students the opportunity to practice the inquiry method, develop critical thinking skills, and help students relate course material to their experience. While working on a case study, students often work collaboratively in a context where learning becomes self-directed and student-centered, thereby giving students the opportunity to “construct” their own knowledge.
CMI can address the main concerns of higher education reform and is a form of active learning that has been positively evaluated by faculty (Yadav, Lundeberg, DeSchryver, Dirkin, Schiller, Maier, & Herreid, 2007).

This study addressed the following research questions:

1. Do students perceive an improvement in their learning gains by using CMI?
2. Which alternative conceptions do students have about genes, biodiversity, and evolution and does CMI promote accommodation of scientific concepts in biodiversity, genes, and evolution?
3. Does CMI enhance student attitudes toward science and learning about science?

Limitations and Key Assumptions

Research on the effects of CMI will assume that learning can be measured and that the actual cases used in the study are effective and appropriate. Case studies that are appropriate for introductory science courses are increasingly becoming available in the literature and on the Internet (Kendler & Grove, 2004, also see http://ublib.buffalo.edu/libraries/projects/cases/ubcase.htm and http://www.udel.edu/pbl/problems/). However, cases that help students learn particular science concepts are difficult to identify and select.

This research study will face some of the obstacles that have prevented other researchers from assessing case studies. First, one concern about the case study method is that it is over contextualized (NRC, 2000). Student understanding of concepts in one setting or scenario does not necessarily transfer to another. This limitation necessitates the use of multiple cases for learning the same concept, but this may not always be practical due to time constraints. One
possible solution may be the use of more complex cases, which deal with multiple concepts.

A second concern is the type of assessment used to measure learning with case studies. Since the case study method is an alternative pedagogy, it may require an alternative assessment (Major, 2001). The use of nontraditional assessment techniques can be validated, however, by the triangulation of data from both qualitative and quantitative sources (Gall, Gall, & Borg, 2003).

Thirdly, there is a contradiction concerning student learning of course “content” with the case study method and PBL, which deemphasize content. Sundblad, Shigrell, John, and Lindkvist (2002) reported mixed outcomes for PBL in short and long-term retention, satisfaction, attitude, motivation, and problem-solving skills. They reported that students were better able to integrate theory and practice with PBL, and were more content with the educational context, but performed poorly on fundamental knowledge content compared to the students taught in the traditional manner. In another study, students reported a preference for lecture in introductory classes, because they felt they were learning more (Kester, Hoover, & McGoun, 2004). Indeed, in other studies students preferred the less energy-consumptive lecture-based classroom (Qualters, 2001; Watters & Watters, 2007).

Finally, instructors who use the case method do so because they prefer it, and their enthusiasm is a variable that cannot be controlled. In order to understand the impact of case studies, it is important to separate instructor bias from the effects of CMI.
Chapter Two

Literature Review

This review will focus on research studies investigating the case method of instruction including definitions and types of case study pedagogies and research assessing the effectiveness of the case study method in both science and non-science disciplines. Then educational research on the teaching of biology, specifically genes, biodiversity, and evolution will be summarized.

The Case Method of Instruction

The case study method of instruction (CMI) is based on the ideas of Socrates, Hegel, and particularly Dewey, who believed that education should be grounded in experience (Rhem, 1998; Kreber, 2002). This method of instruction became popular as a teaching strategy at the McMaster School of Medicine in Canada in the late 1960s (Magnussen, Ishida, & Itano, 2000) and shortly thereafter at business and law schools, most notably at Harvard University (Herreid, 1994).

“Case” Definitions

Researchers define a case in various ways. In general, cases are stories (Herreid, 1994), a “shared slice of reality” (Golich, 2000), or simply a specialized form of discussion (Harling & Akridge, 1998). Some disciplines use cases, such as legal documents or business reports, which are defined by their use (Rippin, Booth, Bowie, & Jordan, 2002). There are several taxonomies of cases as well. Shulman (1986) claimed that cases are prototypes (principles), precedents, or parables (which deal with norms and values). Harling & Akridge (1998) described anecdotes as "near-cases," and "wicked" problems (similar to PBL’s “ill-structured” problems). Rippin, et al.
(2002) distinguished between problem-solving and decision-making cases, and Lynn (1999) explained the difference between a teaching case and a research case.

PBL is considered to be a subset of CMI (Herreid, 1994; Hmelo, 1998; Rhem, 1998; Rippin et al., 2002; Waterman, 1998). Magnussen, et al. (2000) defined cases as “inquiry-based learning” or IBL, in their comparison of CMI to PBL. Both cases and problems are considered to be inductive approaches to teaching (Golich, 2000; Herreid, 1994).

Current Interest in CMI and PBL

Both CMI and PBL are increasing in popularity on many college campuses in the US and abroad, because they are perceived as solutions to some of the current problems of higher education (Herreid, 1994; Waterman, 1998). CMI is believed to help instructors deal with the exponential increase in information which makes course content difficult to “cover,” particularly in the sciences (Rhem, 1998). CMI has been shown to help students learn skills as they construct new knowledge (Harling & Akridge, 1998). Camp (1996) claimed that students retain knowledge longer and are able to transfer concepts better with CMI. Moreover, Golich (2000) believed that concepts learned with CMI have “greater sticking power,” that cases give students the opportunity to develop tacit knowledge as well as explicit knowledge, and that cases help improve writing skills. Another suggested advantage of CMI is that it appeals to women and minorities who are often marginalized in classrooms where traditional methods are used (Arambula-Greenfield, 1996). CMI has been shown to foster a positive attitude and is congruent with adult learning tenets in higher education, such as promoting student autonomy, building on previous knowledge and experience, and providing the opportunity for immediate application of knowledge (Camp, 1996). Furthermore, cases simulate real life, focus on relevant issues, capture
student interest, and are one way to resist the standardization of undergraduate education (Herreid, 1994; Rippin et al., 2002). Learning is enhanced by student engagement derived from the process of solving problems (Ahlfeldt, Mehta, & Sellnow, 2005).

Educators who prefer CMI often recommend it because they believe it enhances students’ critical thinking skills (Dori & Hercovitz, 1999; Dori, Tal, & Tsauhu, 2003; Gabel, 1999; Harland, 2002; White, Amos, & Kouzikanani, 1999; Wood & Anderson, 2001). Hmelo (1998) referred to the student experience with PBL as a “cognitive apprenticeship,” where learning is situated in real-world problems, with scaffolding (temporary assistance provided by the facilitator to compensate for gaps in student knowledge), and student thinking made visible through collaborative discussion. Moreover, Harland (2002) claimed that PBL fosters inquiry, analysis, and synthesis, the very qualities that define higher education, and for that matter, research. CMI enhances critical thinking because authentic problems or case stories provide a type of “narrative intelligence” students can store as episodic memory, which is easy to retrieve and apply to new contexts (Hung, Tan, Cheung, & Hu, 2004).

CMI Research

CMI, particularly as PBL, has been implemented widely in medical and law schools, beginning with its landmark application in McMaster University’s medical school (Albanese, & Mitchell, 1993; Herreid, 1994). Research to assess the effects of CMI in undergraduate education has been sparse and variable, from small action research studies in single classrooms to meta-analyses of studies done in several hundred institutions. However, the effects of CMI and PBL have been researched in both science and non-science courses.

In one action-research study, Arambula-Greenfield (1996) transformed an undergraduate
science class into a problem-based one and compared her teaching evaluations two years prior to and two years after making the change. The student responses to the change in pedagogy were favorable and she concluded that the major advantage of PBL was its effect on the affective domain. She reported that the greatest challenge in making the switch was the development of interesting problems, and the main disadvantage was the trade-off for less breadth of coverage.

Harland (2002) did a qualitative action-research study in which his zoology students used reflective writings to evaluate their experience in developing an Environmental Impact Assessment (EIA) for a coastal area of the Red Sea. He concluded that the students had a positive experience with PBL (project-based learning in this case), although he did not attempt to triangulate his results with quantitative data.

Ahlfeldt, Mehta, and Sellnow (2005) studied student engagement as a means of evaluating the effectiveness of PBL in physics learning. They assessed interactive engagement (IE) measured by the Force Concept Inventory, which resulted in class scores 2 standard deviations higher for their IE classes. They also found higher engagement in classes with more PBL based on items from the National Survey of Student Engagement (NSSE). They observed that this new paradigm engaged students with course material and with one another, and concluded that “engagement is the goal and PBL is the means to reaching the goal” (Ahlfeldt, et al., 2005, p. 6).

In a non-science major biology class, Dori, Tal, and Tsauhu (2003) used Science, Technology, Society (STS) case studies in a biotechnology module designed to engage students and improve their thinking skills. The study included multiple sources of data, including pre-posttests, teacher interviews, student feedback on assignments, and portfolios. The multiple data
sources verified their findings through triangulation. The researchers concluded that they observed an increase in science literacy and higher order thinking skills for students learning with case studies, based on the posttest scores and student comments.

In addition to research in science classes, studies in non-science disciplines have been used to inform practice in science education. One psychology study (Mayo, 2002) used an independent two-group design with two classes equivalent in age, gender, and academic achievement. Both the treatment group and the control group had three hours of lecture followed by an activity. The activity for the treatment class was group work on a case study written by the instructor. The activity for the control class was a writing assignment after each lecture, followed by class discussion. The treatment class did better on a 30-problem exam which led Mayo to conclude that the case method increased students’ conceptual understanding and application of ideas in general psychology.

Hoag, Brickley, and Cawley (2001) measured the transfer of problem-solving ability in communication students with a quasi-experimental research study. The treatment group was comprised of students in a capstone management course that used case method pedagogy and the control group was comprised of students in the same course in a subsequent semester that did not experience the case study pedagogy. The treatment group was given a pretest with one case and a posttest with two decision cases. The cases were related to astronomy to avoid confounding the treatment with discipline-specific knowledge. The researchers concluded student problem-solving skills were measurably improved with CMI.

In a large study with accounting students in South Africa, researchers assessed students for gender-specific and academic perceptions about learning with CMI, with a survey instrument
using 31 learning characteristics purported to be enhanced by case studies. The authors did point out that since the respondents were self-selected, they might have been biased toward the case study method. The major finding of the study was that students perceived cases to be useful because they were exposed to real-world complexity. They also found that lower performing students may benefit more from cases than higher performing students, and that males perceive cases enhancing their critical thinking more than females (Weil, Oyelere, Yeoh, & Firer, 2001).

A longitudinal study by Hmelo (1998) compared the learning of four groups of medical students at two different schools, with one PBL group and one non-PBL group at each school. Her research questions looked at the students’ accuracy, coherence, reasoning, and use of science concepts in their problem solving strategies. Students responded to two problems for each of three sessions by computer. She concluded that PBL students consistently outperformed non-PBL students.

Sundblad, et al. (2002) used a questionnaire to measure the differences in student learning between traditional classrooms and PBL classrooms in a psychotherapy course. However, they reported a possible ceiling effect likely due to student satisfaction with the program, regardless of the teaching method, and they found no differences between the two groups after two years.

Most studies investigated hypotheses and research questions that expected to find a positive effect of CMI and PBL. One study, carried out in three medical schools in the West Indies, reported that researchers were relieved that PBL did not have a negative effect on student exam scores. They were concerned that PBL strategies would mean that student learning would suffer because of exposure to less course content (Alleyne, Shirley, Bennett, Addae, et al., 2002).
In summary, CMI and PBL have been shown to have positive effects on conceptual understanding (Hmelo, 1998; Mayo, 2002), problem-solving ability (Hoag, et al., 2001), critical thinking skills (Dori, et al., 2003; Weil, et al., 2001) student engagement (Ahlfeldt, et al., 2005; Dori, et al., 2003) and the affective domain (Arambula-Greenfield, 1996). Some studies, however, have not demonstrated any net benefit for students with CMI or PBL (Alleyne, et al., 2002; Sundblad, et al., 2002).

**Student Learning in Biology**

This study focused on student learning in three major topics of a non-science major course in biology: genes, biodiversity, and evolution. Each of these topics has a unique history in science education and has been the subject of numerous research studies that have focused on student learning, engagement, and thinking skills. Several of these studies are discussed below.

**Genes Education**

It is widely accepted that genes education is central to biology education and that it is of great social importance (AAAS, 1993; Banet & Ayuso, 2003; Tsui & Treagust, 2004a). The traditional approach to teaching about genetics has been criticized as ineffective because it does not translate to meaningful learning or develop students’ thinking skills (Banet & Ayuso, 2003; Cavallo & Schafer, 1994; Chattopadhyay, 2005; Ibáñez-Orcajo & Martinez-Aznar, 2005).

In one survey, first-year university students considered the most difficult topics to be in genetics (Bahar, Johnstone, & Hansell, 1999), and these topics were widely acknowledged to be difficult for students to learn and for instructors to teach (Browning & Lehman, 1988; Duncan & Reiser, 2007; Ibáñez-Orcajo & Martinez-Aznar, 2005; Jimenez-Alexandre, Rodriguez, &
Duschl, 2000; Tsui & Treagust, 2004b). The problems encountered in students’ learning of genetics topics have been studied widely across the globe, including such countries as the United States (Cavallo & Schafer, 1994; Wynne, Steward, & Passmore, 2001); Australia, Great Britain, South Africa, and Germany (Lewis & Kattman, 2004; Lewis & Wood-Robinson, 2000; Venville & Treagust, 1998); the Netherlands (Knippels & Boersma, 2005), Spain (Ibáñez-Orcajo & Martiner-Aznar, 2007), Sweden (Gericke & Hagberg, 2007), Israel (Marbach-Ad, 2001), India (Chattopadhyay, 2005), and Taiwan (Chen & Raffan, 1999).

Genetics is considered to be difficult for students to learn because the topic is abstract and complex (Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Knippels, 2002), instruction may be simplistic and inconsistent (Browning & Lehman, 1988), and it is often complicated by extensive terminology (Ibáñez-Orcajo & Martiner-Aznar, 2005; Banet & Ayuso, 2003; Lewis & Wood-Robinson, 2000). Genetics requires multi-level thinking, or thinking on three levels. These are referred to as macro (organismal), submicro (chromosomes, gametes, genes, and DNA), and symbolic (Punnett squares and pedigrees) by Bahar, Johnstone, and Hasnell (1999) and macro, micro, and molecular by Marbach-Ad and Stavy (2000). Similarly, Duncan and Reiser (2007) described “ontologically distinct levels” of understanding in genetics that instructors can easily move between, but novices cannot. Gericke and Hagberg (2007) stated that the different levels of genetics are based on historical models. These models are: Mendelian (genes are a hypothetical units of transmission and function), Classical (genes are particles responsible for transmission, function, mutation and recombination), Biochemical-Classical (genes are particles responsible for transmission, function, mutation and recombination by means of enzymes), Neoclassical (genes are DNA units responsible for function), and Modern (genes
exist only as hypothetical constructs that exist only when it functions). If students do not receive instruction about the nature of science (NOS) and the history of science (HOS) along with a discussion of the historical models, Gericke and Hagberg (2007) determined that students had difficulty trying to integrate these five distinct (sometimes contradictory) genetics models of science.

One of the main reasons that students find genetics so difficult is their inability to make connections across the three levels, including connections between structure and function (Marbach-Ad, 2001), reproduction and heredity (Jimenez-Aleixandre, Rodriguez, & Duschl, 2000), genes and chromosomes (Lewis & Wood-Robinson, 2000), genes and proteins (Duncan & Reiser, 2007), genotype and phenotype (Lewis & Kattman, 2004), and meiosis and inheritance (Knippels, 2002 Wynne, Steward, & Passmore, 2001). This failure to make connections forces students to compartmentalize their understanding (Lewis, Leach, & Wood-Robinson, 2000b; Marbach-Ad, 2001) and rely on algorithmic strategies to complete their course assignments (Banet & Ayuso, 2003; Browning & Lehman, 1988; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Wynne, Steward, & Passmore, 2001).

Rather than widespread “misconceptions” (alternative conceptions) in genetics, some researchers report a lack of basic understanding, uncertainty and confusion, and a misuse of terminology (Lewis, Leach, & Wood-Robinson, 2000a; Lewis & Wood-Robinson, 2000). However, Ibáñez-Orcajo and Martínez-Aznar (2005) described three categories of student alternative conceptions: the location of hereditary information, the transmission of hereditary information, and the appearance of new characteristics. Other alternative conceptions mentioned included a misunderstanding of the role of gametes and how they are produced (Browning &
Lehman, 1988), and an “everyday” view of genes as particles that carry traits (Lewis & Kattman, 2004). Some of these alternate conceptions may even be promulgated by the instructor (Cakir & Crawford, 2001).

Many research studies have made recommendations for the improvement of genetics education. These include the teaching of genetics within a conceptual framework, using explicit connections made between concepts (Banet & Ayuso, 2003, Lewis, Leach, & Wood-Robinson, 2000b; Chattopadhyay, 2005). This preferred approach has been described as conceptual rather than procedural (Duncan & Reiser, 2007), beginning with a proposed “spiral” curriculum at the elementary level (Venville & Donovan, 2007).

Tsui and Treagust (2004a) recommended motivating students to learn with interactive technology, while Lewis and Wood-Robinson (2000) and Finkel (1996) proposed that students should learn genetics through a discussion of social issues. Chamany (n.d.) described a genetics curriculum that engages students in inquiry-based real world issues that require collaboration among students and application of concepts to new scenarios. These approaches were seen as more likely to prompt students to learn intentionally, with a “meaningful learning orientation” that promotes understanding of concepts (Cavallo & Schafer, 1994).

Moreover, teaching genetics also provides an opportunity for instructors to teach about the nature of science (NOS) within the content of their courses, rather than as a preview or an add-on topic (Finkel, 1996). Some studies described how students should be given the opportunity to approach genetics the same way that scientists do – as a problem-solving activity with open-ended problems (Finkel 1996; Ibáñez-Orcajo & Martinez-Aznar, 2005). Students can learn to evaluate information and evidence based on NOS, rather than with algorithms (Lewis &
Wood-Robinson, 2000), and appreciate the inconsistencies of genetics models based on NOS (Gericke & Hagberg, 2007). In the process, they not only gain knowledge of genetics, but also knowledge about their own problem-solving abilities, or metacognition (Finkel, 1996).

However, the multiple abstract levels of genetics pose extraordinary problems for students that may require radical conceptual change (Tsui & Treagust, 2000b). Venville & Treagust (1998) described conceptual change in genetics as multidimensional, including ontological, social/affective, and epistemological considerations.

Biotechnology issues such as cloning and gene technology permeate the media and often cause disquiet among many members of society (Dawson, 2007). Since genetics has become increasingly molecular, it is necessary for students to acquire knowledge and associated skills to make informed decisions and contribute to the public debate on issues related to health, forensics, agriculture, and the environment (Banet & Ayuso, 2003; Chattopadhyay, 2005; Dawson, 2007; Tsui & Treagust, 2004b). However, in studies in Australia and the United Kingdom, many students were unable to distinguish between current and potential uses of biotechnology and did not know the difference between genetically modifying food and selective breeding for useful traits, or the difference between genetic engineering and cloning (Dawson, 2007).

So far there has been limited research on student attitudes about biotechnology (Klop & Severiens, 2007). However, a study by Sohan, Waliczek, and Briers (2002), at Texas A & M University, found that students had little knowledge or awareness of biotechnology, and more students tended to reject it, especially if it involved the use of animals. In Australia, Dawson and Soames (2006) found that high school students were more accepting of biotechnology using
microorganisms and plants, but were cautious about genetically modified food. They were less positive about using animals, although they favored gene technology for treating human disease.

Attitudes about biotechnology were considered to be complex, with cognitive, affective, and behavioral components that need to be considered in classroom instruction (Klop & Severiens, 2007). Topics, such as cloning, were typically of interest to students and encouraged classroom discussion (Taras, Stavroulakis, & Ortiz, 1999). Moreover, controversial issues such as genetic engineering increased motivation because they were considered to be real and focused on NOS (Seethaler, 2005). Biotechnology topics have been used to integrate concepts – and disciplines, in courses such as “Cell Biology for Life” at the New School University, New York, where, for example, students work together to apply their knowledge of stem cells in debates (Chamany, n.d.). Also, biotechnology has been a course theme for a non-majors general education biology course called “Biotechnology Transforms Our World” at Santa Monica College, California (Colavito, 2000). However, regardless of its appeal to students, biotechnology instruction was often avoided by teachers who found the content difficult and the associated lab work impractical, or who lacked the necessary support or resources (Leslie & Schibeci, 2006; Steele & Aubusson, 2004).

Biodiversity Education

Environmental education has received sustained international attention since the last quarter of the twentieth century (Jenkins, 2003). Moreover, since Earth Day in 1970, the same year that President Nixon signed the Environmental Education Act, environmental issues have experienced grassroots advocacy (McComas, 2002). With ecology considered to be a central part of the environmental education curriculum in the US, students are expected to acquire a
deep understanding of biology as a “web of interconnected ideas” (McComas, 2002). However, some opponents complain that too much science has been taught in environmental education (Bishop & Scott, 1998) in part because, in addition to relevant conceptual knowledge, students are also expected to learn values and decision-making skills in environmental education classes (Jimenez-Aleixandre & Pereiro-Munoz, 2002). Thus environmental education is not only expected to integrate numerous subdomains of biology, it also has a social action dimension (McComas, 2003). Education for the environment, however, is typically aimed at the middle school grades in the US (McComas, 2002).

In higher education, students are often exposed to environmental issues in an ecology course or in the ecology portion of a biology course. But Gayford (2000) contended that there is a lack of alignment between the global concern for the environment and the lack of urgency in the way ecology is taught. Recently, a committee of the Ecological Society of America (ESA) reported that in order to bolster the impact of ecology on society, ecologists must transform science into action (Palmer, et al., 2005). Furthermore, professors are being urged to teach ecology in a more constructivist way to help students learn to think critically about issues in ecology (D’Avanzo, 2003a, 2003b).

Environmental education epistemology focuses on the concept of sustainability, which includes not only environmental values, but also social and economic values as well (Herremans & Reid, 2002). A precondition for sustainable development is the protection of biodiversity (Grace & Ratcliffe, 2002). Biodiversity became the focus of environmental education after 1992 when the Convention on Biological Diversity (CBD) was proposed at the United Nations Council on Environment and Development (UNCED) conference in Rio de Janeiro. As a
consequence, biodiversity was thrust into the international political agenda, as well as the educational agenda (van Weelie & Wals, 2002). In the US, the “Windows on the Wild” national environmental education program, which began in 1994, used biodiversity as an organizing theme (Braus & Champeau, 1994). But, biodiversity is considered to be more than a topic in biology or ecology. According to Haury (1998), “It is a concept that cuts across disciplinary boundaries and it is an environmental issue with broad ramifications for the quality of human life” (Beyond the Standards, ¶1).

Moreover, as a focus for environmental education, biodiversity has been described as ill-defined and lacking clarity (Gayford, 2000). van Weelie & Wals (2002) considered these attributes to be exactly what makes biodiversity a useful link between science and society. It provides common ground between nature conservation and sustainability and serves as a bridge between environmental education and science education. Because it is multidisciplinary, the biodiversity reduction issue relates to economics, politics, culture, and ethics (Gayford, 2000), and it also involves people, whose daily concerns often take precedence over concern for biodiversity conservation (Foster-Turley, 1996). These elements contribute to the controversial nature of learning about global biodiversity reduction and go beyond teaching science content, which is insufficient to help students resolve the conflict they encounter (Oulton, 2004). This duality presents a challenge to the science-based curriculum and demands new approaches (Jenkins, 2003). Even though, in the past, science education has alternated between emphasizing social aspects of science and avoiding them, recent constructivist initiatives recognize the need for a more authentic version of science as socially constructed and value-laden (Hart, 2007). In fact, the National Science Teachers Association (NSTA) includes in their position statement on
environmental education that “central to environmental literacy is the ability of students to master critical thinking skills that will prepare them to evaluate issues and make informed decisions regarding the stewardship of the planet” (NSTA, 2003, p.1).

Remarkably, the recommendation for the use of constructivist pedagogy in environmental education is not that new (Robertson, 1994). Recently, it has been recognized that teaching environmental issues cannot be accomplished in an ethical or emotional vacuum, but with a “toolbox” to help students cope with the complexity of the issues, including a framework of concepts, understanding of the nature of science, an understanding of the human context, and the recognition of bias among competing interests (Slingsby & Barker, 2003).

Indeed, environment-based education lends itself to project and issues-based pedagogy that is learner-centered and constructivist (Ernst & Monroe, 2004), and may even include story-telling and group discussions – methods not commonly used in the science classroom (Gayford, 2002; Stamp & Armstrong, 2005). Specifically, biodiversity can be contextualized personally, psychologically, or physically for learners (van Weelie, 2001). This is admittedly a difficult task for discipline-based biology instructors who risk appearing dogmatic (Korfiatis, 2005) or in favor of particular environmental agendas (Jickling & Spork, 1998). But the goal should be to engage students in an “informed conversation” with an option to challenge the ideas discussed (Jenkins, 2003). Jimenez-Aleixandre and Pereiro-Munoz (2002) also recommended that students be given the opportunity to act as science practitioners and work on open-ended problems about environmental issues.

Public surveys from more than ten years ago indicated that many people had not heard about the biodiversity crisis (Braus & Champeau, 1994) and often they were skeptical about the
connection between biodiversity and quality of life until they were informed about it (Foster-Turley, 1996). More recently, Slingsby and Barker (2003) reported people felt very strongly about the environment, but they did not necessarily think that conservation should be based on science. Instead their viewpoints typically focused on cultural, aesthetic, and utilitarian considerations (Grace & Ratcliffe, 2002) or social, personal, and institutional issues (Jenkins, 2003). This view stems in part from a public perception that environmental issues reflect the values of activists, not educators (Jickling & Spork, 1998). In the classroom this may translate to student confusion of activities with “action-taking” (Bishop & Scott, 1998). While conservation managers criticize the barriers that scientific principles impose on land use, science is typically taught as a value-free discipline (Grace & Ratcliffe, 2002). Indeed, Kyle (2006) advocated for science education’s more active role in helping to solve sustainable development issues. He proposed the creation of “footpaths” for science educators to challenge academic boundaries and advocated a critical view of science education.

So what should students learn about the environment, and specifically, what should they learn about biodiversity? The “ideal” curriculum in middle school has been discussed among science educators, although the one “intended” by instructors, compared to the one “received” by students, may be quite different (McComas 2002, 2003). With or without a prescribed curriculum, constructivist instructors (including those in higher education), begin with an exploration of students’ alternative conceptions in ecology (D’Avanzo 2003a, 2003b). Although the research on students’ alternative conceptions in ecology has been considered insufficient (McComas, 2002; Sander, Jelemenska, & Kattman 2006), some recurrent conceptions have been reported in the literature. Indeed, ecological “misconceptions” have been associated with
Wood-Robinson (1995) described some interesting anthropomorphic and teleological conceptions of younger children. These included ideas that many herbivores are needed to supply the food requirements of predators and that certain organisms are found in habitats because they “like” them. The students were often at a loss to explain ecological processes, such as decomposition, and simply responded that matter just “disappears” and “things just happen.”

Wood-Robinson (1995) explained that students have an everyday understanding of words such as “food” and “energy” that are much more restrictive that their scientific meanings. Older students also were also often confused about terminology, such as the use of the words ecosystem, community, and population. Sander, et al. (2006) found that some 16 and 17-year old students thought ecosystems and communities differed only by size, and that both words were synonymous with habitats. They also discovered that others thought ecosystems were composed of “organisms and climate” so that climate change must be responsible for the succession of species composition, directed by “climate rules.” A review by Munson (1994) indicated students confused the terms community and population, and had a simplistic view of food webs. Several studies reported that students believed that food webs were made up of individual food chains that did not interact with each other (Hogan, 2000; Munson, 1994; Wood-Robinson, 1995). Hogan (2000) described how students overstate the effects of pollutants in a food web and fail to appreciate their cumulative effects and how they may change as pollutants travel through the food web. In addition, Munson (1994) stated that some students thought when a population of a particular organism varies, some thought it may either affect all other populations the same way, and others thought that it may not affect the ecosystem at all, because
some organisms are “not important.” Wood-Robinson (1995) found some students thought that populations do not affect each other unless they have a predator-prey relationship, but Munson (1994) found that students often failed to see the link between population size and food supply.

Students also had alternative conceptions about trophic levels. D’Avanzo (2003a) reported that college students often thought that organisms at lower trophic levels exist to serve the organisms in higher trophic levels and that energy is not lost in trophic transfers (D’Avanzo, 2003b). She described other common alternative conceptions such as: high biodiversity is always better than low biodiversity, competition alone drives ecology, predators eat everything, air is “nothing,” only top-down regulation exists in communities, plants are weak, nature is in balance, and systems are stable (D’Avanzo, 2003b). McComas (2002) summarized the public’s ecological “misconceptions” described by Krebs (1999). These included ideas that organisms are independent from each other, that a community consists of similar organisms, that the imbalance of species in an ecosystem is “bad,” and that communities destroyed by natural disasters will never recuperate.

Sander et al. (2006) suggested that many alternative conceptions of ecological terms have three common aspects: ‘orientation towards the visible,’ ‘preservation of life,’ and ‘one-sided relationships.’ Students perceive nature as constant and unchanging in their spatial and temporal experience, they think that biotic relationships are most important and are ‘balanced,’ and that organisms are affected by, but do not affect their environment. Based on two studies, Sander et al. (2006) recommended “conceptual reconstruction” instead of conceptual change – to help students ‘reconstruct’ their ideas about these three common aspects.
Evolution Education

Evolution is fundamental to the discipline of biology and serves as its unifying framework (Dobzhansky, 1973; NAS, 1998). Yet, it is considered highly controversial and the view of its importance in education has been met with resistance (Meagher, 1999; Nickles, Nelson, & Beard, 1996). Indeed, the public’s perception of science has been damaged by the controversy over evolution education in the public schools (Rudolph & Stewart, 1998). A 2001 Gallup poll reported that only 35% of the public thought that the theory of evolution was supported by evidence (Alters & Nelson, 2002), and a 2004 Gallup poll reported that 45% of the American public considered themselves to be “Young Earth Creationists,” a religious viewpoint that contradicts current scientific thinking about evolution (Kliman & Johnson, 2005). Yet the same polls also show a poor understanding of the theory of evolution.

Although acceptance of evolution is not linked to an understanding of the theory (Sinatra, Southerland, McConaughey, & Demastes, 2003), people may accept or reject it based on their opinion of the perceived “authority” of science (Demastes, Good, & Peebles, 1995). Farber (2003) recommended a realistic and balanced approach by teaching evolution through the nature of science (NOS), stating “evolution is not the flame-breathing dragon of atheism, but a theory that explains biological phenomena, that relates bodies of information, and that guides research, and like other aspects of science, is open to many philosophical and religious interpretations” (p. 352). Kliman & Johnson (2005) recommended that every undergraduate student needs to achieve an essential understanding of NOS and evolution, and they discussed four elements of
that understanding: the explanatory power of theory, science’s heavy reliance on inference, use of evidence to challenge theories, and the importance of evolution in everyday life. In addition, Nickles et al. (1996) recommended teaching students that although science is tentative, it still produces highly reliable knowledge. They also advocated using human evolution as a case study and teaching critical thinking in the biology classroom.

Undergraduate science education is considered to be largely responsible for the public ignorance of evolution, because of its widespread use of traditional pedagogies, especially for preservice teachers, who are likely to teach evolution in the same manner they were taught (Blackwell, Powell, & Dukes, 2003), or even worse, not at all in order to avoid conflict (Alberts & Labov, 2004). Nelson (2005) bluntly described it this way, “Public rejection of sound science is not primarily the result of some facet of popular culture. Rather, it is the predictable result of ill-founded pedagogical choices” (p. 923). The traditional lecture approach with content-dense textbooks is “dauntingly dogmatic, but also static,” according to Farber (2003, p. 349). Student passivity and the paucity of available time are also barriers to teaching evolution (Demastes, Settlage, & Good, 1995). In order to address this problem, Alters and Nelson (2002) recommended the abandonment of traditional pedagogies to better engage college students.

What are some of the reasons that students have difficulty learning about natural selection? One problem is the use of language by both the instructor and the student. Instructors promote linguistic ambiguity by using anthropomorphic or teleological analogies in the classroom, without clarification (Anderson, et al. 2002). Teachers may also freely shift between abstract and concrete frames of reference in class discussions, further adding to students’ conceptual confusion (Moore, et al., 2002). Even the students’ own use of language causes
confusion when knowledge is constructed using imprecise words, for example, when they
ascribe agency to random and adaptive evolutionary processes (Moore, et al., 2002). Ferrari and
Chi (1998) pointed out another misuse of language occurs when college students refer to
evolutionary processes as events, rather than equilibration processes.

In addition to language problems, students also struggle with the evolutionary way of thinking, which is probabilistic rather than deterministic, and multi-layered rather than simplistic
(Geraedts & Boersma, 2006). Similar to the problem in genetics education, evolution thinking
requires students to understand three levels of organization: the gene (mutation), the individual
(selective pressure), and the population (microevolution) and be able to make connections across
those levels (Andersson & Wallin, 2006; Ferrari & Chi, 1998; Geraedts & Boersma, 2006). This
leads to students failing to distinguish between change at the level of the individual and change
at the population level (Banet & Ayuso, 2003). As a result, learning may become fragmented
when students compartmentalize concepts rather than correlating them (Moore et al., 2002).

Most research studies examining student learning about evolution focus on Posner’s, et
al. (1982) conceptual change theory that accommodation requires that new conceptions must be
intelligible, plausible, and fruitful (Banet & Ayuso, 2003; Bishop & Anderson, 1990; Brumby,
Kampourakis & Zogza, 2007; Lawson & Thompson, 1988; Moore, et al., 2002; Nehm & Reilly,
2007; Settlage, 1994; Sinatra et al., 2003; Trowbridge & Wandersee, 1994; Westcott &
Cunningham, 2005). However, Demastes et al. (1996) objected to the exclusive focus on
conceptual change as a research strategy and Westcott and Cunningham (2005) and Jensen and
Finley (1997) advocated deciphering students’ scientific conceptions in addition to alternative
conceptions. In addition to uncovering students’ alternative conceptions, Westcott and Cunningham (2005) suggested that instructors should uncover students’ scientific conceptions as well, and use them as a foundation for overturning those alternative conceptions. Based on their questionnaire, they discovered that most of their students understood the random nature of mutations, so they could build their understanding of Darwin’s model on that concept. Jensen and Finley (1997) referred to the combination of alternative conceptions and scientific conceptions as a “mixed bag” of ideas that need sorting and consolidation.

In contrast, Geraedts & Boersma (2006) opposed the theoretical framework of conceptual change in learning evolution altogether. They proposed that students do not hold alternative conceptions, but rather, respond to question prompts according to the “dynamic systems theory” of Thelen and Smith (1994). This theory stated that answers to questions are not selected from a cache of pre-existing conceptions, but rather, are constructed instantaneously when a question is posed, and answers may vary or even contradict each other based on the context. They claimed that there is no reason to follow the conceptual change model (Posner, et al., 1982) if students do not have misconceptions. Instead, they proposed a strategy of “guided reinvention” in which answers to sequential questions guide students to “reinvent” Darwin’s theory of natural selection.

Nevertheless, conceptual change has been widely studied in evolution education over the years and alternative conceptions uncovered by research studies have been extremely resistant to change (Brumby, 1984; Demastes, Good, Peebles, 1996; Greene, 1990; Jensen & Finley, 1996, 1997; Lawson & Thompson, 1988; Nehm & Reilly, 2007, among others). These alternative conceptions may be distilled into several general categories: misconceptions about the basis of change, Lamarckian conceptions, contradictory philosophical viewpoints, semantic confusion,
and a misunderstanding of the nature of science.

Students struggle with the concept of change and how it occurs in a population, confusing the cause of change with its effect, thinking that change in organisms is precipitated by environmental changes (Alters & Nelson, 2002; Anderson, Fischer, & Norman, 2002; Andersson & Wallin, 2006; Bishop & Anderson, 1990; Greene, 1990). In addition, genetic variation is often overlooked by students as important, or may not even be considered in their explanations of evolution (Banet & Ayuso, 2003; Moore, et al., 2002; Westcott & Cunningham, 2005). Instead, students may think that evolution is a gradual and simultaneous change in the traits of all members of a population (Alters & Nelson, 2002; Anderson, et al., 2002; Andersson & Wallin, 2006; Banet & Ayuso, 2003; Bishop & Anderson, 1990).

Truly Lamarckian conceptions refer to changes caused by use and disuse of body structures and also the transformation, rather than extinction, of species (Kampourakis & Zogza, 2007). Lamarckian alternative conceptions about changes in organisms, caused by use and disuse of body structures resulting in evolution, are widespread in the literature (Anderson & Wallin, 2006; Anderson, et al., 2002; Brumby, 1984; Ferrari & Chi, 1998; Jensen & Finley, 1997; Jimenez-Aleixandre, 1992; Lawson & Thompson, 1988; Settlage, 1994) and have been reviewed by Banet & Ayuso (2003). However, Kampourakis & Zogza (2007) claimed that some of the alternative conceptions reported as Lamarckian, are incorrectly categorized, and are in actuality anthropomorphic or teleological conceptions, in which change is caused by a need or a goal. In line with this thinking, these miscategorized Lamarckian conceptions will be discussed with the philosophical viewpoints. Student conceptions of Lamarck’s transformation of species have not been found in the literature, perhaps because of the lack of evolution education studies on macroevolution (Catley, 2006).
Philosophical viewpoints also contradict Darwin’s model of evolution by natural selection. These conceptions include a worldview that life has purpose and that evolution is goal-driven. Many students have a deterministic viewpoint that evolution is progressive (Alters & Nelson, 2002; Anderson, Fisher, & Norman, 2002), that changes are need-driven (Bishop & Anderson, 1990; Ferrari & Chi, 1998; Greene, 1990; Jensen & Finley, 1997; Moore, et al., 2002; Settlage, 1994) and that divine intervention is necessary to explain design (Alters & Nelson, 2002; Jensen & Finley, 1997).

As is the case with genetics education, word usage has also resulted in students’ alternative conceptions. Two words (other than “theory” which will be discussed under NOS) appear to be the most problematic for students – “fitness” and “adaptation.” Because of the familiarity with the slogan, “survival of the fittest,” students often equate fitness with strength, longevity, or intelligence, instead of reproductive capacity (Anderson, Fisher, & Norman, 2002; Bishop & Anderson, 1990; Westcott & Cunningham, 2005). In the same vein, students often mistake adaptation as an individual response to the environment rather than the effect of selection on a population (Andersson & Wallin, 2002; Bishop & Anderson 1990).

There is a comprehensive literature about student understanding of the nature of science, or NOS (see for example, AAAS, 1990, 1993, NAS, 1996, NRC, 2003, 2005). One of the common phrases heard about evolution is that “it is only a theory” (Alters & Nelson, 2002; Blackwell, et al., 2003; Moore, et al., 2002). This viewpoint trivializes the heart of the scientific process, which is the development of explanatory models for natural phenomena (Kliman & Johnson, 2005; NAS, 1996). This alternative conception confuses the meaning of hypothesis with theory and thus provides justification for discounting evolution (Alters & Nelson, 2002).
However, Darwin’s theory is a major construct of biology and has an enormous body of evidence to support it (Blackwell, Powell, & Dukes, 2003; Moore, et al., 2002).

The amount and breadth of the alternative conceptions discussed in the research studies varied with the age of the subjects, the pretest instrument, and even the location. However, in their study of nontraditional biology students in New York City, Nehm and Reilly (2007) uncovered some interesting “unanticipated” conceptions not found in other studies. These included survival of the fittest “species,” equating the word “fit” with “dominant,” genetic drift defined as gene flow between species, requirement of drastic climate change for evolution to occur, and heritable “compensation” of one trait for another one that is lost.

To a large extent, students are not achieving a deep understanding of the theory of natural selection, regardless of past course experience in both secondary and post-secondary classrooms, based on the pretest results of many research studies (Alters & Nelson, 2002). Even though students improved their understanding with interventions, based on posttest scores, in most cases course instruction was only moderately successful, with many students left without a working knowledge of natural selection (Bishop & Anderson, 2002; Brumby, 1984; Demastes, Good, Peebles, 1996; Greene, 1990; Jensen & Finley, 1996, 1997; Lawson & Thompson, 1988; Nehm & Reilly, 2007). Clearly recognizing students’ alternative conceptions and addressing conceptual change in the classroom is not enough.

Many studies are now assessing innovative strategies to cope with the robust nature of alternative conceptions. Since alternative conceptions, specifically Lamarckian ones, reflect historical viewpoints, one strategy is to incorporate those models to promote conceptual change (Jensen & Finley, 1997; Rudolph & Stewart, 1998). Other studies have focused on the cognitive
nature of alternative conceptions and used strategies to improve critical thinking (Lawson & Thompson, 1988; Moore, et al., 2002; Nickles, Nelson, & Beard, 1996), or help students how to learn “with” theories instead of just “about” them (Andersson & Wallin, 2002; Jimenez-Aleixandre, 1992), or how to “reinvent” Darwin’s theory (Geraedts & Boersma, 2006). Finally, strategies focusing on the social construction of knowledge using inquiry (Demastes, Settlage, & Good, 1995) or problem solving (Ferrari & Chi, 1998; Jensen & Finley, 1996), or on the affective component of learning (Demastes, Good, & Peebles, 1996) have also been employed.

Summary

CMI is a constructivist strategy that has been implemented successfully in secondary and post-secondary institutions. It fosters critical thinking and the social construction of knowledge in a relevant and motivating context. Though the method has been historically significant in medicine, law, and business, it has been used in science education only in the recent past. However, several studies have already shown that CMI has improved the learning environment in higher education.

Students encounter many unique obstacles in learning concepts about genes, biodiversity, and evolution. The literature base shows that these problems cannot be solved with traditional pedagogies. Research in science education has been able to inform the teaching of undergraduate science, and several innovative pedagogies have been implemented and assessed, with limited success.
Chapter Three

Methodology

The purpose of this study was to assess the impact of the case study method of instruction (CMI) on non-majors understanding of three topics: genes, biodiversity, and evolution. Secondly, the case study method of instruction (CMI) was employed to try to promote conceptual change in these topics. And thirdly, the effects of CMI on perceived learning gains and students’ attitudes about science were examined.

In this chapter, the population, research design, and participants will be described. This was a mixed-methods action research study that used a quasi-experimental design. The study was conducted in the researcher’s own classroom to study the effectiveness of CMI on student learning of genes, biodiversity, and evolution. Qualitative data were obtained from interviews and student comments on evaluations, and quantitative data were obtained from pre-posttest rubric scores, and two instruments.

Population and Setting

The population for this study consisted of introductory biology students (N = 64) enrolled in three sections of the same course (Biology 101, Topics in General Biology) during the spring of 2006 at a small, private university in the southeastern United States.

Taken with its co-requisite, Biology 102 (General Biology Laboratory), Biology 101 fulfills the general studies requirement for a laboratory science, and is also required for the elementary education major. It does not carry credit for the biology major or minor. Students select their courses and preregister in the previous semester online with the guidance of their
advisors, and choice of section focuses on schedule constraints, time of day, and to some unknown degree, on the appeal of the instructor. Students enrolled in Biology 101 are typically freshmen or sophomores, but some upperclassmen have taken this course either to obtain additional science courses for graduate school admission, or due to a delay in fulfilling general requirements.

Biology 101 and Biology 102 are typically taught by multiple instructors, with some instructors teaching sections of both courses. However, instructors teach different students in lab and lecture, with only a coincidental enrollment of students in their lab and lecture sections. Instructors of all sections of Biology 101 are expected to include biodiversity, genes, evolution, and human impacts on the biosphere as their main topics, as these are the topics of the lab activities in Biology 102.

The goals of the course, as described in the syllabus for this researcher/instructor’s sections, are: to improve biological literacy and student understanding of the process of science through the study of the nature of science, bioethics, biodiversity, genes, evolution, and human impacts on the biosphere. The syllabus described case studies as the pedagogical focus along with other student-centered, collaborative approaches. The case method of instruction was defined on the syllabus, which was given to the students on the first day of class:

This course will focus on the case study method of instruction. This is an inductive teaching technique that uses stories, narratives, scenarios, or articles to introduce biology content. The cases encourage students to raise questions that lead to acquiring knowledge of concepts, and an understanding of the relevance of the cases to everyday life. Also, the case study method helps students learn about the process of science and learn to work collaboratively. Cases will be used for homework, in class, and on exams.
Research Design and Participants

This was a quasi-experimental action research study conducted in three introductory biology sections of Biology 101 (n₁ = 20, n₂ = 15, and n₃ = 29). A quasi-experimental design was appropriate for this study because it was not possible to randomly assign students to a particular class section, so convenience samples were used (Gall, et al, 2003).

A pilot study conducted in the fall of 2006 in two Biology 101 classes was used to identify problems associated with using rubrics to assess student answers to the open-ended questions on the pretests and posttests, the administration of the instruments (SALG and SAI II), and to revise questions used in the student interviews, and the timing of the interviews.

The study participants were enrolled in three sections of Biology 101 taught by the same instructor/researcher. Of the 64 participants, there were 46 freshmen, 13 sophomores, 1 junior, and 4 seniors. The majors of the students were: undeclared – 23, communications – 14, business – 6, elementary education – 4, other education – 4, psychology – 3, exercise/sports science – 3, music – 2, history – 2, and 1 each from leisure/sports management, philosophy, and dance.

In each of the three sections, students were informed that they were enrolled in a course section that was part of a research study on the case study method of instruction. The instructor described the research study on the first day of class and distributed consent forms for the students to sign. Two students elected not to participate in the study but remained in the class, and four students eventually dropped the class for reasons unrelated to the study. All three classes received the same treatment in this study.
**Action Research**

Action research focuses on practical research questions dealing with an educator’s own students which may help improve educational practice and identify teaching and learning issues (Fraenkel & Wallen, 2003). Although less formal than other types of educational research, the validity of action research findings may be established through triangulation (Gall, et al, 2003; Mettetal, 2001).

Moreover, action research can break down the barriers between research and practice, thereby accelerating the process of effecting change (Hirsch, 2000). It is furthermore regarded as a powerful way to examine students’ alternative conceptions and improve instructional practices (Raubenheimer, 2004).

**Procedures**

Both qualitative and quantitative methods were employed in this study. The qualitative data, obtained from the interviews, provided the students’ perspective on what CMI is and their view of how CMI compares to familiar teaching strategies. Four recurrent themes were extracted from the interview transcripts that provided insight for interpretation of the quantitative data. The qualitative data collection process will be described before the quantitative data collection process associated with the research questions.

**Interviews**

Student volunteers were solicited in all three classes at the beginning of the semester. More than thirty students volunteered and the final interviewees were chosen at random, based on their availability on the interview dates. Twelve students were interviewed individually on
two separate occasions about their learning of science concepts with the case study method. The interviews were conducted after each course exam, so that students could discuss the case studies that related to that exam. An independent researcher conducted the interviews so that students were free to express their opinion about their experience with the case study method without concern for any negative effects on their course grade or standing. Pseudonyms were used for all interviewees to protect their confidentiality.

The interviews were audio taped and then transcribed. These transcripts were read carefully and coded for specific ideas about how CMI affected student learning of biology concepts. After several readings, these codes were used to formulate common themes about student experiences with CMI. Student quotations were then collected and organized according to these themes. The transcripts were read again to determine what every interviewee had expressed about the four themes. The correlation between themes and student comments for a subset of ten quotations was checked with another biology professor, and after an in-depth consultation, two similar themes were combined. After that modification was made, the interrater reliability score was 1.0 (100%). The interview questions are listed in Appendix A. The interview data were used in conjunction with the quantitative data in order to investigate the three research questions.

*Research question #1: Do students perceive an improvement in their learning gains with the Case Method of Instruction (CMI)?*

Student opinion about their learning from the case study method was examined with the Student Assessment of Learning Gains (SALG), an online survey available at http://www.wcer.wisc.edu/salgains/instructor/. This instrument allows instructors to tailor their
questions for the assessment of particular pedagogies. The SALG provides average scores and standard deviations for responses to each statement and requests that students include verbal explanations for their responses to each main question (Seymour, Wiese, Hunter, & Daffinrud, 2000). All student responses were reported anonymously. These data were used in conjunction with the interview data to determine students’ impression of CMI and how it helped them to learn concepts in biology.

The students completed the SALG evaluation during the last week of classes, right before the final exam. The instrument records the names of student who completed the survey but does not correlate student responses with their names. All 64 students completed the evaluation (a modest amount of bonus points toward the final grade was awarded for doing so).

Research question #2: Which alternative conceptions do students have about biodiversity, genes, and evolution and does the case method of instruction (CMI) promote accommodation of scientific concepts in those topics?

Genes, biodiversity, and evolution are broad topics based on Ernst Mayr’s big questions in biology (Mayr, 1997) typically covered in introductory biology classes. Students frequently have alternative conceptions that are resistant to change (Sundberg, 1997; Wandersee, Mintzes, & Novak, 1994) and these topics are no exception. Pretests and posttests have been useful in identifying these student alternative conceptions and conceptual change in introductory biology courses (Nazario, Burrowes, & Rodriguez, 2002).

Six (two for each topic) open-ended pretest/posttest questions were developed to uncover students’ alternative conceptions and to assess progress made in overturning these alternative conceptions with CMI as an intervention. These study questions were based on the big questions
of the course and the concepts students must understand to answer those big questions (Table 1, p. 53). These open-ended questions were used as a pretest on the first day of class, and were included as posttest questions in the appropriate hour exams later in the semester. The questions were researched, developed, and tested during a pilot study in the fall of 2005, in two introductory biology classes ($n_1 = 30$ and $n_2 = 63$). Two science education professors, two science education doctoral students, and three biology professors assessed the face validity of the pretest/posttest questions.

On the first day of class, the students completed the pretest designed to uncover their alternative conceptions on genes, biodiversity, and evolution. Students were encouraged to complete the pretest to the best of their knowledge at the time. These were given as posttest questions after instruction, in the hour exams. The first hour exam included the posttest questions for genes and the second exam included the posttest questions for biodiversity and evolution.

Changes in student answers on the posttests were used to assess student conceptual change, based on the models proposed by Demastes, et al. (1996) and Duit and Treagust (2003). When students were confused about an answer to a question, but had some knowledge of the concept, the conceptual change was identified as “weak knowledge restructuring.” When students had little knowledge about the concept required to answer the question on the pretest, but had acquired some knowledge to improve their posttest score, the conceptual change was identified as “incremental.” Conceptual change was identified as “wholesale” when an alternative conception was replaced with the scientific conception. Finally, when an alternative conception was replaced by a pivotal scientific one necessary for understanding other concepts,
the conceptual change was identified as “cascade.”

Pretest and posttest answers were scored with rubrics (Appendices B-G) developed and revised multiple times by the researcher/instructor because of the difficulty with matching rubric levels and student answers, and also based on feedback received from three members of the biology department at the university. A biology professor who often teaches Biology 101 at the same university, independently scored a subsample of ten students’ answers with the same rubrics, resulting in an interrater reliability of 0.90 (90%). Pretest and posttest scores were then compared for each participant by means of the Student’s paired t-test (Agresti & Finlay, 1997). Interview data were used in conjunction with data obtained from the rubrics to provide more information to answer this research question.

Pretest/Posttest Questions

Genes question #1: “If you could take a cheek cell and a sperm cell from the same person, how would the genetic information compare?”

This question was adapted from a study by Lewis, Leach, and Wood-Robinson (2000b) to determine South African students’ understanding of genetics at the end of their compulsory education. The study reported that students were confused and uncertain about the topic and did not formulate many alternative conceptions with regard to genetics because they demonstrated very limited knowledge. In contrast, in the pilot study from this research a variety of student misconceptions were revealed that could be addressed with case studies, including those pertaining to the difference between a somatic cell and sex cell, haploid versus diploid cells, a comparison of the processes of meiosis and mitosis, differentiation, and gene expression.

Genes question #2: “Today bacteria are used to produce human insulin for diabetic patients. Explain how this is accomplished.”
This is an original question used to elicit an understanding of biotechnology techniques. An excellent response includes student understanding of the universality of the genetic code, restriction enzyme techniques, and how genes function in both bacteria and humans. Alternative conceptions revealed in the pilot study include a misunderstanding of what is actually transferred from humans to bacteria, a failure to recognize that the bacterially produced insulin is identical to human insulin, and confusion about how the gene is actually moved.

Biodiversity question #1: “Before it became overwhelmed by agricultural and sewage runoff, the watershed of the Catskill Mountains provided New York City with water ranked among the best in the Nation by Consumer Reports. When the water fell below quality standards, the City investigated what it would cost to install an artificial filtration plant. The estimated price tag for this new facility was six to eight billion dollars. New York City decided instead to invest $660 million through an Environmental Bond Issue to purchase land and halt development in the watershed, to compensate property owners for development restrictions on their land, and to subsidize the improvement of septic system.” Explain the reasons behind their decision. (Ecological Society of America, 2000, p.2)

This water pollution question requires that students be able to analyze a scenario and evaluate it with a deep understanding of how ecosystems function. In the pilot study, the question yielded several alternative conceptions, including the ability of humans to easily mitigate ecosystem damage with technology, and a failure to recognize the role natural ecosystems play in the purification of water and the prevention of flooding and soil erosion.

Biodiversity question #2: An Asian clam (Corbula amurensis) was first sighted in San Francisco Bay in 1986. Scientists think that the clam may have hitched a ride from overseas in the millions of gallons of ballast water discharged by ships that visit the bay. When compared to the resident clams that the Asian clam replaced, the Asian clam is a greedy feeder that can filter much larger quantities of phytoplankton from the Bay’s water, and they are capable of living in more extreme conditions than the resident clams could. What effects do you think the clam has had on the natural biodiversity of San Francisco Bay?

This description of an invasive species (United States Geological Survey, 2005) elicited some alternative conceptions in the pilot study. These included the accidental introduction of an
exotic species including the physical displacement of other species, and contamination of the natural gene pool through hybridization.

Evolution question #1: “A farmer was working with dairy cattle at an agricultural experiment station. The population of flies in the barn where the cattle lived was so large that the animals’ health was affected. So the farmer sprayed the barn and the cattle with a solution of insecticide “A.” The insecticide killed nearly all of the flies. Sometime later, however, the number of flies was again large. The farmer sprayed again with the same insecticide. The result was similar to the first spraying. Most, but not all of the flies were killed. Again, within a short time the population of flies increased, and they were sprayed with the same insecticide. This sequence of events was repeated five times. It became apparent that insecticide “A” was less and less effective each time. Why did the insecticide become less effective?

This is a classic natural selection question from the National Academy of Sciences (1998, p. 75) that is used to demonstrate how populations are affected by a change in the environment. The example draws from Darwin’s explanation of natural selection due to variability. The change in the environment allows a subset of the population that is resistant to the insecticide to be more “fit” than flies that lack the genetic resistance. These become more common in the population because they survive and reproduce. Alternative conceptions uncovered by this question in the pilot study included the ability of individual flies to adapt in response to the new environment because of a “felt need,” the development of a insecticide tolerance (often referred to as an “immunity”) in the flies over time, and the resistance of the flies to be caused by the environment. These are typical student alternative conceptions about natural selection (Alters & Nelson, 2002; Anderson, Fisher, & Norman, 2002).

Evolution question #2: Guppies are small fish found in streams in Venezuela. Male guppies are brightly colored, with black, red, blue, and iridescent (reflective) spots. Males cannot be too brightly colored or they will be seen and consumed by predators, but if they are too plain, females will choose other males. Assuming ideal conditions with available food and space and no predators, what would happen over time if a male and a female guppy (of medium coloration) were placed in a large pond where none existed before? (Adapted from Anderson, Fisher, & Norman, 2002, p. 973).
This question is a variation of part of the Conceptual Inventory of Natural Selection (CINS) designed to examine alternative conceptions about evolution, particularly biotic potential, population variability, population stability, and limited resources (Anderson, et al., 2002). The alternative conceptions revealed by this question in the pilot study included ideas about a lack of diversity in the population, a change in female behavior in response to the absence of brightly colored males, and the “extinction” of certain colors that are selected against.

Case Studies used in this Investigation

To assess the effectiveness of CMI, it was necessary to carefully select case studies to address the alternative conceptions uncovered by the pretest questions. The intervention was the use of case studies to help students recognize and work through their alternative conceptions. The case studies used for each topic are explained below.

Genes Case Studies

The genes case studies that were used to focus on alternative conceptions elicited by the first question were Bringing Back Baby Jason: To Clone or Not to Clone (Hayes-Klosteridis, 2002) and Saving Superman (Rubin, 2003), a stem-cell research case. Both cases are from the National Center for Case Study Teaching in Science (NCCSTS) Case Study collection hosted by the University of Buffalo. The teaching notes for the cloning case specifically discuss how the case addresses alternative conceptions about mitosis and meiosis and inheritance. The stem cell case addresses alternative conceptions about gene expression and differentiation.

Torn at the Genes (Nelson, 2002), is a biotechnology case study also from the NCCSTS collection that addresses both scientific and ethical issues. By eavesdropping on a family
conversation about genetically modified foods, students learn about the divergent opinions about this controversial topic. At the heart of the issue, however, is the understanding of the genetic code, gene transfer, and gene expression.

Biodiversity Case Studies

The focus was on ecosystem services and invasive species in the biodiversity topic. The pilot study revealed that students hold unsophisticated economic or “personal freedom” views of ecosystem services, rather than perceiving humans as biological organisms that can both affect and be affected by the health of ecosystems. Often they described technology as a possible solution to a problem they were not familiar with or took for granted in the past. The case study addressing the concept of ecosystem services, Watch Your Step: Understanding the Impact of Your Personal Consumption on the Environment, (Camill, 2002), was selected from the NCCSTS collection. This case was not field-tested in the pilot study because the misconceptions about this subtopic emerged during the course of the semester. Student reaction to the story of “Biosphere II” prompted a search for a related case study that would address ecosystem services leading to the selection of “Watch Your Step.”

Two cases were used to address alternative conceptions about invasive species. Aliens Here and Abroad is a case study developed as a result of personal participation in the College Professors’ Fellowship at the National Tropical Botanical Garden (www.ntbg.org). The case compares the effects of an invasive plant species, Chinese privet, in both North Carolina and Hawaii. This case has been used for four years to address the role of the environment in the establishment of invasive species. Each student brought research to class on one of three topics: characteristics of alien species, information about the Chinese privet, and a description of the
Hawaiian ecosystem. These “fact sheets” were used in small groups to successively answer questions as the story of two students who recognize this familiar plant in an exotic location was progressively disclosed.

Table 1

Connections made between Questions, Embedded Concepts, and Case Studies.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Questions</th>
<th>Concepts</th>
<th>Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genes</td>
<td>• What makes cells different from each other?</td>
<td>differentiation, gene expression, stem cells, cloning, genetic code, protein synthesis</td>
<td>Saving Superman, Bringing Back Baby, Jason, Torn at the Genes</td>
</tr>
<tr>
<td></td>
<td>• Can cells ever be de-differentiated?</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Can genes be turned back on?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biodiversity</td>
<td>• How do organisms obtain energy and nutrients?</td>
<td>ecosystem services, food web, sustainability, food web, biodiversity threats</td>
<td>Watch Your Step, Cane Toads, Aliens Here &amp; Abroad</td>
</tr>
<tr>
<td></td>
<td>• How do ecosystems function?</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• What natural services do ecosystems provide?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evolution</td>
<td>• How does the genetic material of a population provide raw material for natural selection?</td>
<td>polygenic inheritance, population variation, natural selection, Darwin’s model, microevolution, selective pressure</td>
<td>Desiree’s Baby, Fatu &amp; Malaria, Why does evolution matter now?</td>
</tr>
<tr>
<td></td>
<td>• Why do certain traits become more common in an environment?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Cane Toads case study is based on excerpts from the video, Cane Toads: An Unnatural History (Miall & Lewis, 1987), which describes the introduction of the cane toad as a species introduced to eat the cane grub which was devastating the sugar cane in Queensland in the 1930s. Not only does the cane toad become a bigger pest than the cane grub, but also the
Australians have mixed reactions about its presence and eradication. This stranger than fiction video has proven to be an engaging and humorous introduction to an invasive species problem, which is then layered with proposed solutions to prevent toads’ spread across the Australian continent, including a 60 centimeter wall to contain their invasion (Young, 2003). A video clip produced by National Geographic is a useful source of current information about the status of the problem (available at http://video.nationalgeographic.com/video/player/animals/animals/amphibians-animals/frogs-and-toads/toad_cane.html).

Both of these cases address student alternative conceptions about invasive species, including their incorporation into the ecosystem, their presumed and disproven positive effects, their permanent negative effects on the ecosystem, and effects on natural selection. The observation of real scenarios provides context and relevance for the concepts.

Evolution Case Studies

The case, Why does evolution matter now? deals with the threat of antibiotic-resistant tuberculosis spreading to the United States from Siberia, as depicted in a segment from the television series Evolution (Public Broadcasting Service, 2001). Following the case discussion, “Darwin’s Explanatory Model” was presented to the class (Mayr, 1991) to describe the logic behind Darwin’s theory of natural selection as the mechanism for evolution. The “Model” was then applied to the case study. This approach addressed student alternative conceptions about biotic potential, inheritance of variability, and differential survival.

Fatu & Malaria (Public Broadcasting Service, 1993) describes the prevalence of sickle cell anemia in malaria-stricken areas of Africa, as an example of balanced polymorphism. Students learn that the sickle cell allele is common where malaria occurs because it gives
humans protection from malaria. The case study illustrated how the theory of natural selection applies to human populations.

*The Case of Desiree’s Baby* (Schneider, 2004) bridges the topics of genetics and evolution by using the example of human skin color. This polygenetic trait evolved in humans in response to the competing selective pressures of vitamin D production, which requires sunlight, and the health effects of folic acid destruction due to overexposure to ultraviolet radiation. This case study illustrates that natural selection can be more complex when traits are governed by several genes.

*Research question #3: Does the case method of instruction (CMI) enhance student attitudes toward science and learning about science?*

On that first day of class, the students were also asked to complete the Scientific Attitude Inventory, in its revised form, known as the SAI II (Moore & Foy, 1997). The SAI II was given again during the last week of class before the final exam to detect any changes in attitudes toward science that may have occurred over the course of the semester.

Science educators commonly accept the fact that student attitude is important to student learning and that gender, quality of teaching, motivation, and engagement influence attitude (Osborne, 2003). Moreover, the National Assessments of Educational Progress (NAEP) include attitude toward science among their assessments, and have documented a decline in attitude toward science in higher grades (Piburn, 1993).

The Scientific Attitude Survey (SAI II), a revised edition of the SAI (Moore & Foy, 1997) was used to assess student attitudes about science in the research study. The 40-item SAI II, a shorter form of the original 60-item SAI, measures student attitudes about science with a
five-response Likert scale. It was revised primarily to eliminate gender-bias and improve its readability, thereby making it more useful for researchers. Construct validity was demonstrated with the SAI and thus applies to the SAI II, since the items were not changed. Moore and Foy (1997) also claim the SAI II retains the face validity of the SAI established by a panel of judges that included 4 science educators, 4 practicing scientists, and 2 liberal arts science professors. The SAI was field tested with three classes of 10th grade biology students and the SAI II was field-tested with 557 students in 6th, 9th, and 12th grades in the same school district. The SAI II field test indicated that the instrument can distinguish between students with more positive attitudes (top 27%) from those with less positive attitudes (bottom 27%) on each of its five subscales, with a significant t test in each case at the .05 level of significance. The Spearman-Brown correction for split-half reliability yielded a coefficient of .805. Cronbach’s alpha was 0.781 (Moore & Foy, 1997).

Since the research shows that learning is affected by student attitudes, if an innovative pedagogy can affect attitude, it may enhance student learning. The Scientific Attitude Inventory II (SAI II) was used to assess attitude change at the end of the semester. Student changes in attitude were measured by comparing the pre and posttest range of scores, the change in mean scores, and their standard deviations. The SAI II survey questions are listed in Appendix H.

Interview data were used in conjunction with data obtained from the rubrics to provide more information to answer this research question.
Table 2

Time Table for Research Study Tasks

<table>
<thead>
<tr>
<th>Week</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Take pretest for genes, biodiversity, &amp; evolution questions</td>
</tr>
<tr>
<td></td>
<td>Take SAI II in class</td>
</tr>
<tr>
<td>1-3</td>
<td>Nature of science unit</td>
</tr>
<tr>
<td>3-6</td>
<td>Genes unit</td>
</tr>
<tr>
<td>6</td>
<td>Take exam on nature of science and genes topics (posttest questions for genes)</td>
</tr>
<tr>
<td>7</td>
<td>First set of interviews</td>
</tr>
<tr>
<td>7-10</td>
<td>Evolution unit</td>
</tr>
<tr>
<td>10-13</td>
<td>Biodiversity unit</td>
</tr>
<tr>
<td>13</td>
<td>Take exam on evolution and biodiversity topics (posttest questions for evolution &amp; biodiversity)</td>
</tr>
<tr>
<td>14</td>
<td>Second set of interviews</td>
</tr>
<tr>
<td></td>
<td>Take SALG online</td>
</tr>
<tr>
<td>14-15</td>
<td>Human impacts on the biosphere unit</td>
</tr>
<tr>
<td></td>
<td>Take SAI II in class</td>
</tr>
<tr>
<td>15</td>
<td>Final exam</td>
</tr>
</tbody>
</table>

Summary

Table 2 indicates the time line for this study. The pretest for all three topics and the SAI II were given on the first day of class. The genes unit was taught right after the nature of science unit (not in this study), followed by the exam (with both a take-home and in-class portion) on the nature of science and genes topics. The first exam included the posttest question on genes. The first interviews were conducted after the exam, and then the biodiversity and evolution units were taught. The second interviews were conducted after the second exam (with both a take-
home and in-class portion) on biodiversity and evolution. The pretest questions were incorporated into the appropriate class exams. The SAI II was given again on the last day of class. Students completed the SALG online at their convenience during the last two weeks of the semester but prior to the final exam.

*IRB Approval*

This research study was approved by the Institutional Review Boards of the university at which the study was conducted (IRB#05-090) and North Carolina State University (IRB#174-05-9).
Chapter Four

Results

In this mixed-methods study, data were collected from both qualitative sources (the student interview transcripts and the SALG comments) and quantitative sources (pretest/posttest questions scored by rubrics, the SALG, the SAI II). Even though the student interviews focused primarily on research question #3, the interviews provided insight into all three of the research questions. Furthermore, the interviews also elucidated the students’ understanding of CMI, their personal impression of the teaching method, and their learning experiences with CMI. Therefore, the interview data that relate to student impressions and understanding of CMI will be described first, along with the major themes that emerged from the interview analysis. Then, the data obtained from each instrument will be described, organized by research question, along with the interview data that correlates with the findings for each instrument.

Interviews

Student Understanding of CMI

The first interview was conducted after the midterm exam, which covered the nature of science and genes/genetics topics. The second interview was conducted at the end of the semester before the final exam. All of the students (n = 12) described cases as stories, scenarios, situations, conversations, incidents, or examples, which can be fictional or drawn from real-life. In the quotes that follow, pseudonyms are used to protect student confidentiality.

The students used many interesting metaphors for CMI, such as comparing cases to “gossip” (Tammy, interview 2) to comparing CMI to learning from a “sermon” (Karen,
A typical description of CMI was offered by Katelynn in the first interview, who described CMI this way: “We read real life situations that are sometimes hypothetical – and sometimes not – that have ideas that we are learning mixed into them, and then [we] answer questions that help us to understand the topics…”

CMI was satisfactorily described by all of the interviewees. One student, Kendra, had a more limited view of case studies, which, in her opinion did not include videos. She stated in the second interview, “…Oh does that [video] count as a case study… I keep thinking case studies as…written on a piece of paper…” Her perception of cases may have caused her to overlook some of the case examples in her evaluation of the method. Her opinion was apparently isolated, however, as other replies to the interviewer’s question in the second set of interviews, “Is the case always written?” precipitated more inclusive answers, like Katelynn’s: “No, sometimes you can put it on a power point, it would be sort of like pictures and words… it’s oral, more so than written.” The most common word that students used to describe cases was “story” (n = 5), as Krystal explained in the second interview: “Cases are kind of like stories. Everyone likes stories. So I think if you can tell a story and use science with it, that’s good. It’s kind of like a moral, only a ‘science’ moral.”

Moreover, students typically grasped the inherently ill-structured nature of cases, aptly described by Mary:

You learn your facts from the case study; you use it as a reference – it doesn’t necessarily have all the information that you need – and it’s like a starting point…you would apply the information, like biology, facts to real life….

The students recognized that CMI was an inductive method, with the presentation of the case coming before the concepts, as Tammy described in her first interview:
...a case study is individual, specific, to just like a person or maybe a few people...it’s not a huge sample.... [You can easily] connect to that one story, that one person. ...I found that you can then take that information and understand it and then relate it to the larger population or the larger ‘whatever’ you are studying...

This approach varies considerably from the deductive teaching strategies that students may have had in their high school science classes, which typically front-loaded concepts, and then usually later, may have applied the concepts to examples, as expressed by Kendra in the second interview:

I am a lot more interested in it when it’s not as obvious... that I’ve been taught. Normally when I think of being taught I think of somebody standing at a white board and writing notes.... And it’s a lot more about memorization. Whereas [in] the case study ...I was able to apply my knowledge and I was able to... learn, that’s how I am able to take in details.

Students liked the case study method because the cases were often real and provided a context for learning. Since the cases provided content with context, most of the students viewed them as worthwhile and important, and as Mary stated in her second interview, enhanced their self-confidence, compared to other science classes:

I can be scientifically intelligent and be able to understand what’s going on even though sometimes, before I would ...resist the information and I couldn’t really do it in context. Now I have context and I feel like I can have an intelligent conversation about it...I really like it now, because I like having examples... and [I see] exactly how it’s relevant.

Not only were the cases seen as providing relevance, but some students described how the “real-life” aspect of cases helped them to learn concepts, as Kendra said: “I don’t think the case studies explain everything we need to know, but it opens a door for me to understand concepts [and] put them in [the] context of a real life situation.”

John explained CMI as an easier way for him to learn, in his second interview: “My brain takes things from real life better than it does from examples in the text.” But perhaps Krystal, in
In her second interview, Ann described the complexity of case studies as a positive aspect of CMI: “I really like the case studies because … you can see real world examples, and you can see the problem, and – sometimes you can see the solution…and the causes and the consequences of the problem.” John also expressed this appreciation for the complexity and underlying detail of cases after the midterm exam: “while the technical details weren’t there, the idea…gave you that broad perspective about how complex this issue is.” He went on to describe learning biology as more than a collection of facts,

You could go through a whole class with all the facts and not know anything, but the case study seems to broaden the perspective and really teach you biology… It definitely is a conceptual thing, definitely is an understanding thing. The case studies really do help. Because later that day you really do understand that, the different chunks of information…

He reiterated this viewpoint in the second interview at the end of the semester

You can’t be a part of a text book, but a case study – you can get in there, you can think about what they’re thinking about, see proof, see evidence…it’s tangible. It’s not an idea…actually someone has done this.

Comparison of CMI to Traditional Teaching Strategies

In general, the students described learning in lecture and from the textbook as tedious and uninteresting. Yet, they were skeptical that CMI would be different, or change their viewpoint about learning science. In the second interview, Katelynn stated:
In the beginning of the year I was more resistant to the idea of learning through case studies but now, [in] the second half of the year I felt like I was learning more from the case studies and was more accepting of that method. And, it’s kind of a less boring way to learn.

Most of the students (n = 8) referred to CMI classes as less tedious, more interesting, and more motivating compared to traditional classes. Moreover, they pointed out that CMI was more interactive and hands-on. Ann stated in her first interview: “…you’re just not sitting there reading a book… you’re actually doing something and participating.” Mark explained how his interest was piqued in one of the cases this way: “We…were the detectives, we were the scientists trying to figure out what was wrong with these people.” In his second interview, Mark described how CMI fits with his learning style:

…I learn by doing things, hands-on, and I visualize things better with examples. If you give me a concept and say – know that concept – it won’t really process very well, but if you say here’s an example of how this concept comes into play…and how it is related to biology, I can visualize it a lot better and I can understand it a lot better.

Katelynn described in her second interview how the interactive nature of case studies promoted student participation and attendance: “It’s more…hands on, it just keeps you in the game, it makes you want to actually go and be there and be present…” Ann expressed her preference for CMI in the second interview simply: “I really like the case studies because it gets you more involved.”

But did students actually perceive a difference in their learning with CMI? Could they connect the cases with the concepts in the course? Did they understand and retain concepts more easily with the case study method? Ann responded to the interviewer’s query “Are you a connections person?” this way in the second interview:
I think so. It helps me learn, especially in science. It helps me to get the bigger picture, because then you know how everything interlocks and works…It helps when you can see the big picture, when you can see how everything works and it just makes more sense that way.

Students were able to describe a clear difference between CMI and more traditional teaching methods. Mark explained it in the second interview:

I think people who flourish in lecture…like to memorize, to see something written on the board, copy it word for word down into their notes, go back and memorize it…but people who like case studies say…okay here’s the concept and now I am going to apply it to this and I think that’s the difference.

Even though Ann does not necessarily prefer the traditional approach, she admitted that it does help with assessment:

I probably would have fallen asleep [in a lecture class]…it’s really hard when you have someone just dictating to you and you just have to sit there and take notes. Notes are sometimes good for me especially when it comes to quiz time or you’re getting ready for your exams and you need to look back.

Even though most students spoke favorably about CMI, some described reasons for preferring traditional approaches to teaching. In his first interview, John expressed his preference for power point lectures this way: “…for something…like biology, …to have the black and white written out with the important information right there for you – it’s easier for me.”

Some students liked CMI but felt they were not able to let go of their preference for some of the traditional approaches that they believed have been successful for them. They recommended a sort of hybrid teaching method that would incorporate the best of both, as Laura described:

I think it was probably better if like even along with the case study if you…also give a piece of paper that told you what scientifically what is happening so you have both things so you can learn …what’s going on but you can relate it to the story. Rather than just learning it all from the story and not really know what it’s trying to say.
Perhaps the tentativeness of students’ opinions about CMI was related to their inexperience with the method. Jerry expressed his dislike for CMI in the first interview, but indicated a change of heart in the second one. He said, “I guess I didn’t really give it the attention it deserved until the first time of interviews and after we started talking about them I started looking more into it…so [I feel we should] just give new teaching methods a chance.”

Mary also described her experience with cases after using them more:

I could probably learn without it, you know here [are] the basic facts because that is what I’ve been used to, but I like having something different…it’s nice to have a reference first and then figure out all the things because when you hear the case study …and have a conversation about it you don’t really know all the elements that go into it…Now every time I read a case study I try to think about all of the different aspects instead of just like the obvious ones, so it’s kind of a nice way to know …the underlying things that contribute, and so, at first I didn’t really think it was relevant, but now I am seeing the connections…

**Interview Themes**

The student interviews were analyzed for recurrent themes that emerged as students discussed their experience with CMI and four major themes were extracted from the interviews. The interview transcripts were read and reread for key words and phrases that served to identify how the students’ learning was affected by CMI.

The four themes extracted from the interviews are:

1. *Case studies provide cues for information retrieval and help with knowledge retention.*
2. *Case studies enhance the social construction of knowledge.*
3. *Case studies promote student responsibility for construction of knowledge.*
4. *Case studies facilitate concept application and help students see the relevance of science in the real world.*

Interviewees were candid and thoughtful in their responses to the interviewer’s questions. The student quotes that led to the development of the four themes are described below.
1. *Case studies provide cues for information retrieval and help with knowledge retention.*

Most of the students (n = 8) described CMI as a productive and less difficult way to learn because the case studies served as a cue for remembering a concept that could be stored for long-term memory. Kendra mentioned this cuing aspect of CMI in both interviews; in the first one she stated:

> When I’m taking a test or something, I can think…that is a situation like the one I learned before and I can kind of apply it [the test question] to my knowledge [from the case]. It helps me remember it and it just seems more important. It was like just remembering notes or dates or something.

And, in the second interview, Kendra described how the “scenario” would cue her memory, when she said, “…where I learn from the case studies, I’m going to be able to remember [knowledge] because I’ll have a scenario to relate it back to.”

Some of the students explained that learning with case studies allowed them to lump together, or chunk, information that could be retrieved on tests, simply by thinking back to the pertinent case study. Mary referred to it this way in her first interview: “…I know that I have my notes, but since I have the case, I am able to remember the case and how to think through it and it will help me remember the facts themselves for the test…” In the second interview Ann said, “I find that the cases do trigger my memory more,” and Tammy referred to cases as “jogging my memory.” Even Martin, a student more skeptical about CMI, explained in his second interview that:

> …I usually just read the book but the case studies are good examples to refer to. I usually remember them, like see a question on a test and say well, that’s like this case study. It’s hard to pick it [the concept] out by itself, but…you remember exactly what it was that’s important about it.

Students acknowledged that the case studies not only served as cues for knowledge retrieval,
but also that it was specifically the *story nature* of the cases that made that knowledge retrieval possible. Tammy explained it this way in her second interview: “…when you said *Desiree’s Baby*, I knew exactly what you were talking about…It’s just like anything—it’s better when there’s a story.” Laura reiterated this idea in the second interview: “You can…remember a story… so I definitely think it helps me remember things for when it comes to tests…”

Moreover, students viewed the knowledge they gained from case studies as stored in their long-term memory. They acknowledged that they could learn without case studies and be able to pass the tests, but they thought they would retain the concepts longer from case studies. Martin spoke of this more lasting effect on his learning in the second interview:

> I remember more from the case studies, but initially, when it’s fresh in my mind on quizzes and tests that I probably [will] get the same grades and learn the same amount. But maybe in a couple of months I’ll remember the case studies.

And Mary described it this way in the second interview:

> I: Do you think if you [had] taken a class that wasn’t a case study class, would you have learned more science?  
> M: I think I would have learned more but it wouldn’t have stuck as well…It makes it stick in my head and I can compare and contrast different cases…  
> I: So … next year … you’ll remember those?  
> M: … not specific stuff, but the main idea.

2. **Case studies enhance the social construction of knowledge.**

The constructivist model of learning contends that students actively construct their own knowledge to make sense of their own experience. The social construction of knowledge, proposed by Vygotsky, claims that interaction with others plays a major role in students learning (Prince & Felder, 2007). In this study, peer interaction helped students to co-construct knowledge. It is generally accepted that students are able to learn effectively in small group
discussions. The variety of CMI employed in this study relied extensively on small group discussion as an integral part of the pedagogy, in order for students to construct knowledge, build self-confidence, and explore diverse opinions.

All of the students interviewed (n = 12) expressed a positive view of group work in CMI, for most of their experiences during the semester. Typically the students would be introduced to a case study (through a reading, video, or activity) and would work on a series of questions exploring the basis of the case study. These questions were assigned beforehand to ensure that students were familiar with the case study when they came to class and would be prepared to discuss the answers with their group. If all students were prepared to answer these questions, the small group discussions were considered to be successful, as John stated in the second interview: “I do find that group work is a good thing as long as everyone comes prepared,” and Karen said in the first interview: “…because we read the case studies before we come to class and have to answer questions about it, we already have a good idea of what to talk about with the group.”

Although some spoke negatively about unprepared students, they appreciated the group’s help when they themselves were unprepared for class, or unsure about the answers to the case study questions. Katelynn expressed her frustration about group work, however, even when all students in the group come prepared. In the first interview she referred to the ambiguity of both the case study questions and the expected product of the small group discussions:

…I find that I’m not really as good in groups as I thought…I have trouble when we have a disagreement about it [a case question]…I think I understood it this way when I read it, another person understood it this way when they read it, and we don’t really have a good way to figure it out…We just say, well I guess we’ll just go with this way… we’re not really sure if what we got out of the reading is what we were supposed to, or what it was actually saying, so it’s hard, but I guess it’s part of group learning trying to figure that out together…
Katelynn did indicate that the struggle was part of the learning process and by the second interview was more accepting of the ambiguity of CMI. However, she discussed both her annoyance at feeling held back by the group and her appreciation for the group’s help when she herself was struggling. She said in the second interview:

I think sometimes, I’m an overachiever, like when I’m in a group, I…feel held back from doing everything….Because I care more than other people care….But sometimes it’s nice …when I’m struggling with a concept or something that somebody else understood it better than I did.

Several students mentioned this double-edged viewpoint about the value of group work, but acknowledged that the various perspectives of group members greatly enhanced their learning. John said in his second interview: “I bring something to the group and someone else brings something to the group and you present …better ideas and more thorough answers….It’s always better to have more than one input.”

Many students discussed the effectiveness of peer teaching (n = 7) in their group work. Tammy (second interview) mentioned that her group “sometimes explain things to me I just can’t get from a teacher” and Laura (first interview) also preferred to “hear it from a peer who got it right…rather than just being talked at in lecture.” Ann pointed out (in her first interview) that her peers would describe concepts in “laymen’s terms,” making group work most successful for her. Mark (first interview) mentioned that if he didn’t know something, “someone else in the group does know it and we help each other…to better understand.”

Group work was also less intimidating for students than class discussion and gave some of them more confidence. Jerry said he liked group work in his first interview because it “takes a lot of pressure off you.” Mary (first interview) referred to the value of group work to prepare for class discussion this way:
I really like [group work], because a lot of times I’ll…read it and have a few ideas of my own but I’m really…unsure about it, and…we get all of our ideas together and I understand it better before we have…a full class discussion. That way I don’t make a fool out of myself in front of the teacher and so it’s nice to have just …my peers around…I really like having our small groups, and then doing the big group discussion.

Ann, in her first interview, emphasized that group discussions are “more intimate” and “more candid” than class discussions. In her second interview, she reiterated her positive opinion of small group discussions and further described how they provided reassurance, as well as created new ideas, and made the learning experience more enjoyable:

…we all put in our input. So that just helps you reaffirm what you know, or learn something new that someone else picked up…We would usually bring out different things in each other, like, “I never thought of that way,” taking the material and swapping it around just a little bit so we approach it from a new angle and that usually triggers something new as well…You can really learn from each other and say, “Oh, this isn’t so bad, I actually know this stuff, it’s kinda cool.”

Karen, Ann, John, and Mark (in their second interviews) all mentioned the positive experience of learning new ideas from others. Mark compared his group’s diverse viewpoints as analogous to onlookers’ reactions to a work of art:

It gives anybody who is working in the group the opportunity to hear different opinions or different viewpoints on the same thing…everyone loves it, like when everyone looks at a painting on the wall, everybody who looks at it would have a different view and it is interesting to see what other people’s viewpoints are…It does help my learning because they think of things that I wouldn’t have thought about…and they introduce things to me that I wouldn’t have seen by myself.

Students also pointed out that they learned more deeply with their group work in CMI. Krystal mentioned the benefit of discussing “everybody’s point of view” when it comes to controversial issues, like stem cells, in her group. But she thought group work was not necessary when students were learning the “basics of stem cells,” but only when “you are learning to apply that research on how to cure disease.” Kendra also mentioned (first interview) that group work
does not “just talk about science but we’ve also got the ethics to relate to and people have a lot of varying opinions.” Even though she preferred individual work at times, she went on to discuss the value of group work to deal with the complexity of CMI:

I like to be responsible for my own work, but…the case study method…opens up a lot more options and I don’t think there is just one right answer all the time. It’s not as black as white as other science classes I’ve taken, so I enjoy the group work a lot more.

3. Case studies promote student responsibility for construction of knowledge.

Although students were overwhelmingly in favor of CMI for learning biology (n = 11 for the first interview, n = 12 for the second interview) many suggested that a “hybrid” method, combining the benefits of both CMI and the traditional lecture method, would be the ideal method for them to learn (p. 64). For the most part they described the benefits of CMI to be increased interest and motivation, and a long-term retention of concepts, as stated earlier. They were frustrated, however, with the independent learning that many cases required. If lecture was added as needed, for “straight out facts” (John, first interview), with information given in class, they felt would make it easier for them to study for the tests. Some students claimed that they would be able to learn from lecture just as well (Laura, second interview) because biology is “black and white” and even though John said CMI “makes class less tedious, it doesn’t translate to tests as well” (first interview). In her second interview, Mary also expressed frustration that information was not presented in a lecture format for test preparation: “…sometimes I feel like [the instructor] doesn’t really give us our information and so when we’re studying for a test, we have to …go back and re-teach ourselves.”

Katelynn recognized this aspect of CMI when she stated in the first interview, “It’s more about discussion and less about lecturing…it feels like self-learning almost more than
instruction.” In her second interview she was more accepting of this perceived limitation of CMI as she explains, “…but now…I felt like I was learning more from the case studies and was more accepting of the method.”

Some students embraced the opportunity to construct their own knowledge. Ann appreciated that CMI required her to learn differently, even in the first interview, as she says:

You can actually come to your conclusion through research and …I think it would help you become a more intelligent person and a more intelligent thinker…Sometimes it’s hard because you’re trying to figure out … what am I trying to say,…what’s the best approach,…what kind of hypothesis should we make?

Mary (second interview) also recognized the value of CMI as a tool to improve her learning:

I learned that even though you have a case study, it’s just like a starting point or a reference. At first… we’d have to answer [questions] with the case study. I felt …all the answers should be inside the case but that wasn’t the case. So you…have to do your own research and your own … individual work to…get the information. That is also helpful…in finding those answers you find out…other things too. So it makes you more well-rounded.

4. Case studies facilitate concept application and help students see the relevance of science in real world.

Many students (n = 7) indicated that CMI allowed them to transfer and apply concepts from case studies to new questions or scenarios. In the second interview, Kendra stated that she was able to apply her knowledge by using case studies, and Mark described the application aspect of CMI compared to more traditional teaching strategies: “…people who like case studies see the concepts and say, okay here’s the concept and now I am going to apply it to this…”

Ann (first interview) saw this concept transfer as a valuable tool for non-major students who may not recognize the usefulness of undergraduate science courses:
…the questions students like to ask when they’re in a class, that they really don’t want to be in, or they’re just in it for the…grade or whatever, is … how to just apply [it] to life…and this…helps you learn how to think...

In the same interview, she went on to describe that usefulness beyond the classroom:

… I like to have something that is applicable and you can take what you’ve learned and do something with it… Not just have it retained in your head and just sit in there until the test or whatever.

Martin referred to the broader application of long-term retention of case study concepts by stating, “…I like the policy part of it and getting out of just how biology works within us but how it works in society too.”

Most of the students (n = 10) expressed negative views about traditional teaching of science that focuses on a textbook. They viewed CMI as a welcome relief to the formal presentation of science they experienced in their past courses, but were reluctant to forego the safety-net of lectures and the strategy of memorization to pass exams. They admitted that they did not retain many concepts from previous biology courses and did not see the relevance of biology in their lives. Kendra’s comments in the second interview represented what many of the students had to say about science from a non-major’s point of view:

With the lecture classes it’s a lot easier not to pay attention. It’s so dull. And especially with the subject of science. And the case study [method] may force a lot of the students to become involved in the class and actually involved in the homework. And it made the readings a lot more exciting and not as dreaded as reading from the textbook. And I think that just helps make people understand that there’s a huge world out there as far as biology, but we can understand some of these basic concepts and you don’t have to be into science to do it because not everything you read necessarily has to be scientific. In a lot of other lecture classes, people make it so you have to be on one level to understand… But I think the case study [method] allows for a lot of different people with a lot of different sort of traits and feelings about biology and work to function well.

Students were critical of trying to learn science with a textbook, even those who did not express negative views about science. They were disenchanted with science, which they thought
was an alien world, but they were resigned to fulfill the course requirement with the least pain necessary. John (first interview) stated it this way: “That’s why we’re there, especially in a non-majors course. It’s to learn the information, and take the test, and get the grades.” In the same interview he described CMI as learning for understanding, implying that this was not an expected outcome: “The case studies really do help. Because later that day you really do understand…”

As non-majors, the students felt that science classes should emphasize relevance and meaningfulness with less detail. Their positive response to CMI was due, at least in part, to the fact that the method addressed their concerns. Krystal expressed her disconnect with science in this way “…learning how DNA duplicates, like who cares? I mean, I’m a communications major so it doesn’t matter to me…”

Katelynn explained her disinterest in science in her first interview, as follows:

I like the way it [CMI] makes science seem like it actually matters (laughs) because I’m really not interested in biology…That is the part that I do like about case study. The part that I don’t like is that we do … the majority [as case studies] so when I go home to read my book which is … just giving me the facts … it’s hard to understand, because science is like a foreign language to me. So I really have trouble getting the details …but I get the big picture.

In his second interview, John also referred to his dislike of learning from textbooks and the positive effects of learning from case studies:

The case studies and real life examples definitely helped make it a more…something you can be a part of. You can’t be a part of a text book, but a case study you can get in there, you can think about what they’re thinking about, see proof, see evidence…it’s tangible. It’s not an idea, it’s actually someone has done this…It definitely helps the information become more presentable; it kind of dresses it up a little bit.

Many students thought that learning science would require them to learn facts that were not connected to their lives. This experience was regarded as formal, difficult, and painful. Any
pedagogy that provided relief from this burden was welcomed. Mary expressed this sentiment in her second interview:

I think it’s [CMI] made me a little more relaxed about [science]….before I’d be so stressed out cause it’s all this technical stuff and it’s like science, science, science, and I felt like it didn’t really have any relevance to me. But with the case studies I kind of see how I could fit into the cases and how it really does affect my life. So it’s…made me a little more…appreciative and…more aware of science in general. I can be scientifically intelligent and be able to understand what’s going on even though sometimes, before I would kind of resist the information and I couldn’t really do it in context. Now I have context and I feel like I can have an intelligent conversation about it.

In her first interview, Kendra stated bluntly that she “hated science” and “hated going into the science classes knowing it was just going to be lecture.” In her second interview she admits that with cases she felt she was “not as conscious” of her learning, as if the experience was not difficult enough to be a science class. She stated: “I feel like I’m listening to maybe a family story…that makes it a lot more interesting instead of straight-out facts.” Jerry, who was skeptical of CMI in his first interview spoke more positively about it in the second one: “…this is far more appropriate for…non-science majors…this relates more to everyday life and the case studies give examples like something you would read about on the Internet…”

The challenge of CMI was perhaps impressing upon the students that the course was still rigorous, and an accurate depiction of how science works. Kendra warned that this may have been the impression some students have about the method, to their detriment:

The only problem I think is that some people…don’t take it as seriously as real science because so many people consider science in the traditional sense…I definitely think this class is real science. It’s just a different approach. And I think that people are so expecting of the tradition approach that this might appear to be “science-light” for them. But, in the end, after taking the class, it definitely isn’t…once everybody got into it…then I think people realized that it isn’t just sort of a blow-off.
Quantitative Results

The interviews provided insight about the students’ views of their learning with CMI for a small subset of each class. However, all of the students in each of the 3 classes were invited to participate in the 3 assessments used to answer the three research questions. They contributed to the data collected with the pretest-posttest rubrics, the Student Assessment of Learning Gains (SALG), and the Science Attitude Inventory (SAI II). These instruments are discussed in the context of the three research questions as follows.

Research question #1:
Do students perceive an improvement in their learning gains with CMI?

All three classes (n = 66) completed the online instrument known as the Student Assessment of Learning Gains (SALG) provided by the University of Wisconsin (http://www.wcer.wisc.edu/salgains/instructor/). This instrument allows the instructor to alter the questions that assess particular teaching strategies and the students’ perceived effects on their learning. For this study, the SALG was modified to focus on the research questions (Appendix I). The questions that prompted student responses about their learning gains with CMI were Q1, Q3, and Q4.

The percent of positive class responses for Q1D and Q1E are shown in Table 3 (p. 79). These numbers are the sum of percent responses to questions that CMI in class activities, tests, or assignments was of “moderate help,” “much help,” or “very much help.” Each of these responses indicates some level of positive response to the question. The cumulative percents of these responses allows for more pertinent and descriptive comparisons between classes and between questions than the response means. (These response means for all questions and their
standard deviations are in Appendix J-1, J-2, and J-3.) According to Table 3, more than three-quarters of all classes indicated that case studies were at least “moderately” helpful for learning concepts, with similar percentages for help with learning from homework case study assignments. But the class responses varied 63% to 90% in their perceived learning gained from group work using case studies, and 67% to 82% on the effectiveness of case studies in exams. The overall percentage of those who felt that their learning was enhanced by case studies was highest for learning from the class discussions.

More than half of the students who completed the SALG chose to complete the open-ended section where they described the reasons for their responses to the main questions. However the instrument did not correlate students’ scores with their comments, nor did it correlate the comment with any sub-question of the main question. But, some of the students offered explanations for their ratings that shed light on the cumulative percentages of the class scores.

There were 42 comments for question Q1D (How much did use of case studies help you to learn concepts?) with 17 including some less than positive remarks about CMI. These criticisms described cases as “vague” and “not useful,” and 4 students mentioned that the correlation between cases and concepts was sometimes unclear. Two students said that they would have preferred to learn science from a textbook, but one said, “It’s [CMI] not as boring as a textbook.” Others thought that some cases were difficult, and that slackers sometimes stymied the group work. This opinion may account for the different class percentages on the group work item (Q1D.3). However, 10 of the 13 students who mentioned group work said that it was helpful, enjoyable, or that it helped them retain information. These opinions on group work align
with the interview analysis described in the previous section. In addition, seven students stated that case studies reflected the real world, were practical, or provided “tangible examples” that facilitated their learning. These statements support the ideas in interview theme 4.

Forty students provided comments for sub question Q1E (How much did reading case studies for homework and test questions with case studies help your learning?) They again expressed frustration that cases were “more difficult than simply discussing the exact science,” that the correlation of cases with concepts was sometimes unclear, and that some of the material was confusing. These remarks were often aimed at cases assigned for homework, which students subsequently analyzed in class during group work and class discussion. This frustration was unexpected because these cases were assigned as preparation for class and graded only for completion. One student described this frustration as a positive way to learn and apply knowledge on the exams:

Reading case studies for homework was helpful but it was frustrating at times as it was a new form of learning that I was not accustomed to. Test questions using case studies helped me to make concrete the concepts discussed in class. It forced me to have an understanding - not just memorize.

Eight students referred to the benefit of case studies in exam questions as a way to assess their knowledge, and three students mentioned the benefit of the real world context of case studies, similar to the remarks for question Q1D.
Table 3

Student Assessment of Learning Gains (SALG) Percent Results for Q1, Q3, and Q4*

<table>
<thead>
<tr>
<th>SALG #</th>
<th>Survey question</th>
<th>class 1</th>
<th>class 2</th>
<th>class 3</th>
<th>all classes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>*Q1: How much did each of the following aspects of the class help your learning?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1D.1</td>
<td>Use of case studies to learn concepts.</td>
<td>85</td>
<td>75</td>
<td>80</td>
<td>80.0</td>
</tr>
<tr>
<td>Q1D.2</td>
<td>Group work on case studies in class.</td>
<td>90</td>
<td>76</td>
<td>63</td>
<td>76.3</td>
</tr>
<tr>
<td>Q1D.3</td>
<td>Class discussion of case studies.</td>
<td>95</td>
<td>75</td>
<td>84</td>
<td>84.7</td>
</tr>
<tr>
<td>Q1E.1</td>
<td>Reading cases for homework and answering questions about them.</td>
<td>80</td>
<td>75</td>
<td>80</td>
<td>78.3</td>
</tr>
<tr>
<td>Q1E.2</td>
<td>Test questions using case studies.</td>
<td>75</td>
<td>82</td>
<td>67</td>
<td>78.0</td>
</tr>
<tr>
<td></td>
<td>*Q3: How much has this class added to your skills in each of the following?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q3.1</td>
<td>Critically reviewing case studies.</td>
<td>85</td>
<td>87</td>
<td>83</td>
<td>85.0</td>
</tr>
<tr>
<td>Q3.2</td>
<td>Writing a critical essay for the take-home exam.</td>
<td>75</td>
<td>74</td>
<td>80</td>
<td>76.3</td>
</tr>
<tr>
<td></td>
<td>*Q4: To what extent did you make gains as a result of what you did in this class?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q4.1</td>
<td>Understanding the main concepts.</td>
<td>95</td>
<td>81</td>
<td>86</td>
<td>87.3</td>
</tr>
<tr>
<td>Q4.2</td>
<td>Understanding the relationship between concepts.</td>
<td>95</td>
<td>88</td>
<td>80</td>
<td>87.7</td>
</tr>
<tr>
<td>Q4.3</td>
<td>Understanding relevance of these concepts to real world issues.</td>
<td>95</td>
<td>87</td>
<td>96</td>
<td>92.7</td>
</tr>
<tr>
<td>Q4.4</td>
<td>Ability to think through a case &amp; analyze it.</td>
<td>80</td>
<td>100</td>
<td>97</td>
<td>92.3</td>
</tr>
<tr>
<td>Q4.5</td>
<td>Feeling comfortable with complex ideas.</td>
<td>74</td>
<td>87</td>
<td>83</td>
<td>81.3</td>
</tr>
<tr>
<td>Q4.6</td>
<td>Enthusiasm for biology.</td>
<td>55</td>
<td>75</td>
<td>63</td>
<td>64.3</td>
</tr>
</tbody>
</table>

*Student perception of case studies’ helpfulness in learning, as the cumulative percent of students in each class and all classes that felt the item was *moderate* (for Q3 & Q4, the response was *somewhat*) to *very much help* (for Q3 & Q4, the response was *a great deal*). \(n_1 = 20, n_2 = 16, n_3 = 30\)
The percent of class responses for Q3.1 and Q3.2 (How much did critically reviewing case studies and writing critical essays on take home exams add to your skills?) are also shown in Table 3. As stated previously, the cumulative percents of the positive responses allows for more pertinent and descriptive comparisons between classes and between questions than the response means. These numbers are the sum of responses to questions that the class “somewhat” added, added “a lot,” or added “a great deal” to students’ skills in critically reviewing case studies, or writing a critical essay for the take-home exam. Eight-five per cent of all the students felt that they had at least “somewhat” learned to critically review a case study in the class and 76.3% made progress in writing critical essays (open-book test questions), using new case studies correlated with concepts from class case studies. Thirty-six students provided mostly positive comments with their responses for question Q3. Negative comments referred to the ambiguity of the take-home exam questions and the lack of clarity provided for expected outcomes. Many students stated that practice improved their skills but they still believed that the take-home essays were difficult. As one student said,

With all that we've learned this year, I am confident that I could evaluate a current case study if I was reading the newspaper or watching TV. The take-home exams were very helpful in developing my ability to write concise critical essays although it was difficult at times when the cases were a little unclear…

Finally, Table 3 also shows the percent of class responses for Q4. These are the sum of responses to questions about the extent of gains made in understanding concepts, comfort with complex ideas, and enthusiasm for biology, as a result of what students did in the class (“somewhat” made gains, made “a lot” of gains, or made “a great deal” of gains). Again, the cumulative percents of these positive responses provide more descriptive comparisons between
classes and between questions than the response means. Students for the most part felt that they made gains in understanding concepts and the relationship between them. The highest scores were obtained for student understanding of concepts in real-world issues and for their confidence in their ability to analyze a case study, as shown in some of the previous questions. However, they did not show as many gains in feeling comfortable with complex ideas or their enthusiasm for biology. Thirty-five students posted comments for Q4. As one student said, “Biology isn't a strong subject for me, the class was hard….I was pushed to think outside of the box and apply these concepts to everyday life.”

Research Question #2: Which alternative conceptions do students have about biodiversity, genes, and evolution and does CMI promote accommodation of scientific concepts in those topics?

Student prior knowledge of genes, biodiversity, and evolution was assessed by open-ended pretest questions scored with original rubrics. The students then used specific case studies to explore the scientific concepts embedded in the questions. Student knowledge was then assessed with the same question set used as a posttest, and these were scored with the same rubrics. Raw scores for all of the questions are in Appendix K. In addition to the rubric data for each topic, students answered questions about the concepts and case studies on the SALG, and made comments in the interviews that provided insight about their learning experience.

Genes: Alternative Conceptions and Learning of Scientific Concepts

The first pretest-posttest question for this topic was:

If you could take a cheek cell and a sperm cell from the same person, how would the genetic information compare?
The most common alternative conceptions that students had about the first question on the pretest are listed as the zero level of the rubric developed to score their responses (Appendix B). These included such misunderstandings as: different genetic information is found in different cells, a cell’s function is indicative of its DNA, confusion of genetic material with the genetic code, and a lack of understanding of the difference between haploid and diploid cells.

To answer the first question, students had to know what DNA and chromosomes are, the differences between mitosis and meiosis, and they had to understand gene expression and differentiation. These concepts are the subject of several cases and class activities, which are intended to help students build a cumulative understanding. In this study, two cases were used to integrate these concepts and check for student understanding, *Bringing Back Baby Jason: To Clone or Not to Clone* (Hayes-Klosteridis, 2002), and *Saving Superman* (Rubin, 2003), a stem cell research case. For both cases, students needed to understand the concepts listed above in order to discuss the problem in the cases.

The frequency distribution of the student scores on the first rubric reflect the difficulty of this question (Figure 1). Only a handful (n = 10) of all the students (n = 64), actually scored above zero on the pretest for this question. Even on the posttest, a large number of students (n = 25) scored zero on the rubric. (The frequency distribution data for all classes are in Appendix L).

However, for the Student’s paired 𝑡-Test, the difference means for each class were significant, indicating an improvement in student learning (𝑝 < .05). Moreover, the class median score for this question improved by two points for the combined classes (Table 4).
Figure 1. Frequency distribution of genetic material rubric scores (using a level of 0 for no understanding of the concept, to 4 for the highest level of understanding of the concept) for all classes.

Table 4

Pre-Posttest Mean and Median Scores for Genes Question # 1, Genetic Material

<table>
<thead>
<tr>
<th>Class</th>
<th>Pretest Mean (SD)</th>
<th>Posttest Mean (SD)</th>
<th>t</th>
<th>p</th>
<th>Pretest Median</th>
<th>Posttest Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 1</td>
<td>0.50 (1.100)</td>
<td>1.65 (1.66)</td>
<td>3.22</td>
<td>0.005</td>
<td>0</td>
<td>1.5</td>
</tr>
<tr>
<td>Class 2</td>
<td>0.00 (0.000)</td>
<td>1.53 (1.51)</td>
<td>3.94</td>
<td>0.001</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Class 3</td>
<td>0.28 (0.649)</td>
<td>1.86 (1.48)</td>
<td>5.15</td>
<td>0.000</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>All classes</td>
<td>0.28 (0.766)</td>
<td>1.72 (1.53)</td>
<td>7.22</td>
<td>0.000</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

n_1 = 20, n_2 = 15, n_3 = 29

The second pretest-posttest question for this topic was:

*Today, bacteria are used to produce human insulin for diabetic patients. Explain how this is accomplished.*
The typical alternative conceptions that students had about biotechnology mostly focused on a misunderstanding of how bacteria are used in biotechnology. These are listed as the zero level of the biotechnology rubric (Appendix C). To answer this question, students needed an understanding of protein synthesis and recombinant DNA, in addition to the concepts necessary to answer the first question. The case study used to help students integrate these concepts was *Torn at the Genes* (Nelson, 2002), which focuses on a family’s dinner table conversation about genetically modified organisms.

Figure 2 shows the frequency distribution of all student scores for the second rubric. Students showed comparable knowledge on this pretest compared to the other genes question with all but one pretest score a zero. That number rose to 14 on the posttest. Although 24 students scored a zero on the posttest, 53 had scored zero on the pretest.

The difference mean for the biotechnology question for the average of all classes was higher for the biotechnology question compared to the genetic material question, although class 2 actually did the poorest on the second question (Table 5). For each class, the difference means for the biotechnology question for each class were significant, indicating an improvement in student learning ($p < .05$).

The responses to the SALG questions on the genes topic questions are shown in Table 6. These percentages indicate that the students struggled with the concepts, especially in class 1 (n = 20). Only slightly more than half of those students (55%) felt that class work helped them understand the difference between mitosis and meiosis, although the percentages for the other classes were higher (82% and 70%). The students reported more confidence in their understanding of the genetic code (90.3%), the importance of DNA (95%), and even ideas about
cloning from *Bringing Back Baby Jason* (86.3%). They were less confident about learning about stem cells (70%) and the genetic code (65.7%) from case studies.

*Figure 2.* Frequency distribution of biotechnology rubric scores (using a level of 0 for no understanding of the concept, to a level of 4 for the highest level of understanding of the concept) for all classes.

<table>
<thead>
<tr>
<th></th>
<th>pretest mean (SD)</th>
<th>posttest mean (SD)</th>
<th>t</th>
<th>p</th>
<th>pretest median</th>
<th>posttest median</th>
</tr>
</thead>
<tbody>
<tr>
<td>class 1</td>
<td>0.15 (0.671)</td>
<td>1.95 (1.82)</td>
<td>4.56</td>
<td>0.000</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>class 2</td>
<td>0.07 (0.258)</td>
<td>1.40 (1.59)</td>
<td>3.08</td>
<td>0.008</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>class 3</td>
<td>0.48 (0.871)</td>
<td>2.07 (1.53)</td>
<td>5.69</td>
<td>0.000</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>all classes</td>
<td>0.28 (0.723)</td>
<td>1.88 (1.64)</td>
<td>7.92</td>
<td>0.000</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

n₁ = 20, n₂ = 15, n₃ = 29
One student mentioned the importance of this topic in his SALG responses: “I think I will certainly carry with me the aspects of the class that were very controversial and…human-related, as discussions about stem cell research, etc., are bound to arise in my upcoming years.”

Although the genetic material concepts were not new to the students, as most acknowledged in class discussions, students did admit that this information does not stick with them, as Krystal stated in the first interview:

Yeah, some of the stuff, especially with the DNA unit…it’s just the material is more dense, so to put it in a narrative to study a case when you don’t exactly have the basic concepts down yet is difficult because of the dense material.

Two students also described this viewpoint in the SALG comments for Q2 (As a result of your work in this class, how well do you now understand each of the following: mitosis, meiosis, body cells, gametes, DNA, genetic code, etc.). They posted, “I have trouble understanding the DNA and the material that relates to it,” and “I had a hard time with genetics and DNA theories.”

For some students, the case studies were helpful for understanding concepts in context. In the first interview Mary referred to the “Saving Superman” case this way:

I understood what the case was about but I didn’t know the details so when I went through here I was like putting the story together and the information was right in there and it made a lot more sense, but if I read this on its own without the case I would have been a little overwhelmed with all the information so…

The implications of this case were subtle, but the story may serve as a cue for the more technical information as Kendra stated,

I think there was a case…“Torn at the Genes”…about genetically modified plants and different perspectives on it as in families talking at a dinner table, basically having an argument about it. And I can definitely relate to that. And it made it a lot more interesting and easy to remember. And I can apply it to my situation with my family so I would say that case specifically was the most helpful in teaching me about some aspect about genetics.
Table 6
Student Assessment of Learning Gains (SALG) Percent Responses (%) for Genes Questions*

<table>
<thead>
<tr>
<th>SALG #</th>
<th>Survey question</th>
<th>class 1</th>
<th>class 2</th>
<th>class 3</th>
<th>all classes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Q2: As a result of your work in this class, how well do you think that you now understand each of the following?</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2.3</td>
<td>The difference between mitosis and meiosis.</td>
<td>55</td>
<td>82</td>
<td>70</td>
<td>69.0</td>
</tr>
<tr>
<td>Q2.4</td>
<td>The difference between a body cell and a gamete.</td>
<td>75</td>
<td>75</td>
<td>90</td>
<td>80.0</td>
</tr>
<tr>
<td>Q2.5</td>
<td>How to do basic genetics problems.</td>
<td>100</td>
<td>88</td>
<td>86</td>
<td>91.3</td>
</tr>
<tr>
<td>Q2.6</td>
<td>The importance of DNA to life processes.</td>
<td>95</td>
<td>100</td>
<td>90</td>
<td>95.0</td>
</tr>
<tr>
<td>Q2.7</td>
<td>The importance of the genetic code in biotechnology.</td>
<td>90</td>
<td>94</td>
<td>87</td>
<td>90.3</td>
</tr>
<tr>
<td></td>
<td><strong>Q5: How much of the following will you remember and carry with you into other classes or aspects of your life?</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q5.1</td>
<td>Concepts about stem cells from the case study, “Saving Superman.”</td>
<td>65</td>
<td>81</td>
<td>64</td>
<td>70.0</td>
</tr>
<tr>
<td>Q5.2</td>
<td>Ideas about cloning from the case study, “Bringing Back Baby Jason.”</td>
<td>85</td>
<td>81</td>
<td>93</td>
<td>86.3</td>
</tr>
<tr>
<td>Q5.3</td>
<td>The universality of the genetic code from “Torn at the Genes.”</td>
<td>75</td>
<td>75</td>
<td>47</td>
<td>65.7</td>
</tr>
</tbody>
</table>

*Students’ perceptions of learning, expressed as the cumulative percent of students in each class that felt class work was somewhat helpful to a great deal of help. (n₁ = 20, n₂ = 16, n₃ = 30)

Biodiversity: Alternative Conceptions and Learning of Scientific Concepts

The pretest-posttest questions for this topic were based on two scenarios. The first was a question about ecosystem services, using the example of New York City’s decision to protect its watershed using a filtration plant to provide clean water. The goal of this question was student understanding of the importance and complexity of ecosystem services, and their importance for the health of humans and the environment. The case study, *Watch Your Step: Understanding the Impact of Your Personal Consumption on the Environment* (Camill, 2002) was designed to show
students how many resources they consumed over a 2-week period and how much land would be necessary to provide those resources.

Students demonstrated few alternative conceptions about ecosystem services on the pretest but they had a limited view about what services ecosystems actually do provide (Appendix D). In addition to the economic benefit of this decision, many students had an intuitive understanding that construction causes pollution and that an ample freshwater supply would encourage population growth (rubric, level 2). However, after the intervention of the case study, *Watch Your Step*, students broadened their viewpoint about ecosystem services (Figure 3) and viewed preservation of the environment to be worthwhile. However, most students were not able to correlate the hectares calculated to sustain their lifestyle in the footprint project with the natural benefits provided by that amount of land. Most did reach the third level on the rubric:

*Figure 3.* Frequency distribution of ecosystem services rubric scores (with a level of 0 for no understanding of the concept, to a level of 4 for the highest level of understanding of the concept) for all classes.
that ecosystems provide benefits that are not valued in economic terms. Only 15 students in all three classes (n = 64) reached level 4 on the rubric, the level that addresses the natural filtering capability of natural ecosystems.

Nevertheless, the Student’s paired $t$-Test showed that the difference means for each class were significant, indicating an improvement in student learning ($p < .05$). Moreover, the class median score for this question improved by two points for the combined classes (Table 7).

Table 7

Pre-posttest Mean and Median Scores for Biodiversity Question #1, Ecosystem Services

<table>
<thead>
<tr>
<th></th>
<th>pretest mean (SD)</th>
<th>posttest mean (SD)</th>
<th>$t$</th>
<th>$P$</th>
<th>pretest median</th>
<th>posttest median</th>
</tr>
</thead>
<tbody>
<tr>
<td>class 1</td>
<td>1.40 (1.190)</td>
<td>2.85 (0.875)</td>
<td>7.31</td>
<td>0.000</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>class 2</td>
<td>1.33 (0.617)</td>
<td>3.00 (0.845)</td>
<td>6.17</td>
<td>0.000</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>class 3</td>
<td>1.76 (0.786)</td>
<td>2.79 (0.774)</td>
<td>6.77</td>
<td>0.000</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>all classes</td>
<td>1.55 (0.907)</td>
<td>2.86 (0.814)</td>
<td>11.40</td>
<td>0.000</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

$n_1 = 20$, $n_2 = 15$, $n_3 = 29$

The second biodiversity question described the invasion of the Asian clam species in San Francisco Bay and asked students to speculate on the effect the clam would have on the Bay’s biodiversity. Students had several alternative conceptions about invasive species, including the ecosystem’s return to stability with the Asian clam, an increase in biodiversity due to hybridization with native clams, and the possible extinction of either the native clams or the phytoplankton. Students also included some alternative conceptions about evolution in their answers to this question, as evolution was also included in the same posttest (Appendix E).

This second question explored concepts students heard about from two invasive species cases: *Aliens Here and Abroad* (an original case study), which focused on the privet invasion in
North Carolina and Hawaii, and *The Cane Toad, an Unnatural History* (Miall & Lewis, 1987), which focused on the disastrous effects of the cane toad introduction in Australia to solve the cane grub problem. These two cases focused on the threat of invasive species on the native biodiversity of an ecosystem.

![Frequency distribution of invasive species rubric scores](image)

*Figure 4.* Frequency distribution of invasive species rubric scores (using a level of 0 for no understanding of the concept, to level of 4 for the highest level of understanding of the concept) for all classes.

The students did have some knowledge of the effects of invasive species on biodiversity at the beginning of the course. With a pretest median score of 2, students scored the highest on this pretest question \((n = 44)\) at level 2, but 12 students scored at level zero. However, only 8 students reached level 4 on the posttest (Figure 4).

The Student’s paired *t*-Test showed that the difference means for each class were significant, indicating an improvement in student learning \((p < .05)\). Moreover, the class median
score (Table 8) for this question improved by one point for each class as well as for the combined classes.

At the conclusion of the topic, most students understood how human development threatens ecosystem biodiversity. Mary referred to New York City’s vote against the filtration plant in her interview, “It’s a good idea that they stopped development, but they also have to be careful when they’re putting in the filtration plant not to ruin any more biodiversity and disrupt things.”

Table 8
Pre-posttest Mean and Median Scores for the Biodiversity Question #2, Invasive Species

<table>
<thead>
<tr>
<th></th>
<th>pretest mean (SD)</th>
<th>posttest mean (SD)</th>
<th>t</th>
<th>p</th>
<th>pretest median</th>
<th>posttest median</th>
</tr>
</thead>
<tbody>
<tr>
<td>class 1</td>
<td>1.75 (0.851)</td>
<td>2.70 (0.865)</td>
<td>4.25</td>
<td>0.000</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>class 2</td>
<td>1.47 (1.130)</td>
<td>3.00 (0.655)</td>
<td>4.77</td>
<td>0.000</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>class 3</td>
<td>1.83 (0.928)</td>
<td>2.83 (0.658)</td>
<td>5.20</td>
<td>0.000</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>all classes</td>
<td>1.72 (0.951)</td>
<td>2.83 (0.725)</td>
<td>8.18</td>
<td>0.000</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

n₁ = 20, n₂ = 15, n₃ = 29

Students understood their personal impact on the environment, evidenced by some of the SALG comments, as one student stated, “it made me realize how much I am affecting the environment.” and another, who said, “[It was] interesting and informative because it allowed you to see how much of an impact you make on the world.” Kendra explained her answer on the posttest this way in her interview:

What happened is that [with] natural surroundings, you could really see how much biodiversity flourished….when you get human involvement, human-like development in some cases, …biodiversity is just essentially…slaughtered. …we started out [with] such a balanced earth system. And then with humans coming in, trying to make everything so much better and more efficient for them, [we] kind of ruined the whole cycle or system of balances.
Katelynn was able to make the connection between the footprint project and the efforts to protect the New York City watershed:

I guess it [NYC watershed scenario] ties to the footprint because they’re trying to decrease their footprint by fixing something that is using more resources. But then putting in the treatment center would take up a lot of energy, which would increase the footprint…

In the SALG survey (Table 9), students indicated that they understood threats to biodiversity (97.3% for all classes), but responses were mixed for the questions referring to the footprint project. Only 53% of class 3 felt that the footprint project helped their learning, yet that class had the highest number (84%) who believed that they would carry ideas about the impact of their lifestyle into other classes or aspects of their lives. Some of their comments indicated that the case was “interesting and informative,” “caught my attention,” and that because of it they indicated they “planned to be more careful with the way I use my resources….” As for the second biodiversity question, the cane toad case study was by far the most popular case study of the semester due to its humorous portrayal of an alien species problem. In fact, 80.7% of the students responded that they would carry information from the cane toad case into other aspects of their lives (Table 9).

In her interview, however, Krystal referred to the key point she had gleaned from the case:

It’s more of a battle than we think. A lot of the times we think, “let’s save the animals” but it’s usually focused on one species. But we need the entire food web…more than one species in an area to actually maintain that environment….You need the plants species, you need the animal species, the little insects, and the microscopic species. They are so all interdependent. It shows how fragile it is, especially with the cane toads. Because they brought one organism, they brought…14 frogs over and it…nearly ruined the entire ecosystem.
Table 9
Student Assessment of Learning Gains (SALG) Percent Responses to Biodiversity Questions*

<table>
<thead>
<tr>
<th>SALG #</th>
<th>Survey question</th>
<th>class 1</th>
<th>class 2</th>
<th>class 3</th>
<th>all classes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>*Q1E: How much did each of the following aspects of the class help your learning?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1E.3</td>
<td>The case study project on your ecological footprint.</td>
<td>80</td>
<td>73</td>
<td>53</td>
<td>68.7</td>
</tr>
<tr>
<td></td>
<td>*Q2: As a result of your work in this class, how well do you think that you now understand each of the following?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2.9</td>
<td>Threats to biodiversity.</td>
<td>95</td>
<td>100</td>
<td>97</td>
<td>97.3</td>
</tr>
<tr>
<td></td>
<td>*Q5: How much will you remember or carry with you into other classes or aspects of your life?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q5.4</td>
<td>The impact of my lifestyle on the environment from the case study “Watch your Step: Understanding the Impact of your Personal Consumption on the Environment.”</td>
<td>75</td>
<td>62</td>
<td>84</td>
<td>73.7</td>
</tr>
<tr>
<td>Q5.5</td>
<td>The characteristics and effects of invasive species from the case studies, “Aliens Here and Abroad” and “Cane Toads.”</td>
<td>80</td>
<td>75</td>
<td>87</td>
<td>80.7</td>
</tr>
</tbody>
</table>

*Student perception of case studies’ helpfulness, as the cumulative percent of students in each class and all classes that felt the item was moderate (for Q2 & Q5, the response was somewhat) to very much help (for Q2 & Q5, the response was a great deal). (n₃ = 20, n₂ = 16, n¹ = 30)

Evolution: Alternative Conceptions and Learning of Scientific Concepts

The first evolution question was on natural selection, and used the example of pesticide resistance in barn flies from the Natural Academy of Sciences (1998). This question prompted many alternative conceptions on the pretest, including student confusion of immunity with resistance, individual adaptation as something learned through experience, mutation occurring in response to need for adaptation, and confusion of the terms “fit” and “strong” (Appendix F). The natural selection question required students know basic evolution concepts, such as the source of
inheritance of genetic variation, and an understanding of differential survival.

The students were introduced to the concept of natural selection in this study with the case, *Why does evolution matter now*, a video also known in class as *Sasha and Tuberculosis*, that portrays the epidemic of drug-resistant tuberculosis in Siberian prisons (Public Broadcasting Service, 2001). In the group and class discussions, the case illustrated the major tenets of Darwin’s theory of natural selection.

Of the six questions, students accomplished the greatest gains in their posttest scores with the natural selection question. In the pretest, 76.6% of the students scored a zero on the rubric, but on the posttest, 63.5% of the students scored a 4 (Figure 5).

*Figure 5.* Frequency distribution of natural selection rubric scores (using a level of 0 for no understanding of the concept, to a level of 4 for the highest level of understanding of the concept) for all classes.
The difference means for this question were by far the greatest of any of the questions. For each class, the difference means were significant, indicating an improvement in student learning \( (p < .05) \). The pretest median was zero and the posttest median was 4 for all classes (Table 10).

Table 10
Pre-posttest mean and median scores for evolution question #1, natural selection

<table>
<thead>
<tr>
<th></th>
<th>pretest mean (SD)</th>
<th>posttest mean (SD)</th>
<th>( t )</th>
<th>( p )</th>
<th>pretest median</th>
<th>posttest median</th>
</tr>
</thead>
<tbody>
<tr>
<td>class 1</td>
<td>0.90 (1.410)</td>
<td>3.10 (1.330)</td>
<td>5.48</td>
<td>0.000</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>class 2</td>
<td>0.47 (1.060)</td>
<td>2.80 (1.780)</td>
<td>4.81</td>
<td>0.000</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>class 3</td>
<td>0.39 (1.070)</td>
<td>3.11 (1.290)</td>
<td>9.50</td>
<td>0.000</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>all classes</td>
<td>0.57 (1.190)</td>
<td>3.03 (1.410)</td>
<td>11.60</td>
<td>0.000</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

\( n_1 = 20, n_2 = 15, n_3 = 29 \)

The second evolution question used the microevolution example of Venezuelan guppies selected from the “Conceptual Inventory of Natural Selection” (Anderson, et al., 2002). The students held a wide variety of alternative conceptions on their pretests about how a new population of medium-colored guppies were predicted to evolve in the absence of predators. These included speculations that all the offspring would be identical, that the guppies had the ability to intentionally change their color, and that a new species would be created (Appendix G). In addition to the concepts from the first question, the microevolution question required an understanding of biotic potential, fitness, polygenic inheritance, and sexual selection.

The concepts for this question were drawn primarily from The Case of Desiree’s Baby (Schneider, 2004), and Fatu & Malaria (Public Broadcasting Service, 1993). In the Desiree case study, students learned that many characteristics are governed by more than one gene, such as
skin color in humans. The malaria case highlighted the influence of the environment in the
determination of the most fit individuals. Sexual selection was also discussed in class, using
multiple examples.

The microevolution question showed a respectable increase in posttest scores compared
to the pretest (Figure 6). In the pretest, 34% of the students scored a zero, but on the posttest,
40% of the students scored a 4.

![Figure 6. Frequency distribution of microevolution rubric scores (using a level of 0 for no understanding of the concept, to a level of 4 for the highest level of understanding of the concept) for all classes.](image)

For each class, the difference means were significant, indicating an improvement in student
learning ($p < .05$), with a posttest median of 2 points for every class (Table 11).

Student comments on the SALG and in the interviews provided insight into students’
struggles with natural selection. Ann explained the main concept she obtained from the video in
her second interview:
...As a person is taking more and more medication, there would be some bacteria that would die off, but then there would be some that would be actually be strong enough and would be able to reproduce, and the genes…would be passed down…

Table 11

Pre-posttest Mean and Median Scores for Evolution Question #2, Microevolution

<table>
<thead>
<tr>
<th></th>
<th>pretest mean (SD)</th>
<th>posttest mean (SD)</th>
<th>t</th>
<th>p</th>
<th>pretest median</th>
<th>posttest median</th>
</tr>
</thead>
<tbody>
<tr>
<td>class 1</td>
<td>0.90 (0.852)</td>
<td>2.70 (1.170)</td>
<td>6.73</td>
<td>0.000</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>class 2</td>
<td>1.13 (1.060)</td>
<td>2.73 (1.330)</td>
<td>3.78</td>
<td>0.008</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>class 3</td>
<td>1.25 (1.080)</td>
<td>2.71 (1.360)</td>
<td>5.64</td>
<td>0.000</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>all classes</td>
<td>1.11 (1.010)</td>
<td>2.71 (1.290)</td>
<td>9.08</td>
<td>0.000</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 11: Pre-posttest Mean and Median Scores for Evolution Question #2, Microevolution

However, Kendra was one of the students who continued to confuse resistance and immunity, when she stated after the posttest, “I was able to learn how it [TB] spread and…symptoms of the disease and how it evolved and how it was able to fight antibiotics…[and] grow and become more immune to antibiotics.”

The students’ perception of their understanding of natural selection is illustrated in the SALG responses (Table 12). For the answer to Q2, How well do you think you understand natural selection as differential survival, 83.3% of all the students replied that the class work was at least somewhat helpful. In contrast, only 58.7% of the students felt that they would carry information about the tuberculosis case study into other aspects of their lives. One student comment posted on the SALG stated, “I will just keep in mind how natural selection works, but not act upon it.” Another one recognized the personal application in the statement, “The TB [case] will help my decision on medication and weather [sic] I think it is always necessary.”

For the second question, Martin made the connection between Desiree’s Baby and the
guppy question this way:

I: Suppose you put two medium colored guppies, one male and one female, in a pond with no predators, a few years after you did that, what would be the coloration of the population?

M: I guess it could still be brighter if they had different genes for it like in *Desiree’s Baby*. Like they could be medium colors but they could still have genes that could combine and over time I guess would get brighter colored. Over time the same thing would happen.

In the SALG responses, 73.3% of the students indicated that they would remember *Desiree’s Baby*, and carry something from it to other aspects of their lives (Table 11). Only 60.7% of the students felt that way about *Fatu and Malaria*.

Table 12

Student Assessment of Learning Gains (SALG) Percent Responses for Evolution Questions*

<table>
<thead>
<tr>
<th>SALG #</th>
<th>Survey question</th>
<th>class 1</th>
<th>class 2</th>
<th>class 3</th>
<th>all classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q2.10</td>
<td>Natural selection as differential survival.</td>
<td>85</td>
<td>75</td>
<td>90</td>
<td>83.3</td>
</tr>
<tr>
<td>Q2.11</td>
<td>Speciation (macroevolution) due to reproductive isolation.</td>
<td>85</td>
<td>88</td>
<td>93</td>
<td>88.7</td>
</tr>
<tr>
<td>Q5.6</td>
<td>Polygenic inheritance and population variation from the case study, “Desiree’s Baby.”</td>
<td>80</td>
<td>69</td>
<td>71</td>
<td>73.3</td>
</tr>
<tr>
<td>Q5.7</td>
<td>How natural selection works from the case study, “Sasha and Tuberculosis.”</td>
<td>60</td>
<td>56</td>
<td>60</td>
<td>58.7</td>
</tr>
<tr>
<td>Q5.8</td>
<td>How selective pressure drives natural selection from the case study, “Fatu and Malaria.”</td>
<td>65</td>
<td>56</td>
<td>61</td>
<td>60.7</td>
</tr>
</tbody>
</table>

*Students’ perceptions of learning, expressed as the cumulative percent of students in each class that felt class work was somewhat helpful to a great deal of help. (*n*₁ = 20, *n*₂ = 16, *n*₃ = 30)
Research Question #3:
Does CMI enhance student attitude toward science and learning about science?

Scientific Attitude Inventory

The SAI II (Science Attitude Inventory II) is a survey instrument designed to identify a student’s attitude about the process and authority of science, the work of scientists, and about how science progresses (Moore & Foy, 1997). The 40-item survey (Appendix H) analyzes six paired position statements about science. The pairs are intended to be opposite positions of the same viewpoint (Table 13).

The revised form of the SAI II was given to students in all three classes on the first and the last day of the course. However, the data set for comparison was reduced because some students added the class after the first day, others dropped the class, and some failed to provide
the same identification number on both surveys \(n_1 = 13, n_2 = 11, n_3 = 23\). A Student’s \(t\)-Test for paired means did not identify any significant differences between the first and the second iteration of the survey. With this small sample, the paired Student’s \(t\)-Test identified only one position statement that was significantly different \((p < .05)\) for two of the classes. This was statement 2AB, which describes the empirical nature of science (Table 13).

**Interview Comments about Attitudes about Science and Scientists**

Students commented about the tentativeness of science in some of the interviews in support of the idea that science is empirical. Kendra put it this way in her second interview:

I really respect the field of science but I think that it is so much… under the microscope…everybody just …looks at it for all the right answers I think. Science might be right at the moment, but science always evolves. That’s kind of what I’ve learned…. It’s cool to know there’s not just one golden rule in science. There’s a lot of different people interpreting things differently.

Tammy admitted in her second interview that she had a more nuanced attitude about science, one that was less authoritarian and more tentative:

I kind of realize that…so much in science isn’t a definite. It doesn’t have a definite answer, because it’s all …theories. It’s not something exact, it’s not like a fact but it’s because of all these common theories, that all … give you a certain idea of something.

The idea that science does not always provide answers was discomfiting to some of the interviewees. But Ann emphasized the value of theories in science (second interview):

That was interesting to see, sometimes people call it a theory, but there’s more to a scientific theory than just a thought to it… It was just really fascinating to see these scientists can take different things and put them together and show evidence…

Later in the same interview, Ann summed up the nature of science:

[By] taking this science class, … the more I learn about science, the more I learn what we don’t know about science. It seems like…everything has to be falsifiable… It’s just really interesting, the more you learn, the more you learn what you don’t know.
The idea that science arrives at theories which are always considered to be tentative made Karen concerned about the work that scientists do. In her second interview, she said,

“I guess I would find it hard to be a scientist because after all this …what if my theory, this amazing thing that I have come up with, … in 50 or 100 years [we] find out it’s not true?”

However, Mark viewed this uncertainty as worthy of respect in his second interview:

I have complete respect for someone who dedicates their life to just so much work, so much opportunity and possibility for new things and everything is changing everyday and that just means they have to put in more work, more research hours…people who donate their entire lives to that.

The realization of what the nature of science means for the work of scientists precipitated some changed ideas about how students viewed who scientists really are. Ann (second interview) stated simply that “scientists are just basically trying to figure out the universe, how the world works, trying to [understand] that in as much logic as possible and in the end trying to help mankind and the earth….,” At the end of his second interview, Mike came to the realization that scientists really are everyday people:

…before I … pictured scientists as lab junkies... hanging in there and doing their little chemistry and biology stuff. They…do a lot more field research than I thought they would do….It’s a little different, more human I guess. And they go out more and get out of the lab. They seem more normal. They can be a scientist and still have a life.

Summary

The data indicated that students understood the purpose of CMI and its positive effects on their learning of scientific conceptions and concept application. They appreciated the case focus on relevant social issues and felt that they were applicable to their lives. Most agreed that the social construction of knowledge helped their learning if their peers were prepared and
responsible for group tasks. Some were not comfortable with the lack of structure in CMI and others felt that the cases were often ambiguous or did not have enough scientific information.

The pretest-posttest scores were compared for each participant by means of the Student’s paired $t$-Test, and the difference mean and standard deviation were calculated for each class separately and all classes combined (Tables 4, 5, 7, 8, 10, 11). For each question, a statistically significant difference ($p < .05$) was obtained. Each class showed an improvement in their understanding of the scientific concepts embedded in these questions, according to these data.

Based on the pretest-posttest rubric scores, the genes topic appears to have been the most difficult of the three topics in the course (Figure 7). The lowest pretest scores were achieved for the genes questions (genetic material and biotechnology) and for natural selection, but the natural selection posttest scores were the highest of all six questions, while the genes questions showed the smallest learning gains. The pretest median was zero for all classes for genetic material, biotechnology, and natural selection questions. The largest learning gains were achieved for the natural selection question, with a pretest mean score of zero and a posttest mean score of four. The smallest learning gains were observed in the invasive species question, with a one-point increase while moderate gains (two points) were seen in both the ecosystem services question and the microevolution question. Based on the rubric pretest-posttest scores, the biodiversity topic appears to have been the least difficult of the three topics in the course (Figure 7).

The SAI II indicated that two of the classes had changed their view of science as more empirical. Interview comments indicated that some interviewees started to think about science as more tentative.
Table 13

Position and Attitude Statements of the Scientific Attitude Inventory II (SAI II)

<table>
<thead>
<tr>
<th>Position Statements</th>
<th>Attitude Statements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A The laws and/or theories of science are approximations of truth and are subject</td>
<td>4, 16, 34</td>
</tr>
<tr>
<td>1B The laws and/or theories of science represent unchangeable truths discovered</td>
<td>11, 15, 35</td>
</tr>
<tr>
<td>2A Observation of natural phenomena and experimentation is the basis of scientific</td>
<td>10, 19, 33</td>
</tr>
<tr>
<td>2B The basis of scientific explanation is in authority. Science deals with all</td>
<td>2, 7, 26</td>
</tr>
<tr>
<td>3A To operate in a scientific manner, one must display such traits as intellectual</td>
<td>17, 18, 25</td>
</tr>
<tr>
<td>3B To operate in a scientific manner one needs to know what other scientists think;</td>
<td>3, 5, 32</td>
</tr>
<tr>
<td>4A Science is an idea-generating activity. It is devoted to providing explanations</td>
<td>20, 21, 28</td>
</tr>
<tr>
<td>4B Science is a technology-developing activity. It is devoted to serving mankind.</td>
<td>9, 24, 31</td>
</tr>
<tr>
<td>5A Progress in science requires public support in this age of science, therefore,</td>
<td>12, 23, 29</td>
</tr>
<tr>
<td>5B Public understanding of science would contribute nothing to the advancement of</td>
<td>6, 8, 38</td>
</tr>
<tr>
<td>6A Being a scientist or working in a job requiring scientific knowledge and thinking</td>
<td>1, 27, 30, 36, 40</td>
</tr>
<tr>
<td>6B Being a scientist or working in a job requiring scientific knowledge and thinking</td>
<td>13, 14, 22, 37, 39</td>
</tr>
</tbody>
</table>

*SAI I statement numbers (Appendix H)
Chapter Five

Summary, Conclusions, and Discussion

The purpose of this study was to investigate the effectiveness of CMI on students’ perceived learning gains, their progress toward conceptual change and their enhanced attitude toward learning science. The current reform initiatives in higher education and a desire to improve classroom practice based on theoretical perspectives were motivating factors for this study. This chapter summarizes the research study and its findings in relation to the three research questions. After the brief summary, the conclusions based on the qualitative and quantitative data obtained within the context of the research questions will be presented and discussed in the context of the research literature presented in Chapter 2. The chapter will conclude with a discussion, describing the advantages and drawbacks of CMI, limitations of the study, significance of the study, and recommendations for classroom instruction and future research.

Summary

The participants in this study were from three non-majors introductory biology classes ($n_1 = 20$, $n_2 = 15$, $n_3 = 29$) at a small private university in the southeastern United States. The research study used a quasi-experimental action research design in which the case study method (CMI) was used for instruction in three topics: genes, biodiversity, and evolution. CMI is an inductive constructivist pedagogy that uses concepts from case studies as the focus of learning activities, including small group and class discussion. During the course of the semester, case
studies were used to teach all the topics using a student-centered, active-learning approach.

The research study was conducted over the entire semester in the spring of 2006. Instruction for all course topics was based on CMI, but only the genes, evolution, and biodiversity topics were included in this study. Participants completed the Science Attitude Inventory (SAI II) on the first day of class in order to assess their attitudes about science before the course began. Also on the first day of the semester, the participants took a pretest, consisting of six open-ended questions, two for each of the three topics in this study. The pretest questions were based on scenarios, or small case studies, designed to elicit student alternative or scientific conceptions about the topics. The pretest questions were subsequently included in the appropriate hour exams as posttest questions, but students were not informed that the questions would be in those exams. Pretest and posttest questions were scored with original rubrics developed for this study. Analysis of the difference between the pretest and posttest scores of each participant was used to answer research question #2.

In the sixth week, the first hour exam was given, which included the two genes pretest questions. After the exam, but during the same week, twelve student volunteers were interviewed about their learning experience with CMI. The interviews were audio taped and transcribed, and the data obtained from the interviews were used to help answer all three research questions after the course grades were submitted. Then, the next two topics, evolution and biodiversity, were taught with CMI. In the thirteenth week of the semester, a second exam was given, which included the other four pretest questions, two on biodiversity and two on evolution. The second set of interviews was conducted during the same week as the second exam, and
questions about the exam topics were used to probe understanding of CMI and the two course topics, as was similarly done in the first interview. These interviews were also audio taped and transcribed, as before, and the data were analyzed after the course grades were submitted. Students completed the Student Assessment of Learning Gains (SALG) online at their convenience between the second exam and the final exam. Data from the SALG were used to help answer all three research questions. The SAI II was given again on the last day of class. The data were compared to the results from the first SAI II and used to help answer the third research question.

The following section discusses the findings of this research study in the context of the interview themes, the three research questions, and the literature review.

Conclusions

Research Question 1

The SALG questions Q1, Q3, and Q4 and interview data supporting all 4 interview themes were used to answer the research question: *Do students perceive an improvement in their learning gains by using CMI?*

The SALG responses from all 3 classes for Q1, Q3, and Q4 (Table 3) indicated that students felt that they were at least “moderately successful” in learning from case studies in class and for homework, and in group and class discussions, and “somewhat successful” in adding to their case study review skills. They also felt “somewhat successful” in understanding the main concepts, the relationship between concepts, and the relevance of class concepts to real world issues. However, some interviewees were initially skeptical about whether CMI would help them learn biological concepts, and expressed frustration that the method pushed them beyond
their comfort zone. This reaction is typical for undergraduate non-science majors who often have extrinsic motives for taking science courses (Minasian-Batmanian, Lingard, & Prosser, 2006; Watters & Watters, 2007).

The SALG comments and interviewee responses describe some concern about learning due to the ambiguity of some case studies and the realities of group work. These are characteristics of inductive student-centered learning strategies. Prince and Felder (2007) stated that students resist inductive methods because they impose more responsibility on the learner and that instructor scaffolding is necessary to reduce negative reactions. In this study, students indicated that they were not as experienced in constructing their own knowledge but admitted that taking responsibility for doing so, with the instructor’s assistance, increased their learning gains (Theme 3: Case studies promote student responsibility for the construction of knowledge). Students also acknowledged that their learning was enhanced by their peer interactions, which enabled them to see concepts in a different light (Theme 2: Case studies enhance the social construction of knowledge), an indication that they benefited from the social construction of knowledge. Driver et al. (1994) described this social construction of scientific understanding as a result of the social engagement resulting from shared problems or tasks. Moreover, Flynn and Klein (2001) have concluded that student-student interaction is a vital part of case-based learning, but performance is enhanced only if students come prepared for group discussion.

In addition, the case studies provided context for the concepts students struggled to learn. This welcomed departure from strict textbook learning prompted more engagement with the material (Theme 4: Case studies facilitate concept application and help students see the relevance of science in the real world), in contrast to student learning with conventional teaching.
methods. Most interviewees felt that the cases helped them retrieve concepts because they could associate them with cases and use the cases as cues when answering exam questions (*Theme 1: Case studies provide cues for information retrieval and help with knowledge retention*). In a similar way, Khodor, Halme and Walker (2004) reported that nesting facts in a hierarchy that provides context makes them easier to learn and *Project 2061* concluded that learning concepts in context allows a student to embed them in their knowledge system (AAAS, 1993).

For research question #1, it can be concluded that CMI presents a new and different learning paradigm for most students that may cause discomfort and frustration. But learning with this method was more interesting, motivating, and relevant, specifically because cases related back to stories. Students perceived that CMI provided deeper learning that they believed would be retained for a long time. The data support the conclusion that most students believe that learning was improved with CMI.

**Research Question 2**

The analysis of pretest-posttest scores with original rubrics, SALG questions Q1E, Q2, and Q5, and interview data (themes 1 and 4) were used to answer the research question: *Which alternative conceptions do students have about biodiversity, genes, and evolution and does the Case Method of Instruction (CMI) promote accommodation of scientific concepts in genes, biodiversity, and evolution?*

For all six questions, the differences between the pretest and posttest scores were significant (*p < .05*), indicating an improvement in student learning. The rubric scores showed that students learned concepts in all three topics with CMI, but the extent of learning gained
varied with each topic (Figure 7). The learning gains for each of these topics are discussed separately below.

Genes

At the start of the course, many students possessed alternative conceptions for the first pretest question: If you could take a cheek cell and a sperm cell from the same person, how would the genetic material compare? In their pretest answers, some students stated that they thought the genetic material contained in a cell was specific for the cell’s function or that sex chromosomes were only found in sperm cells and not in cheek cells. Some students misinterpreted this pretest question or lacked understanding of the terminology, for example, confusing “genetic material” with “genetic code,” and “genotype” with “genetic sequence.” It is also possible that some students may have interpreted the question as simply too vague. Overall, the results indicate however, that students made progress toward conceptual change with this question, even though the median posttest score was only two for all three classes.

However, other students stated that the information in the cheek and sperm cell would be the same, explaining that this is the basis for comparing evidence in forensic science. In the posttest, some students described the genetic differences between cheek and sperm to be one of quantity only, implying that the chromosomes in each homologous pair in the cheek cell were identical to each other, as one student stated in her posttest:

A cheek cell and a sperm cell taken from the same person would have the same genetic sequence. The only difference between the two would be that the cheek cell would have 46 chromosomes (23 pairs of chromosomes), and the sperm cell would contain 23 unpaired chromosomes since it is a gamete cell.

Another student used different meanings of the word “same.” She stated in her pretest that “the DNA would be the same...[But] the lining up of A, G, C, T would be different.” In her
posttest she contradicted herself within her answer, when she stated, “The cheek cell and the sperm cell would have the same DNA sequences. They would be specific for each cell.” Both of these answers indicate that the student was confused about what the statement, “DNA is the same,” really means. The conceptual understanding of the variability of the DNA molecule between the cheek cell and the sperm cell of the same person is difficult for students to grasp once they have understood that a person’s genome is contained in every body cell.

Other posttest answers, stating the genetic material was identical, showed student understanding of haploid vs. diploid cells when it related to mitosis, meiosis, sexual reproduction, and cloning from the case studies, “Saving Superman,” and “Cloning Baby Jason.” This exception to their understanding in the comparison of gametes and somatic cells may have caused students to hold a “dual construction,” as described by Demastes et al. (1996), who maintained that students are often not logical in applying competing conceptions. Intentional conceptual change, which connects learning and motivation, is necessary for students to reconcile these dual constructions (Duit & Treagust, 2003). Thus some students demonstrated the “conceptual capture” of “ploidy” and the assimilation of the scientific conception in an example of “weak knowledge restructuring” (Duit & Treagust, 2003).

The students’ answers were less predictable for the second genes question on biotechnology: Today bacteria are used to produce human insulin for diabetic patients. Explain how this is accomplished. Those who answered the pretest question appeared to be confused about the role of bacteria in the process and on the posttest might have been distracted by the antibiotic resistance case used for the evolution topic. On the pretest, most students did not appear to have much knowledge of biotechnology, and indeed, of all the questions on the pretest,
this one was left blank most often (n = 14), similar to Dawson’s (2007) description of student lack of knowledge. This may have been an advantage in helping students learn, since they had few non-scientific conceptions that needed to be overturned. This gradual accumulation of biotechnology knowledge is an example of “incremental” conceptual change, described by Demastes et al. (1996) and is very different from the wholesale change of Posner et al. (1982). With incremental conceptual change, students typically do not have full understanding in their initial explanations, but gradually acquire a fuller understanding of a major paradigmatic conception.

Because the pretest scores were low for the genetics questions, posttest gains were expected, and the median score did improve by two points for both questions for all but one class. Students indicated that the material was “dense” and “difficult to learn” in their SALG and interview comments, but some thought the cases made the information easier to put together and remember and also more interesting (Theme 1: Case studies provide cues for information retrieval and help with knowledge retention).

Biodiversity

Answers on the pretest indicated that students had few alternative conceptions for the first biodiversity question on ecosystem services, which described New York City’s decision to protect its watershed rather than build a wastewater treatment plant. Perhaps students had no alternative conceptions because they could evaluate this scenario from an economic viewpoint, without having a perspective informed by their own biology content knowledge. On the posttest, the word “scientific” was added to the question to elicit more responses that were more appropriate for a biology class, and the additional prompt did increase the number of scientific
conceptions. The improvement in median rubric scores from one (except for class 3) to three was due to “incremental conceptual change” (Demastes et al., 1996) or knowledge “accretion” (Duit & Treagust, 2003; Scott, et al., 2007) because the students were subtly changing their conceptions about the value of ecosystem services rather than overturning an alternative conception. In the SALG questions and interview comments, students indicated that they had an appreciation for their personal impact on the environment, as one stated,

I understood the impact of my lifestyle on the environment the best because of how personal it was to me. I gathered a lot of information about myself and it hit me hard how I can impact the environment with my lifestyle.

The second biodiversity question, dealing the invasive Asian clam in San Francisco, elicited multiple alternative conceptions about community interactions, but responses to this question also included the most scientific conceptions of the pretest, thus showing a gain of only one point (from two to three) in the class median posttest scores (Appendix L). Students learned about alien species with two cases, Aliens Here & Abroad, and Cane Toads. The Cane Toads case study especially impressed students (Table 9) about the alien species problem; with 80.7% responding that it was at least “somewhat helpful” in helping them see connections with other aspects of their lives. Student comments from the SALG and interview data indicated that some were personally affected by these case studies (Theme 4: Case studies facilitate concept application and help students see the relevance of science in the real world). The SALG data for the biodiversity questions show that students believed that they understood the threats to biodiversity (97.3% said at least “somewhat”), but it does not appear to be so on a personal level because with the case study Watch Your Step, only 68.7% thought it was at least “moderately” helpful in question Q1E (Table 9).
There are few studies that look at conceptual change in science-technology-society (STS) topics such as biodiversity (Duit & Treagust, 2003). Again, the knowledge gains appear to be due to “incremental conceptual change” (Demastes, et al., 1996) or “knowledge accretion” (Duit & Treagust, 2003) because the students had to slowly accumulate knowledge about invasive species. Some “weak knowledge restructuring” (Duit & Treagust, 2003) was also required to eliminate alternative conceptions about community dynamics, such as the effects of the alien clam species on the food web, and the hybridization of invasive species as a way to increase biodiversity in a community.

Other alternative conceptions for this question, such as the selective advantage of the Asian clam over native species, refer to evolution concepts so this type of conceptual change is described in the discussion of the first evolution question.

Evolution

Students from all three classes showed the most gains in their learning overall for the first evolution question on natural selection (insecticide resistance in barn flies), with a median posttest gain of four points. Forty-nine students scored a zero on the posttest while 40 scored a four on the posttest (Appendix L). The students reported the typical alternative conceptions on their pretest, including resistance as a learned adaptation in response to a felt need, environment-induced mutations, and a gradual change in the resistance of all the flies (Alters & Nelson, 2002; Anderson, et al., 2002; Andersson & Wallin, 2006; Banet & Ayuso, 2003; Bishop & Anderson, 1990). Since the students had to exchange their alternative conceptions for the scientific conceptions, this gain in posttest scores represents “wholesale conceptual change” as described by Demastes et al. (1996), and a strong/radical knowledge restructuring resulting in true
conceptual exchange (Duit & Treagust, 2003).

The second evolution question on the microevolution of Venezuelan guppies showed a two-point increase in the median scores. Twenty-two students scored a zero on the pretest, but 25 students scored a four on the posttest (Appendix L). Alternative conceptions on the pretest indicated that students were confused about biotic potential, sexual selection, and most importantly, variation, and the effect of the environment on variation, similar to student alternative conceptions reported by others (Banet & Ayuso, 2003; Moore, et al., 2002; Westcott & Cunningham, 2005). The alternative conceptions students held about variation prevented them from correctly predicting the pattern of evolution of the population. With this alternative conception overturned, they experienced a “cascade”-type of conceptual change (Demastes, et al., 1996), which allowed them to overturn other alternative conceptions about evolution in a step-wise fashion, thus promoting their understanding of how populations evolve. Students indicated that they had difficulty learning concepts from the evolution cases in their SALG responses (Table 12), although the posttest rubric scores do not support their opinion. In the same question set some of the SALG and interview comments indicated that the tuberculosis case in the Siberian prison had also affected student thinking about their personal health (Theme 4: Case studies facilitate concept application and help students see the relevance of science in the real world).

Based on the data collected for research question #2 several conclusions can be made. First, for all three classes for all six questions there was a significant difference between their pretest and posttest scores, indicating learning of scientific conceptions had occurred (Figure 7). Secondly, rubric scores and comments from the interviews and on the SALG indicate that
students struggled the most with the genes concepts and made the most gains with the natural selection question. Perhaps, the case studies selected for the genes topic may have not been suitable for student learning of the concepts, or perhaps learning was not appropriately scaffolded to allow students to be more successful in moving toward accommodation of those concepts. Finally, true conceptual change based on the model of Posner et al. (1982) occurred with student knowledge gains in evolution, described as “wholesale” and “cascade” by Demastes et al. (1996), with “weak knowledge restructuring” (Duit & Treagust, 2003) and “dual construction” (Demastes, et al., 1996) occurring with the first genes question, and “incremental” conceptual change occurring for the second genes question and the two biodiversity questions (Demastes, et al. 1996).

Research Question 3

The Scientific Attitude Inventory (SAI II) and interview data (theme 4: Case studies facilitate concept application and help students see the relevance of science in the real world) were used to answer research question #3: Does CMI enhance student attitude toward science and learning about science? The SAI II data revealed only one significant difference between the pretest and posttest for two of the classes ($n_1, p = 0.001$, $n_2, p = 0.048$, $n_3, p = 0.516$), which indicated those students had changed their attitude about “science as authority” toward a view that science is more tentative. However, the items on the inventory may have not been able to elicit a personal response from the students because the instrument measures attitudes about science rather than attitudes about learning science. Moore and Foy (1997) explained that the SAI II was designed to distinguish between beliefs and feelings – and that beliefs require
cognitive learning. Science learning may be more about feelings, they contend. The lack of change in student attitude as measured by the SAI II was not likely to be related to lack of cognitive gains (Koballa, 1989).

The work of scientists figured prominently in most of the case studies, and class and small group discussions indicated that this left an impression on the students. For example, Tammy commented in her second interview that science is “not a definite” and Kendra stated, “science always evolves,” in her second interview. Ann reflected on her new scientific understanding of the meaning of the word “theory” in science, but Karen found it hard to accept that a theory could be overturned by new data. The opinion of scientists was changed for at least two of the interviewees. Mark said he had “complete respect for someone who dedicates their life to so much work,” and Mike understated his more informed view of scientists when he said, “they seem more normal.”

Based on the data obtained to answer research question three, the following conclusions can be made. Case studies do affect student attitude about science based on interview and class comments, but it appeared that the SAI II items measured attitude about science, not necessarily learning about science. Difficulties collecting the posttest survey resulted in a lower $n$ and this may also have affected the outcome.

Connections to the Literature

The present study was prompted by a desire to improve classroom practice with learner-centered strategies that engage students and improve learning outcomes by using the case study method of teaching science. The use of case studies in undergraduate biology intended to
address some of the recommendations for current reform in higher education, the challenges of effecting conceptual change, problems with non-major attitude toward learning science, and student learning in three topics: genes, biodiversity, and evolution.

Professors have struggled with delivering a meaningful science education to non-majors for over 200 years (Wright, 2005). One main reason for this dilemma is that postsecondary educators have historically focused on the content of their disciplinary field rather than the construction and transmission of that knowledge (Kreber, 2002). However, Boyer’s (1990) landmark work has been an impetus for initiatives in the Scholarship of Teaching and Learning (SoTL) that seek to address the need for reform. These initiatives include improved support for SoTL on several levels, from institutional changes to national directives (AAC&U, 2007; USDOE, 2006). Included in these initiatives are reforms that address undergraduate introductory courses (Twigg, 2005) and science courses (Handelsman, et al, 2004), including biology (Udovic, et al., 2002).

These reforms promote active learning to engage students in the classroom, using the collective research evidence favoring inductive over deductive pedagogies (Prince & Felder, 2007). CMI is an example of an inductivist strategy that addresses the need for reform in higher education (Ahlfeldt, et al, 2005; Dori, et al, 2003; Mayo, 2002; Yadav, et al, 2007). In this study, students learned concepts through the use of case studies as a variant of experiential learning (Kreber, 2002). According to Kubli (2006), students themselves often transform class material into stories to help them store concepts in their memory (Theme 1: Case studies provide cues for information retrieval and help with knowledge retention). The case studies promoted self-direction in learning and put more responsibility on the learner (Theme 3: Case studies
promote student responsibility for construction of knowledge). Moreover, students acknowledged that the relevance of science to their lives (theme 4) was critical for their learning as Wright (2005) emphasized. Furthermore, Prince and Felder (2007) pointed out that the meaning of science concepts must be co-constructed by learners (Theme 2: Case studies enhance the social construction of knowledge.) with inductive strategies and that “scientific knowledge is discursive in nature” (Driver, et al., 1994).

Even though PBL has been shown to have a positive effect on student attitudes (Prince, 2004), the Science Attitude Survey (SAI II) did not provide sufficient information about student attitude about science. But small group discussion is an integral part of CMI, and student-student interaction is key to attitudinal, as well as cognitive change in students (Flynn & Klein, 2001). The literature reports abundant evidence of the motivational power of inductive methods, like CMI, because they create a “need to know” for student learning (Palmer, 2005). Case studies have the power to convey science concepts to students in a way that sparks their imagination and motivates them to learn science (Stamp & Armstrong, 2005) and motivation is a necessary co-requisite for learning (Palmer, 2005).

Egan (1986, p. 2) said “the power of story is a cultural universal; everyone everywhere enjoys stories…it reflects a basic and powerful form in which we make sense of the world and experience.” CMI is considered a “novel” approach to science teaching because it recognizes the power of story (Herreid, 1994). The appeal of story was also obvious to students in this research study, as Krystal described in her second interview: “Cases are kind of like stories. Everyone likes stories. So I think if you can tell a story and use science with it, that’s good. It’s kind of like a moral, only a ‘science’ moral.” Stories have the power to motivate students and
McKeachie (1999) said that learning is closely tied to motivation. Karen explained her motivation from case studies this way in her first interview:

…When they tell you a story it seems like you remember it a lot better and you want to pay attention to it more because of the personal experience instead of saying this is the way that it is, and this is what you have to remember, and you should make flashcards about this, … So I think with an actual story it makes it easier to relate…

In the interviews, some students were initially skeptical about whether CMI would help them learn biological concepts, and some expressed frustration that the method pushed them beyond their comfort zone. This reaction is typical for undergraduate students who often have extrinsic motives for taking science courses (Minasian-Batmanian, et al., 2006; Watters & Watters, 2007), who are often resistant to teaching strategies that make them responsible for their own learning unless they perceive its usefulness (Prince & Felder, 2007).

The attraction of case studies is fundamentally aimed at the affective domain which Demastes, et al. (1996) contended might be more important than logic in effecting conceptual change. Arambula-Greenfield (1996) also reported that the main benefit of PBL was on the affective domain. The students in this study often referred to the affective appeal of case studies, as Katelynn said, “Well, I don’t know so much if it’s (CMI) important for me to be able to learn it, but for me to be able to care.” With CMI, students in this study reported that they were engaged with the material in a way similar to the findings of Ahlfeldt, et al. (2005). Moreover, Kendra’s description of her original impression of CMI as described as “science-light” reflects the impression of Lieux’s (1999) students, who felt they had learned less content, even though their test scores did not support that opinion.

CMI is not a new teaching method. Many teachers use variants of CMI simply by including stories and scenarios in the classroom to motivate and help students learn. These
teachers are using a strategy that appeals to our common humanity. The “guided reinvention” of Geraedts and Boersma (2006) is a variant of CMI, as are the models of Gericke and Hagberg (2007) and Jensen and Finley (1996). We tell stories because we are human. E.O. Wilson (2002, p.10) citing researchers in his essay said, “Storytelling is not just something we happen to do. It is something we virtually have to do if we want to remember anything at all.”

Although the topics of this study, genes, biodiversity, and evolution, are part of a conceptual framework for biology (Mayr, 1997), the research literature reports that each topic has unique issues as well as advantages for student learning.

In this study, genes terminology was a recurrent problem for student learning, similar to the findings of Lewis, et al. (2000a) and Lewis and Wood-Robinson (2000). In addition, students often misunderstood or ignored the importance of gamete formation, similar to what Browning and Lehman (1988) reported, although the alternative conceptions about this concept were not a focus of this study.

However, as Seethaler (2005) described, controversial topics such as genetic engineering and cloning increased student motivation for learning because they are real issues that are often mentioned in the popular media. The case studies used in biotechnology stimulated student interest because they were multidisciplinary and value-laden, providing students with the opportunity to socially construct science knowledge as described by Hart (2007).

In a similar fashion, the biodiversity topic is embedded in politics, economics, culture, and ethics although it induces fewer alternative conceptions than genes. It is more easily aligned with CMI pedagogy because story telling is a natural approach for teaching biodiversity. Fewer alternative conceptions are reported in biodiversity education, which is likely due to lack of
research in this area. Moreover, environmental issues are often perceived as concerns of activists, not scientists whose work is erroneously presumed to be value-free.

For evolution, the students’ answers on the pretest included the commonly reported alternative conceptions for natural selection, such as change driven by need, gradual change in the entire population, and survival of the “strongest” (Alters & Nelson, 2002; Anderson, et al., 2002; Westcott & Cunningham, 2005). Students overlooked the central importance of genetic variation in their explanations of natural selection as reported in other studies (Banet & Ayuso, 2003; Moore, et al., 2002; Westcott & Cunningham, 2005). Likewise, the Lamarckian idea of use and disuse was prevalent in many students’ answers, similar to the findings of other studies (for e.g., Banet & Ayuso, 2003). Students sometimes failed to relate to the concept of natural selection because examples used were often historical, exotic, or irrelevant. But in this study, the case of ineffective treatments for tuberculosis can help students make connections with problems in real lives, and the potential effect of natural selection on their own lives. The discussion of resistant bacteria and their threat to public health, or the problem of flies in a dairy barn, helps students create an alternative framework understanding of natural selection. The case studies may thus help students to learn intentionally, with a “meaningful learning orientation” as described by Cavallo & Schafer (1994).

Discussion

Advantages and Drawbacks of CMI

The nature of CMI presents some fundamental challenges for educational research. Because this pedagogy relies on a narrative and indirect presentation of content knowledge and
social interaction among students, some of its effects on student learning are hard to assess. Moreover, even when students have come to the classroom with previous constructivist experience, new approaches may be met, at least initially, with skepticism and dislike.

The success of a course based on CMI depends to a large extent on the cases chosen for instruction of particular concepts. The selection must be based on prior knowledge of the students, size of the class, time allotted, and especially, the instructor’s pedagogical content knowledge (PCK). Moreover, most cases present content knowledge in a subtle form that usually needs scaffolding with other class activities or outside readings. But providing an expository lists of concepts embedded in a case study before it is analyzed would negate the main benefit derived from the pedagogy.

The strengths of CMI contribute to some of the confounding variables that are difficult to control in educational research. The success of the method is dependent on the cooperation of groups during discussion and the preparation of students for class tasks. CMI requires considerably more work from students in class than conventional teaching methods. Students who do not favor the strategy may negatively affect the progress of those that do.

The enthusiasm of the instructor for a pedagogy, and for teaching itself, is another variable that is difficult to control, but is of prime importance to the students. As Krystal said in her second interview, “I’ve had good science classes and I’ve had bad science classes and it usually comes down to how the instructor was passionate about the subject.” Enthusiasm and attitude are also difficult to enhance or measure in the students as well.
Limitations

It is often difficult to interpret some of the results in a quasi-experimental study. There were three classes in this study that served as convenience samples and these may have varied due to some pre-existing differences, including class time and class size. To reduce the impact of any differences, pre-posttest results were examined for each class separately as well as for all three classes together. The use of intact classes does limit the generalizability of the conclusions. In addition, there was no control class in this study used to compare student learning of concepts without case studies because assessments that use case studies would not be appropriate for non-case study classes.

In addition, participants in this study were not given preliminary information about the nature of the case study method or its goals to avoid bias for or against the method, but this lack of information may have caused initial confusion and discomfort. On the contrary, the instructor’s enthusiasm for the method may have been a source of bias affecting the learning outcomes with CMI. In other studies using CMI, the instructor’s familiarity with the method, case preparation, and implementation of the method can vary considerably (Mostert & Sudzina, 1996). Indeed, one study claims that instructors must undergo a “conceptual change” in their own pedagogy to effectively use the case study method (Knight & Wood, 2005). Moreover, the selection of specific case studies may also affect the students’ learning gains as the quality and appropriateness of case studies varies considerably. Lack of success in a case study class may be due to the case selection and not the method.

CMI is not really one simple method, but has many constructivist methods embedded within it, such as inquiry, active learning, student-centeredness, and small group discussion, that
cannot be studied separately. In this study it was not possible to separate the effects of CMI from the effects of small group discussion, in particular. Flynn and Klein (2001) reported that students who did cases with groups enjoyed it more than those who did not and that group discussion is integral to the case process. Observed effects of an inductive method are often difficult to sort out because the components of the method are synergistically interwoven (Prince & Felder, 2007). Furthermore the quality of the group discussion is also dependent on the motivation and preparation of the group members.

Conclusions based on qualitative data also have their have limitations. Interviews are important to explore how a student perceives she has achieved a particular learning outcome, when students may be unable to explain how they learn (Robotham, 2004). The interviewees were chosen from available volunteers who were willing to participate in the study and may therefore have differed from randomly chosen subjects. In addition, the original rubrics were developed for this study and assessed for inter-rater reliability. However, it is a challenge to write original rubrics to define the criteria that differentiate levels of performance (Ebert-May, n.d.). Also, the construction of original rubrics for pre-posttests student responses requires instructor judgment and experience and rubrics are often a challenge to apply to some student responses.

Finally, the two instruments used in this study also have limitations. The Science Attitude Survey (SAI II) was given on the first and last day of class, but students’ difficulties with confidential codes, and a reduced sample of students present on those days, resulted in incomplete data for the Student’s paired t-Test. Consequently only a small data set was useful for interpretation. The Student Assessment of Learning Gains (SALG) is an online instrument
made up of items that can be modified by the instructor and included space for student comments after each set of questions. It was an anonymous instrument but the instructor received a list of all the students who completed it. Since the SALG was not specifically described to the students as a learning instrument, student responses were not all related to learning gains, and some students perceived it as an evaluation of the teacher. In addition, the word “learning” was not defined and may have been interpreted as learning content for some students and conceptual understanding for others.

Significance of the Study and Recommendations for Instruction

This study is significant because it explores the effectiveness of the widely promoted case-based active learning methods on student conceptual change in genes, biodiversity, and evolution. This effectiveness was evaluated not only by the assessment of learning gains with pretest-posttest rubric scores, but also by the students’ own reflections in the interviews and the SALG. CMI has been extensively discussed as a beneficial, user-friendly way to help students learn (Herreid, 2005; Yadav, et al., 2007), but this study makes explicit connections between the individual case studies and the concepts students learn in these three topics.

The research literature clearly shows that constructivist, active-learning techniques are more effective in promoting learning than traditional didactic lectures and objective assessments (for example, Handelsman, et al, 2004; NRC, 2003). Gradually implementing case studies in learning activities is a feasible way for instructors to become more constructivist in their teaching. An advantage of CMI is that cases can be used at the discretion of the teacher as the central pedagogy for class, for teaching specific content knowledge, or occasionally as a change
of pace. Case teachers can start with one or two cases and gradually increase the use of cases with experience. Furthermore, a wholesale adoption of CMI is not necessary, but cases can be used in conjunction with other teaching strategies, even didactic methods (Herreid, 1998).

An instructor planning to implement CMI in the classroom should reflect on the many variables that may be unique to their course, including the conceptual framework of the course and how cases would fit into that framework (Gallucci, 2006). Since the goal of constructivist classrooms is conceptual understanding, instructors must be careful to align case studies with concepts, and adapt them when necessary to be sure the concepts are central to the method.

Herreid (2001) warned beginning case study teachers to prepare well, be familiar with controversial material, to make concepts explicit, to give students an opportunity to get to know each other, and to listen and respond to students. Of the variety of case study types available, the small-group discussion cases are the easiest for neophytes, since these do not require experience in class-wide questioning and more students are apt to participate in the discussion (Herreid, 2005).

Because relevant cases that are “good fit” for the course objectives are sometimes difficult to find, instructors may need to adapt or write their own case studies, which requires a large time commitment for case study class preparation. Also, instructors need to be prepared for student resistance to a new teaching strategy when many students have been successful with conventional methods and perceive their grade to be at stake when a new pedagogy is implemented (Herreid, 2001).
Recommendations for Future Research

Case study researchers advise against “horse-race” studies that compare pedagogies with too many confounding variables (Lundeberg, et al., 1999). Rather, research studies can start with the premise that case study learning is valuable and effective and then ask research questions about why that may be so. Student learning with case studies is difficult to assess with conventional methods designed to assess learning with didactic methods. Active learning should be assessed with appropriate active learning assessments. What are some of those appropriate assessments and how would they inform us about the way students learn?

Action-research studies are a fruitful area of research where instructors can focus on their own research questions about the case study method and thereby improve their own classroom practice with the case study method. They can continue to develop new questions on their own findings in an iterative fashion as conclusions based on each data set further inform the next set of questions and the next research study. Furthermore, teachers can share the results of their action research studies with other teachers, thus supporting the intellectual growth of the profession (NRC, 2000).

The interesting questions that need to be studied include what students actually learn from case studies and what makes some of the cases more effective than others. These questions should investigate the effect of the case study’s complexity, how the case study cues student memory, and how it promotes independent learning. Probing how students perceive the way they connect concepts with case studies is another area of research that may yield valuable insights into student learning. How do case studies allow students to retrieve information? How will the case study method impact student learning in the future, and in other learning
environments? In addition, research questions might also focus on new ways to investigate how to separate the context of the case from the learning of concepts with wide application beyond the specific scenario.

Although student attitudes toward science may not be altered by CMI, it appears that student motivation is indeed affected. Research questions that focus on motivational factors of CMI can yield some information that would be useful for improving learning science. Is the authentic basis of case studies a means for students to recognize relevance of science in their lives? Can cases motivate non-science major students to learn more science?

There is clearly a need for more research on how students learn and what part the case study method can play in helping students make learning gains. Quantitative methods, with appropriate assessments can lend support to the effectiveness of CMI for student learning. More qualitative studies, using interviews, can provide insight into how students learn with the case study method.
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APPENDICES
Appendix A

Questions for Student Interviews

These are the formal questions that will be asked of each student interviewee in the first and second interview. At the end of the semester, additional questions will be posed to students listed below.

Introduction:

The purpose of this interview is to find out what you think of the case study method of instruction and how it may have affected your learning in Biology 101 in the spring semester of 2006.

1. Please explain to me what you understand by the term “the case study method of instruction.”
2. Do you like the case study method?

YES: If the student liked the case method, the following questions will be asked:

3. Why do you like the case study method?
4. Did you find that the case method helped you to learn biological concepts (from genes topic for the first interview; for biodiversity and evolution for the second interview)? Please give examples.
5. What are some of the cases you found useful in this biology class? Please give examples.
6. What have you learned about yourself (i.e., personally) from your experience with the case study method?
7. How do you feel about group work after experiencing it in this class?

NO: If the student did not like the case method, the following questions will be asked:

3. Why do you dislike the case method?
4. What other kinds of teaching techniques do you think help you learn biological concepts (about genes)?
5. What have you learned about yourself (i.e., personally) from your experience with the case study method?
6. How do you feel about group work after experiencing it in this class?

Additional questions for the second interview:

1. What have you learned from the cases that may be useful in other classes you are taking now or will take in the future?
2. Please compare your past learning experiences in classes that do not use the case study method with this class.
3. What is your opinion about scientists and their work after taking this class?
4. Do you think the case study method has affected your attitude toward science?
5. The interviewee may be asked additional questions about some of their pretest/posttest answers for clarification.
### Rubric for Pre-posttest Question for Genes Question #1, Genetic Material*

<table>
<thead>
<tr>
<th>Level</th>
<th>Concepts</th>
</tr>
</thead>
</table>
| 4     | - The cheek cell and the sperm cell are produced by different processes.  
       | - Sperm cells have half the amount of genetic material that cheek cells have.  
       | - The cheek cell would contain all of the genetic material found in the sperm cell.  
       | - The genetic material in the sperm cell would match some of the genetic material in the cheek cell. |
| 3     | - Sperm cells have less genetic material that cheek cells have.  
       | - The cheek cell would contain all of the genetic material found in the sperm cell.  
       | - The genetic material in the sperm cell would match some of the genetic material in the cheek cell. |
| 2     | - The cheek cell would contain all of the genetic material found in the sperm cell.  
       | - The genetic material in the sperm cell would match some of the genetic material in the cheek cell. |
| 1     | - The genetic material in the sperm cell would match some of the genetic material in the cheek cell. |
| 0     | Sample alternative conceptions:  
       | The cheek cell carries no reproductive information.  
       | Sperm cells have X-chromosomes and Y-chromosomes, cheek cells do not.  
       | The sperm cell would only have the male chromosomes.  
       | The cheek cells do not carry the same chromosomes as sex cells.  
       | The genetic material found in a sex cell is identical to that of a somatic cell.  
       | The cells have different functions so their genetic information must be different.  
       | Cheek cells and sperm cells have the same genetic code (confused with genetic information) |

*If you could take a cheek cell and a sperm cell from the same person, how would the genetic information compare?

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Appendix C

Rubric for Pre-posttest Question for Genes Question #2, Biotechnology*

<table>
<thead>
<tr>
<th>Level</th>
<th>Concepts</th>
</tr>
</thead>
</table>
| 4     | • Human insulin can be harvested from bacterial cultures and used to treat diabetic patients.  
      | • The gene for making human insulin can be inserted into bacterial cells and subsequently the bacteria can produce human insulin.  
      | • Bacterial cells can make products of inserted genes.  
      | • Cells express genes, including those from other organisms. |
| 3     | • The gene for making human insulin can be inserted into bacterial cells and subsequently the bacteria can produce human insulin.  
      | • Bacterial cells can make products of inserted genes.  
      | • Cells express genes, including those from other organisms. |
| 2     | • Bacterial cells can make products of inserted genes.  
      | • Cells express genes, including those from other organisms. |
| 1     | • Cells express genes, including those from other organisms. |
| 0     | Sample alternative conceptions:  
      | Bacteria contain the gene for insulin.  
      | Bacterial genes are injected into human cells.  
      | Bacteria are used to break down sugars or alter unhealthy genes.  
      | Scientists use plasmids to create new medicines.  
      | Bacteria can “eat” or break down the sugar.  
      | The body produces insulin to fight off bacteria. |

*Today bacteria are used to produce human insulin for diabetic patients. Explain how this is accomplished.*
Appendix D

Rubric for Pre-posttest Question for Biodiversity Question #1, Ecosystem Services*

<table>
<thead>
<tr>
<th>Level</th>
<th>Concepts</th>
</tr>
</thead>
</table>
| 4     | • Natural ecosystems are able to filter pollutants and provide a sustainable source of clean water.  
• Development threatens natural ecosystems and decreases their biodiversity.  
• Construction of the filtration plant would cause more pollution and encourage population growth.  
• It was cost-effective. |
| 3     | • Development threatens natural ecosystems and decreases their biodiversity.  
• Construction of the filtration plant would cause more pollution and encourage population growth.  
• It was cost-effective. |
| 2     | • Construction of the filtration plant would pollute the watershed and encourage population growth.  
• It was cost-effective. |
| 1     | • It was cost-effective. |
| 0     | Sample answers that do not address the ecological impact:  
Development restrictions are a violation of landowners’ rights.  
Preservation of land is a barrier to economic development. |

*New York City watershed protection (http://www.actionbioscience.org/environment/esa.html)
### Appendix E

**Rubric for Pre-posttest Question for Biodiversity Question #2, Invasive Species**

<table>
<thead>
<tr>
<th>Level</th>
<th>Concepts</th>
</tr>
</thead>
</table>
| 4     | • The Asian clam has compromised the integrity of the ecosystem in San Francisco Bay.  
       | • The Asian clam has reduced the biodiversity of the Bay.  
       | • The Asian clam can out compete the native species for resources and has no natural predators.  
       | • The Asian clam has taken over the habitat. |
| 3     | • The Asian clam has reduced the biodiversity of the Bay.  
       | • The Asian clam can out compete the native species for resources and has no natural predators.  
       | • The Asian clam has taken over the habitat. |
| 2     | • The Asian clam can out compete the native species for resources and has no natural predators.  
       | • The Asian clam has taken over the habitat. |
| 1     | • The Asian clam has taken over the habitat. |
| 0     | Sample alternative conceptions:  
       | The community will eventually stabilize because the Asian clam is now part of it.  
       | The Asian clam may be a food source for some organisms and a predator to others.  
       | The Asian clam has made the Bay cleaner because it filters the water.  
       | The biodiversity of the area will be greater due to presence of the Asian clam.  
       | The Asian clam may hybridize with native clams & increase the biodiversity.  
       | The increased number of clams may become an economic advantage for the area.  
       | The Asian clams are better, stronger, or more powerful than the resident clams, and they will die off.  
       | There will be less phytoplankton biodiversity or the phytoplankton may become extinct because of the Asian clam.  
       | The Asian clam will outlive all the other clam species, or cause them to die off.  
       | The other clams will have to move out of the area. |

Appendix F

Rubric for Pre-posttest Question for Evolution Question #1, Natural Selection*

<table>
<thead>
<tr>
<th>Level</th>
<th>Concepts</th>
</tr>
</thead>
</table>
| 4     | • The resistant flies are able to produce more offspring than the nonresistant flies. Thus the population contains more resistant flies with each spraying.  
• Flies pass on their resistance to their offspring.  
• The flies that survive had resistance to the insecticide before it was sprayed.  
• The population changes as a result of exposure to the insecticide. |
| 3     | • Flies pass on their resistance to their offspring.  
• The flies that survive had resistance to the insecticide before it was sprayed.  
• The population changes as a result of exposure to the insecticide. |
| 2     | • The flies that survive had resistance to the insecticide before it was sprayed.  
• The population changes as a result of exposure to the insecticide. |
| 1     | • The population changes as a result of exposure to the insecticide. |
| 0     | Sample alternative conceptions:  
Individual flies become immune to the insecticide over time; they built up antibodies to the insecticide.  
The flies “learned” to adapt to the insecticide.  
The next generation was born with the insecticide in their bodies (like a vaccination).  
The flies became “used to” the insecticide and adapted to it, and passed this on to the next generation.  
The population of flies changes because of a “felt need” to do so.  
Exposure to the insecticide causes the flies’ genes to mutate.  
Weak flies die, the strongest flies survive (“survival of the fittest”). |

*“A farmer was working with dairy cattle at an agricultural experiment station. The population of flies in the barn where the cattle lived was so large that the animals’ health was affected. So the farmer sprayed the barn and the cattle with a solution of insecticide “A.” The insecticide killed nearly all of the flies. Sometime later, however, the number of flies was again large. The farmer sprayed again with the same insecticide. The result was similar to the first spraying. Most, but not all of the flies were killed. Again, within a short time the population of flies increased, and they were sprayed with the same insecticide. This sequence of events was repeated five times. It became apparent that insecticide “A” was less and less effective each time.” (NAS, 1998)
### Appendix G

**Rubric for Pre-posttest Question for Evolution Question #2, Microevolution**

<table>
<thead>
<tr>
<th>Level</th>
<th>Concepts</th>
</tr>
</thead>
</table>
| 4     | • The population will evolve to be brightly colored. Since there is no selective pressure against bright colors in the environment, these organisms will be most fit.  
• Males will become more brightly colored over time because the females prefer them.  
• The population will eventually have more diverse coloration than the two founder parents.  
• The population will grow rapidly until resources become limited. |
| 3     | • Females will mate with the more brightly colored males.  
• The population will eventually have more diverse coloration than the two founder parents.  
• The population will grow rapidly until resources become limited. |
| 2     | • The population will eventually have more diverse coloration than the two founder parents.  
• The population will grow rapidly until resources become limited. |
| 1     | • The population will grow rapidly until resources become limited. |
| 0     | Sample alternative conceptions:  
Individuals in the population will all look the same as the parents.  
Some individuals will become more colorful in order to attract females because of the lack of predators.  
The guppies would go extinct because the female would not mate with the male.  
They would retain their medium color because there is no mating competition.  
Slowly the males would become more brightly colored.  
They would become overpopulated.  
They would mate and create a new species of guppy.  
The brighter genes would become dominant and so they would be passed down.  
With no predators, the males could become as colorful as they wanted.  
The female guppy may mate with another type of fish that she finds more appealing.  
The female would change her mind about what is attractive. |

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*Guppies are small fish found in streams in Venezuela. Male guppies are brightly colored, with black, red, blue, and iridescent (reflective) spots. Males cannot be too brightly colored or they will be seen and consumed by predators, but if they are too plain, females will choose other males. Assuming ideal conditions with available food and space and no predators, what would happen over time if a male and a female guppy (of medium coloration) were placed in a large pond where none existed before? (Adapted from Anderson, et al., 2002)*
Appendix H

The Scientific Attitude Survey (SAI II)

1. I would enjoy studying science.
2. Anything we need to know can be found out through science.
3. It is useless to listen to a new idea unless everybody agrees with it.
4. Scientists are always interested in better explanations of things.
5. If one scientist says an idea is true, all other scientists will believe it.
6. Only highly trained scientists can understand science.
7. We can always get answers to our questions by asking a scientist.
8. Most people are not able to understand science.
9. Electronics are examples of the really valuable products of science.
10. Scientists cannot always find the answers to their questions.
11. When scientists have a good explanation, they do not try to make it better.
12. Most people can understand science.
13. The search for scientific knowledge would be boring.
14. Scientific work would be too hard for me.
15. Scientists discover laws, which tell us exactly what is going on in nature.
16. Scientific ideas can be changed.
17. Scientific questions are answered by observing things.
18. Good scientists are willing to change their ideas.
19. Some questions cannot be answered by science.
20. A scientist must have a good imagination to create new ideas.
21. Ideas are the important result of science.
22. I do not want to be a scientist.
23. People must understand science because it affects their lives.
24. A major purpose of science is to produce new drugs and save lives.
25. Scientists must report exactly what they observe.
26. If a scientist cannot answer a question, another scientist can.
27. I would like to work with other scientists to solve scientific problems.
28. Science tries to explain how things happen.
29. Every citizen should understand science.
30. I may not make great discoveries, but working in science would be fun.
31. A major purpose of science is to help people live better
32. Scientists should not criticize each other’s work.
33. The senses are one of the most important tools a scientist has.
34. Scientists believe that nothing is known to be true for sure.
35. Scientific laws have been proven beyond all possible doubt.
36. I would like to be a scientist.
37. Scientists do not have enough time for their families or for fun.
38. Scientific work is useful only to scientists.
39. Scientists have to study too much.
40. Working in a science laboratory would be fun.
Appendix I

Student Assessment of Learning Gains (SALG) questions

Q1D How much did each of the following aspects of the class help your learning? The class activities.
  Q1D.1 Use of the case studies to learn concepts.
  Q1D.2 Group work on case studies in class.
  Q1D.3 Class discussion of case studies.

Q1E How much did each of the following aspects of the class help your learning? Test, graded activities, and assignments.
  Q1E.1 Reading case studies for homework and answering questions on them.
  Q1E.2 Test questions using case studies.
  Q1E.3 Case study project – the ecological footprint.

Q2 As a result of your work in this class, how well do you now understand each of the following?
  Q2.1 The characteristics of a scientific hypothesis.
  Q2.2 The importance of evidence in science.
  Q2.3 The difference between mitosis and meiosis.
  Q2.4 The difference between a body cell and a gamete.
  Q2.5 How to do basic genetics problems.
  Q2.6 The importance of DNA to life processes.
  Q2.7 The importance of the genetic code in biotechnology.
  Q2.8 The three levels of biodiversity.
  Q2.9 Threats to biodiversity.
  Q2.10 Natural selection as differential survival.
  Q2.11 Speciation (macroevolution) due to reproductive isolation.
  Q2.12 The basis for the creationism-evolution controversy.

Q3 How much has this class added to your skills in each of the following?
  Q3.1 Critically reviewing case studies.
  Q3.2 Writing a critical essay for the take-home exam.

Q4 To what extent did you make gains in the following as a result of what you did in this class?
  Q4.1 Understanding the main concepts.
  Q4.2 Understanding the relationship between concepts.
  Q4.3 Understanding the relevance of these concepts to real-world issues.
  Q4.4 Ability to think through a case study and analyze it.
  Q4.5 Feeling comfortable with complex ideas.
  Q4.6 Enthusiasm for biology.

Q5 How much will you remember and carry with you into other classes or aspects of your life?
  Q5.1 Concepts about stem cells from the case study “Saving Superman.”
  Q5.2 Ideas about cloning from the case study “Bringing Back Baby Jason.”
  Q5.3 The universality of the genetic code from the case study “Torn at the Genes.”
  Q5.4 Lifestyle impacts from the case study, “Watch Your Step: Understanding Personal Consumption.”
  Q5.5 The characteristics and effects of invasive species from “Aliens” and “Cane Toads.”
  Q5.6 Concepts about polygenic inheritance and population variation from “Desiree’s Baby.”
  Q5.7 How natural selection works from the case study “Sasha and Tuberculosis.”
  Q5.8 How selective pressure drives natural selection from the case study “Fatu and Malaria.”
Appendix J-1

Student responses as % and mean (SD) to Student Assessment of Learning Gains (SALG)

Class 1

<table>
<thead>
<tr>
<th>Question</th>
<th>NA</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>total</th>
<th>average (SD)</th>
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</thead>
<tbody>
<tr>
<td>Q1D.1</td>
<td>0%</td>
<td>5%</td>
<td>10%</td>
<td>30%</td>
<td>50%</td>
<td>5%</td>
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<td>3.4 (0.92)</td>
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<td>Q1D.2</td>
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<td>5%</td>
<td>40%</td>
<td>30%</td>
<td>20%</td>
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<td>0%</td>
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<td>3.6 (0.86)</td>
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Appendix J-2

Student responses as % and mean (SD) to Student Assessment of Learning Gains (SALG)

Class 2

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Appendix J-3

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