Effects of Participation in Inquiry Science Workshops and Follow-up Activities on Middle School Science Teachers' Content Knowledge, Teacher-Held Misconceptions, and Classroom Practices

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EFFECTS OF PARTICIPATION IN INQUIRY SCIENCE WORKSHOPS
AND FOLLOW-UP ACTIVITIES ON MIDDLE SCHOOL SCIENCE
TEACHERS’ CONTENT KNOWLEDGE, TEACHER-HELD
MISCONCEPTIONS, AND CLASSROOM PRACTICES

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Dr. Linda F. Cepeda

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Advisor: Dr. James Platt
ABSTRACT

An important aspect of developing science literacy for all students is developing science-literate teachers. With the implementation of the No Child Left Behind Act, many middle school teachers found themselves in a position where they were no longer qualified to teach middle school science. This study was designed to help science teachers increase their science content knowledge, identify and resolve misconceptions/errors they may have, and assist them in their teaching by providing strategies for inquiry-based teaching, science laboratory exercises, and science equipment.

Teachers enrolled in biology courses offered by the Rocky Mountain Middle School Math and Science Partnership participated in this study. They were required to take pre-, post-, and follow-up assessments over course concepts, complete a survey over their background and teaching pedagogy, and be observed teaching in their classrooms for three class periods followed by an interview after each observation.

The results included key findings:

1) These assessments indicated that science teachers can increase their science content knowledge by attending high-quality professional development
courses designed to help increase basic science content knowledge on science content.

2) Teachers held numerous misconceptions as shown by the assessments and classroom observations. Some were resolved, some that appeared to be resolved at the time of the post test reappeared again on the follow-up test, and some were not resolved.

3) Teacher observations showed that they did use science equipment provided by the course instructors and they taught the content from the Biology course where appropriate. Teachers teaching classes other than biology demonstrated their ability to teach inquiry science by employing inquiry activities and teaching with a "scientific method" approach.
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CHAPTER 1 INTRODUCTION

“There is nothing more difficult to manage, or more dangerous to execute, than the introduction of a new order of things.” Niccolo Machiavelli

Even though Machiavelli was not an educator and he lived more than 300 years ago, this quotation is appropriate to describe the problems faced when implementing a widespread reform in any area of teaching. The efforts to reform science teaching are worldwide – 141 countries are now in the process of revising their outdated science educational programs due to the rapid increase in science information (Hurd, 1997). The ultimate goal of science education is to educate students so they will be literate in science and able to make decisions based on some knowledge of science (Hurd, 1997). It is a daunting task; one that requires the support of every individual and every aspect of the science educational process. Education in the United States has a long history of reform efforts, and this one is the most far-reaching yet.

20th Century Major Education Reforms

The First Reform Effort (1940s and 1950)

Educational trends after the Second World War included the development of student personal and social goals, a definitive list of academic subjects (humanities, social studies, mathematics, and science), and support for ability
grouping. Science education was characterized by integration and comparing the individual areas of science as well as the history of science and the problems of society. High school was the focus of science education improvement with science curricula arranged in graded complexity so teachers could organize meaning at successively higher levels of learning (Bybee, 1997).

The Second Reform Effort (1960s and 1970s)

By the 1960s, another educational reform began. Contemporary education was described as "mindless" - students were “doing” things, but did not know why because they were asking how questions instead of why questions. Ability grouping, which was implemented during the first educational reform wave of the 1940s, came to be seen as isolating and alienating students (Bybee, 1997). This new phase ushered in education that focused on getting students reconnected to society. The Biological Sciences Curriculum Study (BSCS – started in 1958 by a grant from the National Science Foundation) was providing new curricular materials based on science and technology for schools.

During the 1970s there was reduced National Science Foundation concern for educational innovation due to U.S. involvement in the Viet Nam War (Dunbar, 2002). Congress asked the National Science Foundation (NSF) to examine the status of American education (Bybee, 1997). The Advisory Committee for Science Education advocated science curricula with an educational focus of science and mathematics that showed connections between
science and technology to societal issues (Hurd, 1997). The topics of environment and ecology were added into the curricula.

A review of the literature shows that the goals of science education were still to prepare scientists, provide background for careers in technical occupations and to provide general science education for the citizens (Bybee, 1997). It would be some years yet before this last goal would be the main focus of science education.

**The Third Reform Effort (1980s to the present)**

In the 1980s, another educational reform was launched in response to the publication of *A Nation at Risk* (National Commission on Excellence in Education, 1983). A weak United States economy and strong international commerce were indicators that a new crisis was approaching with the need for a strong national defense system combined with higher levels of academic achievement (Bybee, 1997). The purpose of science education was linked to scientific literacy and the connections between science and society were re-emphasized as were the roles of science and technology in U.S. society. A “back-to-basics” effort was proposed that included a longer school day, an emphasis on basic subjects and homework for students. Competency exams, graduation requirements and college entrance requirements, assessments, textbooks, and other matters were reviewed (Bybee, 1997).
The American Association for the Advancement of Science Efforts

In 1985, Project 2061 was formed (AAAS, 1990) to study science and technology education in the United States. Project 2061 is part of the American Association for the Advancement of Science (AAAS). Its function is to evaluate curriculum and assessment materials, provide teacher education materials and reform tools for educators, and offer development workshops for teachers. The document resulting from their efforts recommended decreasing the number of concepts students should learn and contained a precise listing of what students should know at each grade level. Shamos (1995) believed that even this document was too cumbersome and that what there is to know about science (with the explosion in science research and information) was so vast, that listing the benchmarks with details would result in an enormous amount of information for students to learn and for teachers to teach.

By the 1990s, the science education movement had split into two fronts. One front consisted of a policy group wanting to develop new conceptual frameworks centered on educational policies reflecting the culture change and the nature and actual practice of science with the new discoveries. The other front (the majority) viewed problems with science education more from the standpoint of teaching and getting equipment and necessary supplies so the teaching could be done appropriately and with current technology (Hurd, 1997). In 1991, the U.S. government targeted science education (K-12) as a priority in education reform and established a group to study this called the Committee of Education Coordination and Council for Science, Engineering, and Technology.
Its job was to set up guidelines for funding and programs affecting math and science education (Hurd, 1997).

National Standards

Major science education reform work was completed. Standards and benchmarks were put in place that provided guidance and concrete plans of what pupils should know and when they should be taught specific topics so they would be scientifically literate. Science education reform was supported by Bill Clinton, then governor of Arkansas. He wrote the national goals for education when he attended an education summit called by President George Bush Sr. in 1990. The goals and principles of science education were clarified and what non-scientists (the general populace) needed to know about science was also established. The consensus was that non-scientists needed enough background to grasp and deal with matters involving science and technology as well as the ability to understand science in its day-to-day context (Bybee, 1997).

Congress created the National Council on Education Standards and Testing in 1992, and they began by defining the content standards which were passed into law in 1993. The specific details were elaborated and clarified in the Goals 2000: Educated America Act which was passed into law in 1994 by President Clinton (Goals 2000, http://www.ed.gov/pubs/G2Reforming/index.html, Hurd, 1997).

So that educational issues could be debated in the House of Representatives, the Education 2005: the Role of Research and Development in
an Overwhelming Campaign for Education in America was put together to outline the research in this area done from the 1980s to the mid 1990s (Hurd, 1997). It proposed five years of comprehensive experimentation, five years of intensive evaluation, and then five years of consolidating and implementation of what worked (as determined by the ten years of experimentation and evaluation). This would be done by 2005 and would usher in a new era of education. Policy concerns were that education be linked to work, that parents participate in the education of their children, that students would be knowledgeable in math and science, and that business, labor, and education leaders would work together to help students learn (Hurd, 1997).

Key Resources

A number of major books for science education and teacher professional development were published in the 1990s: AAAS Project 2061 published Science for All Americans (1990), Benchmarks for Science Literacy (1993) and Resources for Science Literacy Professional Development (1997); the National Research Council published the National Science Education Standards (1996) and Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology (1999); and Third International Mathematics and Science Study released Toward a New Understanding of Basics in Mathematics and Science Instruction (1997). Bill Clinton and Al Gore published a series of three books outlining the plans for this and basically came up with the goals of the Education 2000 Act (Hurd, 1997).
Goals 2000: Educate America Act

There was a long-term strategy in the late 1990s to increase achievement. America 2000 was released by President Bush. It contained a four-part ambitious plan to: 1) improve schools and make them accountable, 2) invent new schools for a new century, 3) encourage continued learning for graduates, and 4) involve communities and families in school programs. There were eight goals: 1) all students will start school ready to learn, 2) the high school graduation rate will be at least 90%, 3) students in grades 4, 8, and 12 will pass a competency exam, 4) America will be first in the world in science and mathematics, 5) all Americans will be literate and ready to compete in a global market, 6) schools will be violence and drug-free, 7) teachers will have access to programs for their continuing education needed to prepare them to teach for the next century, and 8) every school will promote partnerships to increase parental involvement in their children’s education (Goals 2000, http://www.ed.gov/G2K/index.html).

These reform measures involved the entire educational system and although specific strategies for their implementation were not laid out, this document gave the educational community an opportunity for their input for specific programs to achieve those four goals. The time frame in which to accomplish these was by the year 2000. Bybee (1997) maintained that the contemporary reform movement in science education was different from that of earlier times because it was more vigorous, was driven by actual data and information from assessments (both national and international), and was more penetrating, pervasive and political.
Results of Reform Efforts

The cycles of reform over the last 65 years have two distinct characteristics. They have put the emphasis on input features like curriculum materials and teaching strategies and *they have had virtually no effect on teaching and learning in classrooms* (Bybee, 1997). Bybee maintains that the reason has to do with implementation – that educational reform has to be approached in a systematic way and all aspects of the educational process must be involved with the decisions. That is, teachers, school personnel, science supervisors, teacher educators, and other science educators all must be involved. The central role of the teacher must be recognized since they are the main people interacting with students. They select the materials and concepts that they will teach, and they do the teaching. All other components of the educational process need to be considered as well. So, the focus should not be only assessment, but teaching strategies, curriculum, activities, and all the complex parts of the educational system. Emphasizing only one component of the education system to be changed will not fix the whole system since it is a complex system with many components and regulatory mechanisms. Even addressing several components would still result in lack of continuity, coherence, and coordination within the system (Bybee, 1997, Trefil, 2003).

Hurd (1997) maintains that there are two major reasons why reform efforts have not had a more significant effect on educational outcomes. One is the fact that the first five or six years of children’s lives are spent at home or in some type of child care arrangement. Expecting all children to start school ready to learn is
not realistic. Even with schools promoting partnerships between parents and schools, the transition from home to school is not always a smooth one. Families have become vastly different than those of fifty years ago and unless education/educators find better ways to deal with current family structures and situations, educational goals will be hard to reach (Hurd, 1997).

The second reason Hurd feels that reforms have failed is that school is not linked to work. Most people have to work for most of their lives and students are not getting the skills they need to succeed in the work place. Word from employers is that high school graduates lack higher order thinking skills and science knowledge that includes economic and technology dimensions (Hurd, 1997). The results from one of the many committees formed to look at educational issues showed that part of the problem in reaching those goals is that many science teachers are not able to relate science concepts to real-world situations – either they do not have that experience themselves or they do not have an appropriate curriculum to use (Hurd, 1997). An extensive summary of national recommendations regarding science education is located in Appendix A.

**Science Literacy as a Contemporary Science Educational Goal**

The goal of science education now is scientific literacy for all students instead of only those students planning on a scientific career. During the 1960s, the term “science literacy” was introduced and became the single term expressing the purposes of science education. This term was first used by James Bryant Conant to convey a broad, contextual understanding of science
with no elaboration. Later Paul DeHurt used the same term to explain the understanding of science and its applications to social experience (Bybee, 1997).

His definition of a scientifically literate person was:

“A scientifically literate person has a precise understanding of some of the key concepts, laws, and theories of science. He can relate these concepts, laws, and theories in a logical and coherent manner and can appreciate their significance. To be scientifically literate is to understand the place of the individual in the process of discovery and to recognize how the temper of the times influences the evolution of ideas. The scientifically literate recognize the limitations of science and know about its many unresolved problems. Most of all, they appreciate how the use of intelligence in inquiry and experimentation has advanced man’s understanding and influenced the course of society.” (Bybee, 1997)

A definition of science literacy for society in general was compiled to contain five points. The scientifically literate person should:

1. understand the interrelationships between science and society.
2. understand the methods and processes of science.
3. have a knowledge of fundamental science concepts or conceptual schemes.
4. understand the difference between science and technology.
5. understand the relationship between science and the humanities or look upon science as one the humanities (Bybee, 1997).

DeHurt’s thought was that science should have a prominent role in society and that economic, political and personal issues should not be considered without reference to science (Bybee, 1997). Trefil and Lederman agreed saying that educated individuals should be able to deal with scientific matters they come across in public life with the same facility they would demonstrate in dealing with political, legal, or economic matters (Trefil, 2003, Lederman, 2003).
“Today, most aspects of human welfare and social progress are in some manner influenced by scientific and technological innovations. In turn, scientific knowledge establishes new perspectives for reflection upon social problems. The ramifications of science are such that they can no longer be considered apart from humanities and social studies. Modern education has the task of developing an approach to the problems of mankind that considers science, the humanities, and the social studies in a manner so that each discipline complements the other.” (Bybee, 1997)

Our society is increasingly called upon to deal with issues that contain scientific or technical components, so science literacy is a necessity. Without science literacy, our society would be one in which decisions are made by an intellectual elite, or perhaps the opposite – an uneducated mass (Trefil, 2003).

Morris Shamos published “The Myth of Scientific Literacy” in which he accused the science education community of using scare tactics to increase awareness and funding for science education. He claimed that the information presented by the science education community was misguided and based on incorrect information using data collection methods that were inappropriate (Shamos, 1995). He also stated that the true motive for increased attention to science education was to increase the number of scientists and engineers.

Shamos lauded the aim of having an informed and scientifically literate public, but maintained that it was an unachievable and unrealistic goal. He stated that there were no accurate ways to measure whether it was achieved or not because science is a difficult subject in which knowledge must be built from the ground level up due to its cumulative nature. It is often counter-intuitive and involves a strong mathematical component which makes a general high-level
science education of students an unlikely prospect (Shamos, 1995). His book, while interesting, did not change American educational goals.

Teacher Education Goals

The educational reform that is taking place today in the United States is not only a reform for students - it also contains reform measures for teachers. Over time, reform for teachers has involved changes in their subject curriculum and the way in which they are taught, what they are taught, and how they are tested (Bybee, 1997). The Goals 200 Educate America Act includes a goal to support the continuing education of teachers so they will be prepared to teach contemporary subject material (Goals 2000, http://www.ed.gov/G2K/index.html).

Laying a foundation for a scientifically literate workforce begins with developing outstanding K-12 teachers in science and mathematics. The No Child Left Behind initiative requires a highly qualified corps of teachers. Improvements in student achievement are linked to teacher excellence, and characteristics of excellent teachers are: they are knowledgeable about content and pedagogy, have the ability to motivate students, and they utilize opportunities for continuing their education. Excellent teachers inspire young people to develop analytical and problem-solving skills, the ability to interpret information, the ability to communicate what they learn, and to master conceptual understanding (Committee on Prospering in the Global Economy of the 21st Century, 2007).
The findings regarding teachers indicated that they were inadequately prepared due to a preponderance of education classes in place of subject matter classes. The public's opinion of teaching suffered due to the low pay for career teachers, a shortage of teachers in critical subjects like science (earth, life, and physical sciences) and mathematics; as well as foreign language, and special education. Bybee (1997) and Kanstoroom (1999) addressed the issue of teachers who were not qualified to teach, but were teaching. Recommendations called for strengthening all science subject areas, but specifically the critical areas of math and science. The need for reform in student and teacher curricula and the need for standards and ways of measuring success in achieving the goals were also points of contention. The ultimate goal was to train more qualified teachers, and have teachers take more math and science courses in their high school and college careers resulting in more college degrees being awarded in mathematics and the sciences (National Commission on Excellence in Education, 1983).

Science educators are realizing that in terms of scientific literacy, prospective teachers of science in the elementary grades are not much different than the general US population in which only 5% of the adults are scientifically literate (Fleury et al., 1991). Preservice teachers often have little understanding of basic concepts of life, earth, and especially physical science since in-depth science courses covering this information are not required for their certification. Programs focusing on the content set out by state standards could have a
substantial impact on the problem by preparing teachers to teach science (Fleury et al., 1991).

In 1996, the National Research Council placed emphasis on the importance of teaching secondary science teachers critical evolutionary concepts. Crawford et al. (2005) did a study to address research in the areas of teacher understandings of scientific inquiry and conceptual understanding of evolutionary processes. Forty two percent of Americans (Novotny, 2005) deny the existence of evolution – something that many scientists consider to be the central organizing theory of biology. Few science educators have made any real strides in addressing students’ struggles with understanding fundamental Darwinian concepts or the central importance of theories to the scientific endeavor (Shtulman, 2006). It is fairly evident that many high school and college students as well as the general public do not have a good grasp of key scientifically accepted evolutionary concepts, but cling to alternative conceptions – especially those based on the Lamarckian approach that evolution proceeds as a result of need (Crawford et al., 2005, Bishop et al., 1990).

Science literacy as a goal is more closely aligned with the current general education plan of schools, but is more difficult to achieve. Designing science programs to accommodate the diversity in our public schools and to have quality and excellence while developing the each student’s potential is a challenge. The No Child Left Behind Act was introduced to the American Public in 2001 (U.S. Dept of Education, 2001) in an attempt to raise the standards of education for all
students by redistributing teaching resources and equalizing the distribution of federal money for education. We are still working on this in 2009.

Teachers are the key to improving student performance, but there is a shortage of highly qualified K-12 teachers in many of our nation’s 15,000 school districts, so uncertified and “underqualified” teachers have been hired in desperation. Table 1 shows the percentage of public school students taught by teachers without proper qualifications in their subject area.

**Table 1. US Students Taught by “Underqualified” Teachers**

Students in US Public Schools Taught by Teachers with No Major or Certification in the Subject Taught, 1999-2000

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Grades 5 - 8</th>
<th>Grades 9 - 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>English</td>
<td>58%</td>
<td>30%</td>
</tr>
<tr>
<td>Mathematics</td>
<td>69%</td>
<td>31%</td>
</tr>
<tr>
<td>Physical Science</td>
<td>93%</td>
<td>63%</td>
</tr>
<tr>
<td>Biology/Life Science</td>
<td>NA</td>
<td>45%</td>
</tr>
<tr>
<td>Chemistry</td>
<td>NA</td>
<td>61%</td>
</tr>
<tr>
<td>Physical Chemistry</td>
<td>NA</td>
<td>67%</td>
</tr>
<tr>
<td>Physical Education</td>
<td>19%</td>
<td>19%</td>
</tr>
</tbody>
</table>

(Bobbit & McMillen, 2003)

Many middle school and high school teachers teach outside of their discipline. Even though this report is for the 1999-2000 school year, the results are not much different today. A U.S. high school student has now has a 70% chance of being taught English by a teacher with a degree in English, but only a 40% chance of studying chemistry with a teacher who has a degree in Chemistry. In all fairness, it should be noted that rarely can a student in any
grade be taught physical education (P.E.) by a teacher with a degree in P.E.; however, oftentimes teachers with degrees in an academic subject will have a minor in P.E. (Committee on Prospering in the Global Economy of the 21st Century, 2007).

Student Science Literacy Now

Test scores of 4th, 8th and 12th grade students from 1996, 2000, and 2005 show that younger students are making the most progress in science. Fourth grade student basic science scores were highest in 2005, while 8th grade student scores remained the same and twelfth grade student scores decreased (Grigg et al., 2006). The percentage of fourth grade students performing at or above the Basic achievement level increased from 63% in 1996 to 68% in 2005. The percentages for eighth grade students remained the same (59%). For twelfth grade students, the average score decreased and the percentage of students scoring at or above the Basic level was only 54% (Grigg et al., 2006). This points to a deficiency in their high school science education (Associated Press release of NCES report).

The U.S. was 9th in the world (tied with Australia) as evidenced by their science scores in 2003 (46 countries participated in the testing). When scores from 1995, 1999, and 2003 were compiled by TIMSS, the U.S. ranked 9th in science (eighth grade).

These scores do not portray a dire picture, but they do not fulfill the expectations that the U.S. has of its students as expressed by the America 2000
document released by President George Bush and the No Child Left Behind Act 2001 (107th Congress, 2002). These statistics alone provide justification for a study to see how best to help middle school science teachers learn more about science and the process of science and, in turn, help their students fulfill their potential in the area of science.

We need to recruit, educate, and retain excellent K-12 teachers who fundamentally understand biology, chemistry, physics, engineering, and mathematics. There is a vital need for unqualified teachers properly to be properly trained in the disciplines in which they teach. It would be better to not have unqualified teachers in the science and mathematics classroom, but the reality of the situation is that they are already in the classrooms and they are teaching the nation’s children. If we cannot replace them due to teacher shortages, we must at least give them the opportunity to better learn the material they are teaching.

**Rationale for this study**

It is different aspects of the problem of middle school science teachers’ qualifications that this study addresses. The problem with finding qualified teachers at the middle school level is especially acute since the academic requirements for middle school teachers changed dramatically with the No Child Left Behind Act (107th Congress, 2002). There are stricter guidelines regulating the academic background teachers must have in order to teach at specific grade levels. The field of science teaching has been greatly affected by these changes.
Elementary school certified teachers may teach 6th grade science at the middle school level with no additional academic subject training which means that they may not have taken any science courses in college, but are teaching science. Teachers certified in middle school teaching or in an academic area may teach 7th and 8th grade (but not 6th) science if the academic area of their certification is in one of the sciences (life, physical, or earth science) or if they have had 24 hours in science coursework. Teachers are allowed to teach science with 24 hours of science coursework, but content specificity is not legislated. This situation has created the problem of middle school teachers with highly varied science back-grounds -- from no science coursework to those with a major or even a graduate degree in science. Teachers themselves realize the situation and those with deficiencies in science subject matter have been trying to obtain additional science training so that they are better able to understand the material they are now required to teach (personal communication, Linda Morris, then district science coordinator for Jefferson County Schools, now with Denver Public Schools).

The reality of the situation is that many schools, especially those in poorer and rural districts, find themselves unable to adequately staff their classrooms with science teachers that meet the new qualifications. This has created a necessity for middle school teachers to upgrade their credentials. This is the rationale behind the study – the design and implementation of an effective method of bringing “underqualified” middle school science teachers up to meet the new standards.
The University of Colorado at Denver faculty from the College of Education wrote a science education grant to the National Science Foundation to obtain funding for classes in mathematics, chemistry, and earth, physical, and life sciences for middle school teachers. They were awarded a grant (the Rocky Mountain Middle School Math and Science Partnership (RM-MSMSP)). It was a five-year project designed to provide a venue for teachers to upgrade their science and mathematics credentials in an educationally appropriate way with other teachers and with professors and specialists involved in the design and teaching of the courses.

The course structure was hands-on science inquiry classes with heavy emphasis on academic material, strategies to implement the material into their teaching, laboratory exercises and time for discussion between teachers concerning subject material, pedagogy, and other matters. There were follow-up classes for each of the summer courses to further clarify academic conceptions, concentrate more on teaching pedagogy, and allow time for commiseration between teachers.

**Problem Statement**

The problem of a lack of qualified middle school science teachers was addressed by offering two professional development Biology courses designed by University of Denver faculty and science professionals and teachers. The two courses offered content knowledge in biology as well as pedagogical knowledge in an integrated way with inquiry techniques, relevant activities for teachers to do
hands-on science as well as receive take-home labs and equipment for use in their classrooms. The course instructors modeled different teaching strategies during the courses. The purpose of the two courses was to increase middle school science teachers' background science content knowledge and to provide good teaching strategies and pedagogy. While this study is not an evaluation of the courses, per se, the teacher feedback, assessments, projects, and other course requirements allowed the instructors a critical look at teacher science content background and provided the opportunity to improve the courses with each successive class of teachers by adjusting content, pedagogical activities and laboratory exercises to suit the needs of the teachers.

This study problem has basically three parts:

1. teacher learning and retention,
2. teacher misconceptions, their resolution or retention, and their recognition of their students' misconceptions in the classroom
3. teacher use of the labs, activities, or equipment from the courses in their classrooms.

The Biology 1 and 2 courses serve as professional development for the teachers' goal to improve their science content knowledge and fulfill the teacher qualifications required by the No Child Left Behind Act. Many professional development courses are designed for a two-week intensive experience, but have no follow-up to support the teachers or additional help in clarifying concepts or help with pedagogy. With the two-week class and follow-up format, it was possible to ascertain the level of academic content teachers had at the start of
the course, at the end of the course and at the end of the follow-up course. If teachers retain content information with this course format, then this is direct evidence that classes with follow-up courses and classroom support are an effective way to help teachers.

The two biology courses’ pre-, post-, and follow-up multiple choice assessments were written such that misconceptions could be charted and tracked for resolution. The Biology 1 course had classroom observations built into the follow-up course, so there was an opportunity to see if teachers were still holding various misconceptions and if they were able to note student misconceptions in the classroom. This way, in addition to noting teacher and student misconceptions, it could be seen if misconceptions/errors were resolved by participation in the course and if the teachers were able to recognize and address their students’ misconceptions/errors.

The classroom observations also allowed the researcher to see if the teachers were incorporating any of the material from the course into their classrooms and if they used any of the labs or materials from the course in their teaching. Teachers also completed a questionnaire over their academic and experiential background, what practices they employ in their teaching and if the material from the course was helpful to them in their teaching. This information on teaching practices was corroborated by the researcher in the classroom observations.
CHAPTER 2 LITERATURE REVIEW

Constructivism in Education

The kind of learning in which learners construct knowledge for themselves by using sensory data and prior knowledge is known as constructivist learning (Hein, 1991) (Appendix B). Christianson et al. (1999) reported that college students in a constructivist course learned significantly more than students in a traditional lecture course. Their suggestions for enhancing and motivating student-learning in the classroom were to allow discussion between students and teachers and between students and other students, allow time for prediction, use concept maps to anchor concepts and construct meaning, and to use a variety of teaching methods. Davis (2003) and Even (1993) state that teacher learning (like student learning) should be steeped in constructivist theory. Specific strategies mentioned were to scaffold student experiences and information from simple to more complex, to be aware of misconceptions and select appropriate activities to challenge them, and to reinforce conceptual change by engaging students in small-group and whole class discussions of data (Christianson et al., 1999).
Principles of Inquiry in Science

Inquiry describes an instructional methodology that supports constructivism. Science for all Americans Project 2061 (1990) states that the teaching of science should be consistent with the nature of scientific inquiry. Scientific inquiry is often presented as the “scientific method” – a list of science process skills that are performed to study a problem (Wilke et al., 2005). The development of the ability to think and act in ways associated with the processes of science inquiry includes key elements such as: asking questions, planning and conducting an investigation, using appropriate tools and techniques, thinking critically and logically about the relationships between evidence and explanations, constructing and analyzing alternative explanations, and engaging in and making scientific arguments (Enger, 1998). Lederman (2003) and Wilke (2005) state that scientific inquiry is not just using science process skills, but is also the combining of these processes with scientific knowledge, reasoning, and critical thinking skills to actively learn by doing.

Learning science is different than learning other subjects and constructivist learning with inquiry methods is particularly useful in helping students learn science. Situations in which students are given the opportunity to have their own experiences to create knowledge, logically critique their work, and judge the credibility of their own conclusions would be ideal since they could reflect on their reasoning processes and evaluate scientific knowledge (Fleury et al., 1991, Lawson et al., 1988, Bransford et al., 2000, Donovan et al., 2005).
One way for students to learn by doing is for them to have meaningful laboratory experiences. Freedman (1997) found that laboratory instruction with inquiry methods influenced students’ attitudes toward science and their achievement in a positive way. However, the use of “cookbook” labs used in place of authentic science experiences short-changed students’ imagination and learning and left them with incomplete understanding of the purpose of the lab (Bransford et al., 2000).

An essential part of scientific inquiry in the classroom is collaboration reinforced by frequent group activity or cooperative learning. Group activities have been associated with improved attitudes toward subject matter, expanded student-faculty interaction, improved classroom behavior climate, and the development of life-long learning skills (Tanner et al., 2003). The Boyer Commission Report of 1998 pointed out that undergraduate students attending large universities were often inadequately taught, due in large part to high student/faculty ratios and large lecture-format classes (Wood, 2004) where there was little or no chance for in-class collaboration. He recommended that university science departments transform their undergraduate course format to accommodate smaller groups and to use inquiry-based curricula employing a broad spectrum of research-related experiences which range from student-centered, inquiry-based introductory courses to laboratory projects to faculty-mentored independent research. He stressed that the idea behind inquiry is that the learner should not have already been taught the correct answer or outcome (Loughran, 2003). The process of discovery should be an active one for the
student (Wood, 2004) which would closely reflect the nature of scientific inquiry (Anderson, 2002).

Meta-analyses have shown that inquiry teaching produces positive results (Anderson, 2002). Costenson et al. (1986) discussed results of a sizable meta-analysis done on inquiry in classrooms from 1957 through 1980. The results were that an inquiry teaching approach led to significantly better performance when high levels of thought were considered and it led to essentially equal performances on low level cognitive outcomes. However, many teachers are still uninformed about inquiry methods, their deployment, and their usefulness (Loughran, 2003).

Zembal-Saul (2002) maintained that the teaching of science change from exploration and experiment to argument and explanation. It is the opinion of the researcher that all of these are needed to teach inquiry.

**Inquiry in the Science Classroom**

There are several school factors that play important roles in the extent of inquiry-based practices teachers use. One is the amount of support from the school principal. Teachers who feel supported by their school principal report significantly greater use of reform approaches than do teachers who are not encouraged by their school leader. Appropriate school resources, planning time, and availability of science-related resources also play an important role. Schools in rural districts or those in poorer neighborhoods without adequate resources
use considerably less inquiry-based or investigative practices (Supovitz et al., 2000).

Tretter et al. (2004) state that there are fundamental abilities students (as well as their teachers) must have in order to do scientific inquiry. They must be able to:

1. identify questions that can be answered through scientific investigation
2. design and conduct a scientific investigation
3. use appropriate tools and techniques to gather, analyze, and interpret data.
4. understand that mathematics is an important tool in all aspects of science inquiry
5. develop descriptions, explanations, predictions, and models using evidence
6. think critically and logically to construct/see the relationships between evidence and explanations
7. recognize and analyze alternative explanations and predictions and that science advances through legitimate skepticism
8. communicate scientific procedures and explanations that may result in fresh ideas for future study (Shavelson et al., 2002).

If there is such a strong case for inquiry, why is it not used in more classrooms? Many teachers do not possess the necessary tools to understand curriculum material or be proficient with critical skills such as creating meaningful graphs and building evidence-based arguments. If teachers themselves do not have the skills, they cannot teach them to their students.

Crawford et al. (2005) also found that teachers, in addition to their limited understanding of scientific inquiry, did not value the importance of teaching with
inquiry. Teacher polling revealed ten reasons why they do not use inquiry in their classrooms (Costenson et al., 1986, Lawson, 1995).

1. It takes too much time and energy to develop good inquiry materials.
2. It does not allow enough time to cover the large amount of material required in the standards.
3. Reading inquiry textbooks is too difficult for most students.
4. The risk of poor end results is too high to chance it. Teachers do not know how the units will turn out.
5. Tracking has reduced the number of formal thinkers in regular biology classes (i.e., They have moved to advanced or advanced placement classes).
6. Students are too immature; they waste a lot of time and do not learn.
7. Teachers have been teaching in a certain way for many years and do not want to change their methodology.
8. Inquiry texts lock you in with such sequential material that you cannot skip labs or sections of the text.
9. Teachers are uncomfortable with not being in absolute control of what is going on in the classroom
10. Many classrooms/labs are not equipped for inquiry and districts will not purchase the necessary supplies/equipment.

Teaching with inquiry does increase the cost of supplies and equipment and initially increases the amount of time a teacher must spend designing and writing lessons and preparing for laboratory exercises. A teacher can be quickly overwhelmed with all the class activities and laboratory preparation. New teachers may have difficulty with managing student movement around the classroom and mainstreamed special needs students have additional requirements.
Reasoning Levels and Student Learning

There are four stages of intellectual development or reasoning levels as proposed by Piaget (Lawson, 1995). They are: sensorimotor, pre-operational, concrete operational, and formal operational and they roughly correspond with physiological processes and growth spurts (Lawson, 2000a, Kwon et al, 2000). The concrete operational stage is what virtually all middle school students and most high school students have attained. Certified teachers should be in the formal reasoning stage (Lawson, 1992, 1995) and should be able make full use of inquiry learning opportunities, concept comprehension, and problem-solving exercises. Lawson states that the formal operational stage is about hypothesis testing and theory building, but that there may be a fifth stage in which theory-testing can occur (Lawson, 2000).

Lawson has refined his ideas on hypothesis-testing skills to imply that there are two developmentally based levels of hypothesis-testing skills – one involves skills associated with testing hypotheses about observable causal agents, another involves skills associated with testing hypotheses involving unobservable entities (Lawson, 2002a, 2002b). Success at testing hypotheses involving observable causal agents is a prerequisite for becoming proficient at testing hypotheses involving unobservable causal agents.

Lawson (2002) tested preservice biology teachers enrolled in a teaching methods course and analyzed their arguments. When the teachers were able to manipulate the observable causes, they could correctly identify the correct hypothesis. However, when the causes were such that they could only be tested
indirectly, their performance dropped. The type of faulty arguments that were used fell into three groups: arguments using missing or confused elements, arguments whose predictions did not follow from hypotheses and planned tests, and arguments that failed to consider alternative hypotheses. In science, unobservable theoretical entities and processes are used to explain observable phenomena, so effective teaching requires deep understanding. Many student teachers have not developed adequate hypothesis-testing skills or do not have sufficient awareness of the nature of science (NOS) to teach science in the inquiry mode required by reform efforts. Lawson, therefore, advocated designing biology courses to improve students’ hypothesis-testing skills (Lawson, 2002).

Research has documented that improvements in reasoning as a consequence of instruction can and has occurred (Trowbrigde et al., 2000), but only when students have been given the necessary developmental conditions do they become skilled at testing unobservable causal agents (Lawson et al., 2000b). Declarative knowledge alone is not sufficient to produce successful hypothesis-testing performance. Learners must examine their knowledge and become dissatisfied with their understanding because they recognize it as ineffective, unsuccessful, or because it leads to dissonance or dilemmas in practice. A new practical theory must appear reasonable to teachers for it to be accommodated and opportunities to deepen and expand subject matter knowledge must be provided (Lawson, 1995). Therefore, it would be advantageous for science departments to develop students’ hypothesis-testing skills by providing specific opportunities for them to generate and test
increasingly complex and abstract hypotheses and theories in a hypothetico-deductive manner so they can increase their reasoning abilities (Lawson et al., 2000c, 2005).

Johnson et al. (1998) report that the primary determinant to success in college biology courses (both expository and inquiry classes) is students’ reasoning ability, not prior knowledge of biology or amount of biology coursework completed. Their original hypotheses were that reasoning ability should be a significant predictor of achievement in inquiry classes and prior knowledge should be a significant predictor of achievement in expository classes. They found that reasoning ability was a limiting factor of achievement in inquiry classes and that prior knowledge was not a limiting factor of achievement in expository classes or inquiry classes. Previous coursework does not influence how well a student does in a class and inquiry classes (as opposed to expository classes) actually increase reasoning ability (Johnson et al., 1998). Johnson et al. (2004) stated that it is well-established that science education, especially at the pre-college level, focuses on the teaching of facts in expository classes. They feel that it is unreasonable for instructors to expect factual information and science knowledge to automatically translate into conceptual understanding of science and improved critical thinking skills without benefit of inquiry instruction, explanation, and other helpful learning experiences.
Science Reasoning by Hypothetico-deductive Methods

There is disagreement in the literature as to whether science reasoning is done primarily by induction (reasoning in which the premises of an argument are believed to support the conclusion, but do not entail it) or deduction (reasoning in which the conclusion is of no greater generality than the premises). Lawson (2005) maintained that people process information in terms of increasingly abstract cycles of hypothetico-deductive reasoning (formulation of a hypothesis in a form that could be falsified by testing observable data). Lawson (2000c) maintained that many, if not all scientific discoveries are hypothetico-deductive in nature. Hypothetico-deductive thought is basically is a simple three-step process by which scientists investigate nature: 1) observe something in nature, 2) speculate about its explanation, and 3) test those speculations. It is this testing of hypotheses process and proposing alternative hypotheses that requires the formal operational level of reasoning (Lawson, 2005).

The Learning Cycle

The three-step process of learning previously mentioned is referred to as the learning cycle and it is an important pedagogical method used to help students learn. Robert Karplus (2002) proposed the first learning cycle consisting of three stages: exploration, concept introduction, and concept application (Appendix C). Lawson later slightly changed the names of the stages to exploration, term introduction, and concept application. Lawson was convinced that changing the sequence of stages or leaving out a stage resulted
in inappropriate learning because students need those steps in that order to examine the adequacy of prior beliefs, reveal prior conceptions, argue about and test those beliefs to provoke a situation of disequilibrium. Lawson et al. (1988) stated that the process of constructing knowledge usually begins with an observation and a question which then leads to stating predictions and/or hypotheses. If student observations fit the expected outcomes, then the observations are assimilated into the student’s constructed mental framework. However, if the observations do not fit into the expected outcomes, disequilibrium results and some accommodation is needed (Lawson et al., 1988). To make the accommodation, alternative mental structures are constructed until a good match between expected and actual outcomes is reached and equilibrium is restored. The disequilibrium is necessary for students to have their beliefs contradicted so they have the opportunity for self-regulation and the construction and testing of more appropriate concepts. Karplus and Lawson (Karplus et al., 2002) felt that this process must occur in the proper classroom atmosphere and must be the explicit focus of classroom attention. As students repeatedly progress through the cycle, they become more conscious of it and learn how to learn (Lawson, 2002). The Biological Science Curriculum Study (BSCS) expanded the learning cycle to have five stages: engage, explore, explain, elaborate, and evaluate (Appendix D) and listed appropriate teacher and student activities for each of the five parts of the stage (Appendix E). This five step cycle is still in use.
Teacher Learning and Preparation

If teachers are to teach science through critical thinking skills and increased reasoning ability, then having these skills should be a prerequisite for teaching certification. This is not always the case.

A common conclusion of many studies on teacher learning and teacher preparation is that it is poorly done in the United States. The subject matter preparation that prospective teachers currently receive is inadequate for teaching toward high subject-matter standards (Even, 1993). The National Research Council (Bransford et al., 2000) stated that preservice teacher education plays an especially important role in the kind of teachers this country produces. Wilson et al. (2001) and Rowan et al. (2001) conducted research that showed a positive correlation between teachers’ preparation in their subject matter and their performance and impact in the classroom on student achievement in science, mathematics, and reading. They stated that subject matter knowledge and deeper conceptual understanding necessary to field student questions can only be obtained by taking subject-specific coursework taught using inquiry techniques and appropriate teaching pedagogies.

STEM Background

In 1999, the National Research Council set forth an ambitious set of visions to transform Science, Technology, Engineering, and Mathematics, (STEM) (NRC, 1999) college undergraduate level courses to encourage more
students to study and enter those fields to become teachers. They proposed six reforms:

1. All post secondary institutions would require all entering students to undertake college-level studies in STEM.
2. STEM would become an integral part of the curriculum for all undergraduate students through required introductory courses that engage all students in STEM and their connections to society and the human condition.
3. All colleges and universities would continually and systematically evaluate the efficacy of courses in STEM.
4. STEM faculties would assume greater responsibility for the pre-service and inservice education for K-12 teachers.
5. All post-secondary institutions would provide the rewards and recognition, resources, tools, and infrastructure necessary to promote innovative and effective undergraduate STEM teaching and learning.
6. Post-secondary institutions would provide quality experiences that encourage graduate and postdoctoral students (and especially those who aspire to careers as post-secondary faculty in STEM disciplines) to become skilled teachers and encourage post secondary faculty to acquire additional knowledge about how teaching methods affect student learning (NRC, 1999).

Researchers agree that reform in science education should be founded on scientific teaching - teaching that is approached with the same rigor as science (Handelsman et al., 2004, Putnam et al., 2000). Scientific inquiry may be the core of reform in science teaching and learning, but few teachers were taught this way during their teacher preparation coursework (Putnam et al., 2000). These researchers question why professors and scientists who demand rigorous
proof for scientific claims in their research continue to use and defend teaching methods in science classes that are not effective in fostering conceptual understanding or scientific reasoning skills (Handelsman et al., 2004). Otero et al. (2006) provide an explanation: even though content knowledge is one of the main factors positively correlated with teacher quality, science faculty members directly responsible for undergraduate science courses for teachers are rarely involved in teacher recruitment and preparation. They implemented a program at the University of Colorado in which competent science students from different disciplines of science were recruited as assistants to attend specific science classes and help students in those classes who plan to go into the teaching field. Their program increased the number of quality future science teachers and also brought a number of educational issues to the attention of science faculty such as which subject topics they wanted prospective science teachers to learn and the best methods of getting certain ideas and concepts across to them (Otero et al., 2006).

Luft et al. (2007) state the need for a science induction program for prospective science teachers. Zembal-Saul et al. (2002) felt that there needs to be innovative, technology-rich, inquiry-based science courses for science teachers so they can learn science through inquiry and use those experiences to help define their teaching. Unfortunately, most teachers take classes in which this process of acquiring new ideas, changing or deleting old ones, gleaning new knowledge and skills is not part of their classroom experience; therefore, they hold on to beliefs about their subject and understanding about the nature of
science that are counter to the instructional approaches promoted by reforms (Davis, 2003). Without inquiry science courses, beginning teachers tend to teach using traditional practices of emphasizing facts, extensive lecturing, and providing few opportunities for teachers to engage in science as inquiry. When prospective teachers are properly trained, they can become effective science teachers who can translate content into learning activities resulting in student understanding (Luft et al. (2007).

The Pedagogy/Content Conflict

One of the major problems in providing appropriate teacher-training programs is the differences in philosophy and approaches to teaching and learning between colleges of education and colleges of sciences (Ramey et al., 1998). Secondary teacher preparation programs are often organized so that teachers acquire their science methods knowledge in science classes offered through the science department with no teaching pedagogy and their pedagogical knowledge in education classes offered through the department of education with no specific science focus. Education students without a degree in science lack enough subject knowledge to teach currently required content concepts. Student teachers with a degree in science do not have the pedagogical techniques specific to their discipline (Abd-El-Khalick et al., 1997). Pedagogy in one subject is not necessarily applicable to all subject areas (Enfield, http://www.msu.edu/~dugganha/PCK.htm ). Science and education
departments must work together to provide appropriate educational experiences in both disciplines (Abd-El-Khalick et al., 1997).

**Teacher Training and Student Achievement**

Laws require the teaching of science in public schools with teachers competent to teach that subject (107th Congress, 2002). Many teachers are "caught in the middle" – they qualify on paper to teach science in the elementary and middle grades, but they really do not have all the training they need.

Marx et al. (2004) devised a multi-pronged effort that was a combination of well-designed curriculum materials with embedded learning technologies serving the needs of low through high level-learners, high quality professional development, policies supporting reform, and collaboration among teachers and district personnel. They showed a statistically significant increase on student curriculum-based scores for each year of teacher participation with the strength of the effect increasing growing over the years. This demonstrated that inquiry-based, technology-infused curricula can help teachers and their students learn the science content put forth in the national standards (Marx et al., 2004).

Darling-Hammond (2000) stated that quantitative analyses indicate that measures of teacher preparation and certification are by far the strongest correlates of student achievement in reading and mathematics; both before and after controlling for student poverty and language status. The teacher, his/her education, ability, experience, small school and class size, and lower teacher/pupil ratios are all things which can make a difference in student
achievement. Subject matter plays a significant role in this because mathematics students who have had fully certified teachers show higher gains in achievement than those taught by teachers not certified in mathematics (Keeley, 2005).

Districts with greater proportions of licensed teachers had students who were more likely to pass state achievement tests. Teachers with four or more years of teaching experience are more effective than those with less than four years.

Teachers that use a range of teaching strategies, use a range of interaction styles, ask higher order questions, and probe student comments are strikingly more effective – especially for diverse students. Experience and teacher education appear to influence the use of these practices and result higher achieving students (Darling-Hammond, 2000).

Elementary Teacher Education

Lack of science content knowledge is a particular problem with elementary level teachers (James et al., 2001). A number of different studies have shown that elementary school teachers’ content knowledge fails to meet the standards required by contemporary elementary school curricula and standards (Kikas, 2004). More than 50% of elementary teachers take very few or no courses in science, science methods or have any science experiences (Çacıroğlu et al., 2002) so very few elementary school teachers have even a rudimentary education in science and mathematics (AAAS, 1991, Akerson et al. (2007).

Blosser (1987) found that when 333 elementary teachers were given the NAEP science tests written for 17 year-old science students in high school, fewer
than 50% of them could correctly answer more than 11 out of 31 test items. In the same context, Tekkaya et al. (2004) tested Turkish preservice elementary teachers for their misconceptions in science and found that elementary teachers were able to answer less than 50% of the questions correctly. Çaciroğlu et al., 2002, did a study on preservice elementary teachers’ understanding of the topics of photosynthesis and inheritance along with their self-efficacy beliefs. The participating teachers had misconceptions regarding both topics, but, surprisingly, they also had positive self-efficacy beliefs regarding their science teaching (Çakiroğlu et al., 2002).

These studies indicate that preservice teachers feel adequately prepared to teach science concepts although they themselves actually have a low level of conceptual understanding in science (Tekkaya et al., 2004).

In 1985, Stepans and McCormack tested the level of understanding of selected science concepts typical of freshmen and senior elementary education students at the University of Wyoming. The results showed that the number and kind of science classes did not impact students’ understanding of science concepts, attitudes toward science, or confidence in personal ability to teach science. They found that freshmen held seriously negative attitudes toward science and teaching science which abated somewhat as they matured to seniors. Stepans et al. (1985) concluded that education students at the University of Wyoming were not adequately prepared to teach science.

The required practicum for elementary certification has little effect on the knowledge or attitude of preservice elementary school teachers (James (2002).
He and his colleagues designed a course that provided elementary teachers with an opportunity to learn successful methods of teaching science that included inquiry and constructivist theories. After taking that class, teachers improved in the use of inquiry in their science lessons, changed the kinds of assessments they had been using, and improved in facilitating collaboration between their students (James, 2002).

Akerson and Hanuscin (2007) evaluated a three-year professional development program designed to provide elementary teachers with specific science experiences embedded in a program emphasizing inquiry learning and inquiry-based instruction. They established that teachers showed positive changes in their views of the nature of science and improved their science pedagogy as shown by classroom observations.

**Secondary Teacher Education**

Junior and senior high school teachers of science and mathematics do not always meet reasonable standards of preparation in those fields (AAAS, 1993). Raloff (2001) states that many secondary science and mathematics teachers in the United States are not qualified to teach their subjects. Abd-El-Khalick et al., (1997) evaluated data concerning teachers’ knowledge bases and found that they were lacking in all aspects. Teachers from the U.S. are less likely than teachers from other countries to have a math or science college degree.

Loughran (2003) states that science teachers must be competent enough in their academic field to recognize and challenge students’ alternate conceptions
and engage in plausible discussions about the material so that students can begin to construct new knowledge and let go of their old conceptions. Teachers planning to teach science should be able to demonstrate knowledge of the concepts and relationships they are preparing to teach. Often teacher candidates leave college science courses with limited knowledge of science and little understanding of the nature of science (Saderholm et al. 2006, Enfield, http://www.msu.edu/~dugganha/PCK.htm, Ramey et al., 1998).

Teacher Education Program Continuity

Teacher education programs are extremely varied, not just from state to state, but also from institution to institution. As a result, they are disjointed and follow different regulatory rules from state accreditation boards and federal education programs. This makes it difficult to develop coherent, non-fragmented teacher certification programs (Ramey et al., 1998). Many districts have allotted three years for the education process of teachers to occur, but it is not enough time to complete the curriculum and instruction classes as well as provide the necessary support teachers-in-training need (Davis, 2003). A number of US colleges are now using a five year model in which candidates in a teacher certification program earn a bachelor’s degree in their major so they can be proficient in content knowledge and a then earn masters’ degree in education to learn pedagogy and to develop teaching skills (Darling-Hammond, 1998). The fifth year allows students to devote their energies exclusively to teacher education and these programs allow for extended practice teaching in schools 15
to 30 weeks instead of the usual 8 to 12 weeks of student teaching. Graduates of these extended teacher-preparation programs are more highly rated by principals and teaching colleagues. Retention rates are much higher for these graduates (90% as opposed to 60 – 80% for graduates of four-year programs) so that it actually costs less money per teacher to educate them (Darling-Hammond, 1998). Other countries such as West Germany have their prospective teachers earn the equivalent of academic majors in two subjects and then pursue two to three more years of rigorous teacher preparation that combines pedagogical seminars with classroom observations and intensively supervised practice teaching (Darling-Hammond, 1998).

The National Research Council (1996) recommends programs with common components such as: 1) subject matter preparation programs for both elementary and secondary education that include concepts and principles taught by inquiry methods, 2) concepts and relationships that unify science domains, 3) processes of investigation in a science discipline, 4) and applications of mathematics in science research (Abd-El-Khalick et al., 1997, Bransford et al., 2000).

Education reform cannot happen without the teachers (Bransford et al., 2000) which makes teacher learning a key ingredient to educational reform (Davis, 2003). Very little research has been published on teacher learning other than there is a great lack of opportunity to get it and little support for it. There are few actual formal learning opportunities for practicing teachers and when the opportunities do present themselves, teachers generally have to take sick
days/leave to participate in them or attend them on the weekends or in the summer. This lack of support is unheard of in leading corporations or schools in other countries (Bransford et al., 2000).

**Pedagogical Content Knowledge**

Information about Pedagogical Content Knowledge (PCK) began to appear in the literature in 1986 when Shulman published a paper in which he described a new educational construct. He first outlined the three types of knowledge necessary for teaching: content or subject matter knowledge (SMK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK). It is the interaction of SMK with PK that describes a unique form of professional knowledge or pedagogical content knowledge. PCK depends heavily on content knowledge (Even, 1993, Loughran, 2006), but SMK and PK alone are insufficient for good teaching and student understanding (Cochran, 1997, Sperandeo-Mineo et al., 2003, Thoren et al., [http://www.hig.se/pdf/n-inst/Slutrapport 0501F3 .pdf](http://www.hig.se/pdf/n-inst/Slutrapport 0501F3 .pdf)). Teachers integrate what they know about teaching with what they know about the content they teach to synthesize a plan for their lessons that incorporates representations of subject matter with understanding specific learning difficulties and student conceptions with respect to that subject matter (Van Driel et al., 2003, Mulhall et al., 2003). It is what allows teachers the use of certain instructional strategies to present different concepts, the order in which concepts should be presented, the different ways in which to teach them, and the kinds of problems that help students learn (Irving, 1999, Loughran, 2004, Rowan et al.,
Another characteristic of PCK is that it includes an understanding of what makes the learning of specific topics easy or difficult.

PCK is what makes teachers educators instead of scientists because teachers organize their science knowledge from a perspective of teaching to help students understand specific concepts, while scientists organize their science knowledge from a perspective of research to develop new knowledge in the field (Cochran, 1997). Rowan et al., (2001) are of the opinion that Shulman’s ideas had a considerable impact on American education since they prompted changes in pedagogy that were generalized across disciplines and grade levels.

Rowan et al. (2001) state that PCK is a contentious issue because the effort to measure the knowledge base for teaching and the distinction between teachers’ different types of knowledge is hampered by the lack of precedent. There is very little terminology to even try to describe what these different knowledge types are. Loughran et al. (2004) state that it is very hard to measure PCK - that its integrative nature would make it hard to know whether PK, SMK, or PCK was being measured. Since PCK is different for each teacher, it does not lend itself to checklists very well. PCK is an unquestioned academic construct, but it has not been well-characterized because it takes a long time to unfold, it may not be evident, and there is no language or structure to adequately discuss it due to the fact that many teachers keep their PCK implicit rather than explicit (if they are even aware of it (Loughran et al., 2004, 2003).

Research indicates that the development of PCK is embedded in classroom practice which means that new teachers or experienced ones that
have not taught a particular subject before will not have any PCK in that area (Dawkins et al., 2003, Thoren et al. (http://www.hig.se/pdf/ninst/Slutrapport-0501F3.pdf). Successful teachers have taught in a given area before and have developed PCK for that specific content (Mulhall et al., 2003). This has obvious implications for preservice teachers since they have had no actual classroom experiences of their own, so whatever they glean from student teaching experiences will provide them with something on which to build PCK. The other implication is that they must have fundamental knowledge of their subject as well as some pedagogical knowledge so that they can build interrelationships and develop PCK (Dawkins et al., 2003).

Enfield (http://www.msu.edu/~dugganha/PCK.htm) devised a model of the interactions between pedagogy, content, professional practice, and other science teaching elements. His figure follows:
This model illustrates the interactions of the various elements of science teaching with PCK. Unfortunately, it does not show all the interactions between PCK and the elements it affects, but it does show how important inquiry and NOS are to the teaching of science. It also indicates the part that professional practice
plays in integrating the different factors of science teaching with each other through inquiry experiences.

Enfield (http://www.msu.edu/~dugganha/PCK.htm) states that scientific knowledge is built on evidence and teachers of science need to understand the implicit value scientists place on evidence as well as the consequences of these ideas and beliefs. PCK provides a useful lens for teachers to begin to help students see the assumptions of science. Many high school science teachers are literate enough in science to implement the goals presented in Benchmarks and Standards, but developing science literacy and the ability to transform this knowledge into learning opportunities requires more than an understanding of content and pedagogy. It requires understanding of their intersection and the development of PCK (Enfield, http://www.msu.edu/~dugganha/PCK.htm).

**Professional Development**

The National Research Council (NRC, 1996) and the American Association for the Advancement of Science (AAAS, 2003) recommend fundamental changes in mathematics and science content taught in American schools. They also recommend changes in how science and mathematics are taught. They advocate that learners (including teachers) be engulfed by scientifically oriented questions, give priority to evidence which allows them to develop and evaluate explanations in light of alternatives and communicate and justify their proposed explanations. There are new expectations for teachers, classroom behaviors, and student performance. The requirement is for
increased emphasis on higher-order content with more demanding thinking skills from students (Smith et al., 2003). Many teachers are not prepared to implement teaching practices based on the integration of high academic standards because they have not had the proper training for this kind of teaching. The NRC (1996) and NSTA (2003) recommend professional development (PD) as a mechanism to effect these changes and it is the single largest investment of most reform initiatives (Garet et al., 2003, Smith et al., 2003). The idea behind the focus on PD as a means of improving student achievement is that high quality PD will hopefully produce superior teaching in classrooms which will translate into higher student achievement (Schlang, 2006).

One of the questions on teachers’ minds is whether or not they are getting high quality PD. Certainly, agencies that fund PD opportunities for teachers also want to know that same thing (Smith et al., 2003). Wilson et al. (1999) state that PD often consists of traditional inservices, given by “experts” with little knowledge of local conditions and who present irrelevant, generally boring pre-packaged information. Teachers feel they do not learn much and they rate these district-sponsored inservice workshops very low (Wilson et al., 1999, Jeanpierre et al., 2005). Also, teachers who take PD courses expect to learn new teaching theories and instructional strategies; they do not really expect to have their knowledge and teaching practices challenged. Van Driel et al. (2001) say that reform efforts in the past have often been unsuccessful because the planners failed to take teachers’ existing beliefs, knowledge, and attitudes into account.
Garet et al. (2001) lament the fact that there is little evidence as to what extent PD produces positive outcomes for teachers and students. They feel that more research is needed to determine the efficacy of various types of PD activities and formats (inservices, workshops, summer institutes, and other PD designs); especially since there is conflicting data about exactly what good PD is (Guskey, 2003). They suggest that studies be extended over time and across broad teacher-learning communities in order to identify the processes and mechanisms that contribute to the development of these learning communities (Bransford et al., 2000). Kennedy (1998) disagrees since she found that the literature supports the fact that there were greater improvements in student learning when students had teachers who had attended science PD workshops and had incorporated engaging experiences for students in their classrooms. Sykes (1999) reiterates that the type of PD and the content of the workshops is the decisive factor. Supovitz et al. (2000) did some research on the relationship between PD and teaching practice and found that inquiry-based PD changed teachers’ attitudes towards reform; their willingness to use reform-based practices increased, and their use of inquiry-based teaching practices increased. Additionally, these changes persisted at least several years after the conclusion of their PD experience.

Carpenter et al. (2004) and Bybee et al. (2003) suggest that PD and the organizational support required for successful PD are the keys to creating classrooms in which students learn with understanding. They state that there are a number of things teachers need in order to teach for understanding. They must
be firmly grounded in their subject material, have considerable pedagogical knowledge, and they should have enough teaching experience to have PCK. Additional skills in these three areas can be provided by PD. Carpenter et al., (2004) developed PD which blends critical concepts and methods of inquiry with knowledge of the ways that student thinking develops and the nature and effect of their teaching practices.

Jeanpierre et al. (2005) conducted two-week training sessions for teachers that provided intense instruction on inquiry, with short inquiry-based projects, and strategies for teachers on group management and organizational skills. The research scientists who helped teach the course provided continued support for participating teachers. Their results indicate that teachers who had participated in their training sessions provided more opportunities for their students to conduct full inquiry using real-world, inquiry-based science activities (Jeanpierre et al., 2005).

Dass (2001) stated that finally realization of the importance of PD in bringing about the reforms in teaching has been recognized. Making science relevant to the lives of students requires the proper classroom environment. The specific teaching capabilities needed cannot be developed through brief, one-shot inservice sessions that are traditionally regarded as professional development. Supovitz et al. (2000) conducted a study and found that the quantity of PD in which teachers participated along with the amount of content preparation is strongly linked with both inquiry-based teaching practice and investigative classroom culture. Teachers require carefully designed, sustained,
professional development opportunities which actively involve them in the learning process (Dass, 2001). The format for Dass’ workshops was a two-week commitment in the summer and follow-up afterwards for an entire year. This kind of PD required a commitment from the teachers that they would practice the instructional approaches in their classrooms that they learned during the summer workshops. James (2002) found that there were two basic reasons that teachers gave for their continued use of what they learned in inquiry workshops: materials were provided for them to conduct inquiry science in their classrooms and continued support was given for at least a semester from the instructors.

Based on an extensive review of the literature, VanDriel, et al., (2001) concluded that changes in teachers’ practical knowledge can be achieved when they attend and commit to long-term PD programs. Reform activities tend to produce better outcomes primarily because they tend to be of longer duration (Garet et al., 2001). Along with longer duration, activities that encourage collective participation of teachers from the same school, subject or grade level tend to place more emphasis on content, provide more opportunities for active learning, and provide more coherent PD than traditional ones. These features, in turn, promote positive teacher outcomes (Porter et al., 2003).

**What is Effective PD?**

Numerous educators have indicated what they believe constitutes effective science PD experiences. Most PD courses do not take all of these
statements into account and therefore are incomplete (Zembal-Saul, 2002). A synthesized list of desirable characteristics of good PD is as follows:

1. It should be designed by a development team composed of science educators to limit the amount of pedagogy and educational theory to be included so teachers can learn more about the topics they teach. It should have a clear purpose and be focused. All participating teachers’ needs should be taken into account as much as possible (Zembal-Saul, 2002, Bransford et al., 2000).


3. It should create enough of a level of cognitive dissonance to disturb the equilibrium between teachers’ existing beliefs and practices and their experiences with subject matter and students’ learning. Activities creating and resolving dissonance should fit in with teachers’ contexts and their students’ contexts (Bybee et al., 2003, VanDriel et al., 2001).


5. It should be intensive and sustained with long-term, coherent professional development plans, continuous assessment (pre- post-, and follow-up tests, and other assessments for teachers), help and support to show gains in knowledge, skill, and confidence. The end result should show a change in teachers’ teaching practices (Bybee et


7. It should support teachers as professionals, active learners, and leaders as part of a learning community who are collaborating and participating in their training to develop shared investment and understanding (Loucks-Horsley, 2003, Putnam et al., 1997, Shepardson, 2001, VanDriel et al., 2001, Garet et al., 2003, Porter et al., 2003, Guskey, 2003, Little, 1993, National Research Council, 2001). Support from a PD team is critical as teachers begin to incorporate new approaches in their classrooms. Continued learning opportunities and the time to reflect and interact with other teachers is also important (Davis, 2003, Darling-Hammond, 2000, Guskey, 2000).

8. It should be linked to other parts of the educational system and other aspects of school change as well as placing classroom practice in the larger contexts of school practice and the educational career of each student (Little, 1993, Loucks-Horsley, 2003, Supovitz et al., 2000, Garet et al., 2003, Porter et al., 2003).

9. It should employ appropriate teaching strategies that teach teachers in the way they should teach students. It should also employ the use of some type of evaluation for instructors to use the feedback to restructure portions of the program that are not effective (Putnam et al., 1997, Porter et al., 2003, Zembal-Saul, 2002, Weiss, 1999).

10. It should include developers and planners for teacher learning that can facilitate multifaceted learning experiences and strategies for
maintaining class control while implementing new teaching formats (Jeanpierre et al., 2005, Smith et al., 2003). It should take into consideration analyses of student learning data (Guskey, 2003).

11. It should provide a way for teachers to develop a repertoire for practice that is consistent with the new understandings that teachers are building. Inclusion of technology is important (Bybee et al., 2003, Smith et al., 2003).

12. It should be grounded in a common set of PD standards and show teachers how to connect their work to specific standards for student performance (Supovitz et al., 2000). PD should be based on the best available research evidence for what constitutes effective professional development (Guskey, 2003).

13. There should be evaluation procedures and the activities and goals should be aligned with reform initiatives (preferably site-based PD should be merged with district-level initiatives (Guskey, 2000, 2003).

These are ambitious goals, but it is an enormous problem to educate teachers to be knowledgeable in the subjects they teach, use inquiry in their classrooms, and understand the NOS. Unfortunately, the content of many PD programs promotes views of teaching and learning that are not endorsed by current reform initiatives. Little (1993) further states that oftentimes school districts will fund packaged and standardized PD programs because they are readily defended, managed, evaluated because they present specific knowledge and skills even though alternative programs are more beneficial to teachers.

Supovitz et al. (2000) found that increasing the amount of PD was statistically associated with both greater teacher use of inquiry-based teaching practices and higher levels of investigative classroom culture. Teachers with less
than 40 hours of PD had more traditional practices than did the average teacher. Those with between 40 and 70 hours of PD had about average teaching practices – including some inquiry. It was only after 80 hours of PD that teachers reported using inquiry-based teaching practices significantly more frequently than the average teacher (Supovitz et al., 2000). These investigators found that workshops shorter than two weeks duration were ineffective. Porter et al. (2003) found that between 70% to 80% of district sponsored PD was only 15 hours duration, only 20% of district PD spanned at least six months, and 2% of the teachers are in district activities that span more than one year. Only 20% of teachers participated with other teachers from their discipline, department, or grade level. Smith et al. (2003) found that in 1994, 70% of the teachers took no content-focused PD and 35% took no methods-focused PD. By 2003, those numbers had changed to 41% and 27%, so more teachers were taking an interest in increasing their content knowledge of their subjects. Between 1993 and 2000, teachers taking sustained PD (9 or more hours) increased from 12% to 48%.

Are teachers participating in higher quality PD? Additional work by Porter et al. (2003) indicates that more than 75% of teachers attending district PD report that their activities are aligned with state and district standards. PD focused on in-depth study of the content in teachers’ main assignment field reported participation rates increased twice as much as those in methods of teaching (Smith et al., 2003). Teachers are thus interested in taking more content-focused PD rather than taking PD focusing on methods, technology, student assessment,
or discipline and management (Smith et al., 2003). Their data indicate that teachers participating in content-focused PD found it more useful than those participating in methods-focused or technology-focused PD. They believe teachers are participating in higher quality PD than they did in 1993 (Smith et al., 2003).

Money spent on teacher education was the single most productive financial expenditure for schools (Darling-Hammond, 2000). Darling-Hammond advocates the additional expense for ongoing PD for experienced teachers because the students of those teachers perform better on state assessments as a result of their teachers employing more of the reform-oriented teaching practices they got from their PD experiences. She believes that additional money spent for teacher PD could make big strides toward improving science teacher education and that this is a large factor in student improvement (Darling-Hammond, 2000).

**The Nature of Science (NOS)**

Various lists of NOS characteristics have been organized by different researchers, in part because of the vague nature of definitions of the NOS that are prevalent in the literature (Lederman, 2003). A list of tenets drawn from the information of several authors is as follows:

1. Scientific knowledge is cumulative and revisionary and therefore tentative.
2. Science requires testing everything thoroughly against observed facts and rules of logic and reason.
3. There are different types of scientific knowledge.

4. Scientific knowledge is general and universal; it has intrinsic cultural value and is socially and culturally embedded.

5. Common public perceptions of science perpetuate a number of myths which give an erroneous impression of the methods and nature of science (Appendix F).

6. Science has a distinctive, but common language that evolves with use.

7. Scientific knowledge is produced by humans and is a shared activity and subject to peer review. It involves human observations, imagination and creativity.

8. A fundamental feature is the construction of understanding through the logic of inference.

9. Scientists can believe in the existence of theoretical entities that have never been directly observed only when there is sufficient and extensive evidence from which those entities can be inferred.

10. Deductive logic plays a role in science, but conclusions, discoveries, theories, and laws that comprise nearly all of scientific knowledge are built on statistical inferences that use inductive reasoning to get the most plausible and probable interpretations of the observations made (As mentioned earlier, this is controversial).

11. Scientists use distinctive forms of communications for reporting results.

12. Scientists perceive and claim their work is value-free, objective, and that assumption is open to challenge. Others say that the nature of science is subjective.

13. There is a distinction between science and technology.

These authors believe that this list covers all salient features that are components of any basic knowledge and understanding about the NOS and they think that teachers should encounter these ideas before the end of their required schooling. These tenets of the NOS are not to be confused with the processes of science, but rather all the means and methods that are employed in science (Carrier, 2002, Schwartz et al., 2004). Abd-El-Khalick et al. (1998) feel that to get the NOS into the classrooms, preservice teachers must be helped to develop adequate understanding of NOS, but that is not enough – teacher preparation programs for science teachers should help them with their understanding of the rationale behind and comprehension of the importance of emphasizing the NOS in their teaching. These preservice teachers also need more extensive experience in teaching and assessing the NOS, and they need support in their field experiences for teaching the NOS (Abd-El-Khalick et al. (2004). Lederman (1999) and other researchers feel that teachers need professional development opportunities to help them learn strategies and how to focus on and teach the NOS in their classrooms.

**Misconceptions about the Nature of Science (NOS)**

Aside from misconceptions about scientific phenomena, teachers and students also hold misconceptions about the nature of science and what it means to do science (Bransford et al., 2000). Elementary and secondary teachers often hold nonscientific views of the NOS (Appendix F). One of the primary reasons for this is that many teachers have not mastered the ability to engage in thinking
scientifically themselves (Crawford et al. (2005). This is not so surprising since most teachers do not understand how scientists develop theories and solve problems; and if they do understand those processes, they lack the pedagogical knowledge of how they can engage their students in extended investigations of the type in which scientists engage. Therefore, science education investigators recommend that education students have authentic scientific inquiry experiences in their teacher education programs (Crawford et al., 2005, Heppert et al., 2002, Osborne et al, 2003). This would also alleviate some of the misconceptions of science education that are currently held by the public and also science teachers (Appendix G). Part of this is due to the practice of teaching science as a collection of facts and theories about certain science phenomena rather than as a set of principles or guidelines for understanding the world (Gabennesch, 2006). Students are not likely to spontaneously learn the type of logic involved in the nature of science (NOS). Both teachers and students should realize that it is the refutation and elimination of alternatives that give power to the predictions that survive the science process. It is not that predictions are confirmed in the process, but that there are still possibilities of different outcomes (Fleury et al., 1991). These authors further state that they have noticed a specific trend in teaching NOS - that scientific knowledge is subject to change upon the acquisition of new information. Although this is technically correct, students become confused and think that scientific knowledge is absolutely confirmable and that it takes only one factor or one set of experiments to prove a theory wrong (Fleury et al., 1991).
Lederman (1999) emphasized that the NOS is currently being cast as an important educational objective worldwide – a significant aspect of scientific literacy. This goal is to attain an understanding of the NOS that will enable students and the general public to be more knowledgeable citizens who can make more informed decisions when scientific claims and data are pitted against tabloid sensationalism (Nowotny, 2005). Both Carrier (2001) and Lederman (1999) feel that despite the concern about students’ conceptions of science, very little progress has been made towards this goal.

Views of the NOS Survey

A number of researchers have either developed or used a Views of the Nature of Science Survey (VNOS) and have found that students at all grade levels (K-12), their teachers, college teachers, preservice and student teachers, and even teachers with all levels of experience have an inadequate to “astonishingly poor” understanding of the NOS (Carrier, 2001, Lederman, 1999, Lederman et al., 2002, Lederman, 2003, Abd-El-Khalick et al., 2004, Akerson et al., 2006). Akerson et al, (2006) tested a group of preservice elementary teachers using the VNOS and nearly all of them had inadequate ideas of the NOS prior to instruction in an explicit science methods course. Five months after instruction, the same teachers were re-interviewed and retook the questionnaire. It was found that those with lower cognitive skills had reverted back to their earlier views (Akerson et al, 2006).
Misconceptions

The body consists of three parts - the brainium, the borax and the abominable cavity. The brainium contains the brain, the borax contains the heart and lungs, and the abominable cavity contains the bowls, of which there are five - a, e, i, o, and u.

Water is composed of two gins – Oxygin and Hydrogin. Oxygin is pure gin and Hydrogin is gin and water. Littlewood (http://www.jlittlewood.com/discuss/humour/science.htm)

Incorrect beliefs are generally referred to as misconceptions or alternative conceptions. Odom et al. (1995) refer to misconceptions as mistakes, errors, misunderstandings, misleading ideas, misinterpretation of facts, preconceptions, private concepts, and naïve theories. They further elucidate misconceptions as students’ post-instruction ideas which are different from those generally accepted by scientists. Lawson et al. (1988) would add more to this definition in that misconceptions are not merely misunderstandings or trivial gaps in knowledge that teachers may have forgotten, but rather, they are allegedly embedded in “highly robust” conceptual frameworks for the interpretation of natural events, many of which were seriously advocated by leading intellectuals of the past. Blosser (1987) agreed with this and lists six characteristics that misconceptions have:

1. They may have historical precedence.
2. They may involve alternative belief systems comprised of logically linked sets of propositions that are used systematically by students and teachers.
3. They are at variance with conceptions held by experts in the field.
4. They tend to be pervasive and are shared by many.
5. They are highly resistant to change by traditional teaching methods.
6. They may arise due to neurological hardware or genetic programming (automatic language processing structures).

The Committee on Undergraduate Science Education (1997) breaks misconceptions down into five very specific types:

1. **Preconceived notions** – popular conceptions rooted in everyday experiences. These are especially prevalent in the physical sciences and are difficult to get rid of since they seem “logical” rather than the counterintuitive correct answers.

2. **Nonscientific beliefs** – include beliefs learned by students from sources other than scientific education (religious, mythical, mystical, etc. teachings). These are especially tenacious since they may be supported by the student’s family, church, and other authority figures.

3. **Conceptual misunderstandings** – arise when students are taught scientific information in a way that does not provoke them to confront paradoxes and conflicts resulting from their own preconceived notions and nonscientific beliefs. To reconcile their confusion, students construct faulty models.

4. **Vernacular misconceptions** – arise from the use of words that mean one thing in everyday life and another thing in science (like theory, hypothesis, work, etc.).

5. **Factual misconceptions** – these are false items learned early on and are retained into adulthood when they may surface and be challenged.

It is the Committee’s belief that the last two of these types of misconception are more easily corrected than the first three.
Science Misconceptions

Scientists and educators have long been concerned about Americans’ resistances to certain scientific ideas (Nowotny, 2005). Both adults and children resist information that clashes with their “common-sense” intuitions about the physical domain or information that comes from a trustworthy source. Experience is not always the best teacher when it comes to science because everyday experiences often reinforce the very conceptions of phenomena that scientists have shown to be false, and everyday modes of reasoning are often contrary to scientific reasoning (Donovan et al., 2005, Sadler, 1998). Children arrive at school with a vast store of ideas about the natural world that have arisen from their past experiences and that reinforce incorrect conceptions Fleury et al., 1991, Driver et al., 1994, Bransford et al., 2000, Mulhall et al., 2003, Kikas, 2004). Sometimes their beliefs are so firmly held that even with hands-on physical experiences which result in evidence for the correct scientific explanation, their bias remains and interferes with their acceptance of what they just witnessed (Bloom et al., 2007). Science misconceptions can be a major barrier to learning (Westcott, et al.

http://facctr.wcu.edu/mountainrise/archive/vol2no2/html/science_evolution.html)

While these incorrect ideas may arise from home interaction or school instruction, they are unlikely to be changed without specific teacher and curriculum intervention (Driver et al., 1994, Donovan et al., 2005). For a change or restructuring of ideas to occur, a teacher must be able to differentiate between scientific conceptions and misconceptions, teach concepts around it, choose
relevant activities to enable the student to glean information from the specific learning experience, and question the student about what he/she learned from the activity (Driver et al., 2000, Kikas, 2004). The teacher must be knowledgeable about common student misconceptions, monitor students’ understanding, design and introduce experiences at the appropriate point to promote learning, introduce new concepts, and provide experiences so that the student will become proficient users of those concepts. Perhaps even more critically, teachers must not hold the misconceptions themselves. Progress toward understanding key scientific concepts is not simple or straightforward and giving up a misconception without a replacement is confusing and frustrating for students (Sadler, 1998). The kind of teaching that will allow a student to replace a misconception with accurate understanding takes much longer than the conventional teaching approaches, so the breadth of content that can be covered is less than what has been traditionally expected (Mulhall et al., 2003).

Misconceptions are so pervasive and troublesome that the Missouri Department of Education (2005) stated that one of the reasons why students in Missouri are not learning the material they are required to is that they harbor serious misconceptions that were not identified prior to instruction. Kikas (2003) agrees and says that in addition to what students bring with them from home, teachers and textbooks are the next two most important sources of misconceptions – teachers create misconceptions by over-generalizing analogies that cause student confusion and by erroneously applying the properties of one category to objects in a different category (molecules “melting” when substances
melt). Book diagrams and illustrations contribute to this confusion – especially physical science books since words such as “force” and “moment” have a different meaning in science than in everyday language. Many textbook drawings are not well-thought out and give rise to faulty conceptions (Committee on Undergraduate Science Education, 1997). An example of this is the stretched-out ellipse (indicating an oval) that usually signifies earth’s orbit around the sun. The actual orbit resembles a circle, but when depicted as an ellipse, the earth appears to be further away from the sun at different times. “This means that as the Earth goes around its orbit the Northern hemisphere is at various times oriented more toward and more away from the Sun, and likewise for the Southern hemisphere, as illustrated in the following figure.

![The Seasons in the Northern Hemisphere](http://csep10.phy.utk.edu/astro161/lect/time/seasons.htm)

**Figure 2.** The seasons in the Northern Hemisphere

There is a popular misconception that the seasons on the Earth are caused by varying distances of the Earth from the Sun on its elliptical orbit.
This gives rise to the misconception that the earth is further away from the sun at different times of the year and if it is further away, then it must receive less heat at those times and therefore be colder. The transition from this information to the idea that winter is caused by the distance between the earth and the sun is easily made and hard to dispel. Misconceptions are barriers to learning and to complete understanding of certain concepts (Kikas, 2004).

Students’ personal beliefs and experiences may present a conflict between what their textbook says and what they have learned from sources other than school. Teachers might be surprised to know that even though they explain things carefully and completely, and that students give the correct answers when questioned; they may not really understand the concepts. Further investigation reveals that students cannot really satisfactorily explain concepts. With additional questioning, teachers can determine what needs to be done to help a student learn the material correctly and overcome misconceptions (Committee on Undergraduate Science Education, 1997).

Blosser (1987) proposed educational inservices that would give teachers the chance to confront their own as well as student science misconceptions. She further suggested that these inservices address the following issues:

1. conceptual change in teachers’ view of learning
2. knowledge of strategies useful in achieving these conceptual changes
3. knowledge of misconceptions in the area they are teaching with strategies for helping themselves confront them
4. skill in selecting and adapting materials based on common misconceptions held by elementary teachers
5. skill in diagnosing student misconceptions
6. allowing students to explore their own ideas in an appropriate classroom climate (Blosser, 1987, Kikas, 2004)

Kikas (2004) did an additional study in which three sets of teachers (teacher candidates, elementary teachers, and subject-educated secondary teachers) were tested for how many and what kind of misconceptions they had concerning motion of objects, seasonal changes, and changes of matter. Biology and other science-trained teachers showed a rather good understanding of these concepts and held many fewer misconceptions than trainee and primary school teachers. Kikas became an advocate for additional coursework in elementary school teacher preparation programs.

The Role of Explicit Instruction

Science methods courses show a limited impact on elementary teachers’ NOS views. An explicit approach seemed to work best, but it was not equally successful for all teachers for all NOS aspects (Abd-El-Khalick et al., 2004). They recommend teaching for a conceptual change which involves explicit teaching, metacognition, and metaconception (reflecting on the very content of concepts). When preservice teachers in his study were taught using these methods, changes in their NOS views showed a substantial improvement from previous attempts. There were three different factors that affected improvement: 1) teacher level of cognition (ability to process deeply) 2) teacher perception of
learning and teaching about the NOS; and 3) the importance of religion. Those who viewed science and religion as two opposing forces rather than as two different ways of knowing did not show growth in their NOS views (Aabd-El-Khalick et al. (2004).

Lederman (1999, 2003) found that there was a gap between what teachers understood about the NOS and what they taught about it. There is little information about what teachers who understand the NOS do to translate their understanding into classroom practices that impact students (Lederman, 1999). His research shows that more experienced teachers have classroom practices that agree with their professed views of the NOS and they incorporate a lot of inquiry-oriented activities that require students to collect data, infer explanations for the data, analyze it, and other activities which give students a chance at seeing what the NOS really is. Lederman’s research (1999, 2003) indicated that unless a teacher clearly intends to address the NOS and follow through with explicit emphasis during instruction, students will not develop an understanding of the NOS.

There is a growing body of research that suggests that the relationship between teachers’ conception of the NOS and their classroom practice is more complex than originally thought (Aabd-El-Khalick et al., 1998). Gess-Newsome et al (1999) found that experienced secondary teachers teach about the NOS in several ways: directly (giving instruction geared toward various aspects of NOS), indirectly (doing science inquiry activities), or they do not teach about it at all.
(Schwartz et al., 2004). Lederman (2003) feels that the direct method is the most successful.

A study completed by Abd-El-Khalick et al. (1998) showed that teachers felt that teaching about the NOS was important, but their lesson plans rarely indicated evidence of planning to teach the NOS, nor was it listed as a specific goal. References to the NOS from lessons were isolated, lacked focus, or addressed only a single aspect of the NOS. Eighty-six percent of the teachers in the study stated that they taught the NOS; but notes, interviews, and videos indicated that only a few did so. Teachers grossly overestimated their teaching of this topic and none of them formally assessed this topic. Further investigation revealed that if teachers mentioned anything about it, they thought they had “taught” it, and that many of the preservice teachers in the study thought that they had taught the NOS if they “did science” in the classroom. Since they did not truly understand the NOS themselves, they confused the NOS with the processes of science (Abd-El-Khalick et al., 1998). To illustrate, observing and hypothesizing are science processes, while the NOS conceptions around those processes would be the understanding that observations are constrained by our eyes and cultural influences, and hypotheses involve creativity and imagination (Lederman et al., 2002). It is important for students and their teachers to be aware of the differences between these two things (Osborne et al., 2003).
Misconceptions and Teaching Efficacy

Schoon et al (1998) completed a study to determine the extent of certain common alternative conceptions held by preservice elementary teachers and the relationship between the number and types of misconceptions and teaching efficacy. They found that teachers with the highest content knowledge had higher teaching efficacy measures. They found no direct relationship between teaching efficacy and the number of misconceptions held. A surprising finding was that there were five specific misconceptions associated with low efficacy teachers. Those misconceptions were: 1) planets can only be seen with a telescope, 2) dinosaurs lived at the same time as cavemen, 3) a rusty nail weighs less than the iron that it came from, 4) electricity is used up in appliances, and, 5) north is toward the top of a map of Antarctica. They state that teachers with these misconceptions have a critical barrier to understanding science because these concepts are very fundamental and yet, they do not understand them. Their science content knowledge is very low. Teachers holding these misconceptions also hold many other misconceptions thereby compounding the problem. Science may confuse them because of the cognitive dissonance resulting from perceiving science phenomena that do not support their misconceptions (Schoon et al., 1998).

Atwood and Atwood (1997) found evidence that some misconceptions are not firmly held. They studied the effectiveness of brief instruction to address specific misconceptions of the causes of day and night and the reason for seasons. Most elementary school teachers had misconceptions concerning both
concepts, but after instruction with hands-on activities, 80% of the teachers were able to explain these concepts using a more scientifically accepted explanation.

Identifying and Resolving Student Misconceptions

Lawson and Thompson (1988) state that students often hold misconceptions about natural phenomena, but in order to overcome them, students must recognize that the evidence they have collected does not support their present conception. The ability to generate logical relationships requires formal operational reasoning patterns. This gave rise to the hypothesis that students who were formal operational thinkers would hold fewer misconceptions than concrete operational thinkers. The authors conducted a study and found that the only statistically significant variable related to the number of misconceptions was reasoning ability, so students who could reason should have fewer misconceptions.

Lawson et al. (1988) postulate that it is not enough to teach scientific conceptions; teachers must also “unteach” naïve misconceptions by arranging classroom instructions in which students can collect data and resolve their misconceptions. Klymkowski et al. (2006) agree saying that it is essential for teachers to identify and address student misconceptions. Teachers are instrumental in identifying misconceptions, helping students overcome them, and communicating new concepts to students (Committee on Undergraduate Science Education, 1997). This is more easily accomplished using student-centered teaching methods, and teachers must be able to answer higher order questions
and clarify conceptual conflicts that arise with more contemporary teaching strategies (Kikas, 2004).

Misconceptions can be uncovered by asking students to support their explanations, by revising the explanations of difficult concepts (Committee on Undergraduate Science Education, 1997), by asking students to draw and describe some object or phenomenon (Bristol City Council, 2002), and then having them explain their drawings (Committee on Undergraduate Science Education, 1997). Teachers have to address student misconceptions explicitly and realize that some misconceptions are more firmly held than others (Bransford et al., 2000).

Diagnostic Tools

Hestenes et al. (1992) designed an assessment tool to be used in physics classes to probe conceptual understanding of Newton’s Laws of motion. The tool is called the Force Concept Inventory (FCI) and it revealed that good grades did not correlate with a robust conceptual understanding of mechanics. The FCI demonstrates that active learning leads to far superior student conceptual learning than traditional lectures and it pointed to the need for diagnostic instruments that can be used in other science fields (Klymkowski et al., 2003). Klymkowski developed the Biology Concept Inventory (Klymkowski et al., 2006) to be used as a pre-/post- instrument rather than an assessment tool. The instrument is unique in that it is two-dimensional - it tests content as well as student confidence in their answers. Students who answer incorrectly, but are
overly confident in their answers can be identified. If the distracters used in the inventory are misconceptions, then student responses mirror misconceptions. The rationale is that student misconceptions can be easily indentified and addressed by the instructor (Klymkowski et al., 2006).

Odom et al. (1995) also conducted research on student learning using diffusion and osmosis as the indicators. They compiled a list of 22 propositional knowledge statements required for understanding these two concepts at a level of sophistication appropriate for college biology (Appendix H). Their study provides evidence that biology major and non-majors continue to have alternative conceptions of diffusion and osmosis after instruction related to these concepts. Odom et al. (2007) conducted another set of studies on osmosis and diffusion using the DODT (Diffusion and Osmosis Diagnostic Tool) to gauge for misconceptions. Students had more misconceptions than actual knowledge and most students were either guessing or had misconceptions about every item related to the concepts of osmosis and diffusion. When asked to rate their confidence in their answers, students showed that they were very confident in their answers; an indication that their misconceptions will be very hard to change. Simply telling students the “correct” scientific view was not an effective strategy to misconception resolution (Fleury et al., 1991). It required using a variety of teaching approaches and activities to give their students the opportunity to discover and resolve their misconceptions – an inquiry approach.
Sanger et al. (2001) found that the concepts of diffusion and osmosis were very difficult for students to truly comprehend. Since diffusion is the primary method of short-distance transport in cells and cellular systems and osmosis explains water uptake and turgor pressure in plants, water balance in aquatic creatures, and transport in living organisms, this is a substantial problem. One reason students have so much trouble with these two topics is that they require students to visualize and think about chemical processes at the molecular level (Odom et al., 2007). Computer animations were used to explain the molecular behaviors associated with the processes of diffusion to students. They then performed experiments on diffusion and osmosis using dialysis tubing. After this exercise, they were less likely to choose responses suggesting that particle motion stops after equilibrium is reached compared to students who did not see the animations or complete the lab activities (Sanger et al. 2001). The students seeing the videos still had misconceptions about why particles do not stop moving, but they had fewer other misconceptions concerning these processes.

Specific Teaching Pedagogies

An additional suggestion for overcoming misconceptions comes from Christianson et al. (1999). They did a study using three different science classes with nearly the same type of students in each one. All students were given a pretest on which they scored about the same. Two of the classes were taught using traditional lecture format and one course was taught in a constructivist
manner with fewer topics, but taught to a deeper degree. All three classes were taught by professors very knowledgeable in their subjects and committed to the highest level possible of learning for their students. The data suggest that the students in the nontraditional course had a deeper understanding of the concepts than the students in the other two courses. The assessment tool even matched one of the traditional course’s content very closely, but the students did not learn it as well as the nontraditional constructivist course. The information and experiences of the students were scaffolded from simpler to more complex and the professor was fully aware of naïve conceptions. Discrepant events were used to challenge the naïve ideas, and there were frequent small-group and whole-class discussions of data. The students in the class taught in this manner performed better than those not taught with these innovations (Christianson et al., 1999).
CHAPTER 3 METHODS AND MATERIALS

Goals

The first goal of this mixed-method quantitative/qualitative study was to investigate whether two professional development courses in biology offered by the Rocky Mountain-Middle School Math Science Partnership effectively increased teacher background knowledge of the information covered in the courses. The Biology 1 (Cells, Human Systems, and Heredity) course material covered cell structure and function, photosynthesis, respiration, structure of DNA and RNA, DNA homology, the genetic processes of replication, transcription, and translation, and ended with information about forensics. The Biology 2 (Ecology, Biodiversity, and Adaptation) course covered characteristics of fossils, timelines, classification and phylogenetic trees, adaptation, population dynamics, natural selection, diversity, trophic structures, evolution, and ecology. Both courses included information on differences between facts, opinion, hypotheses, laws and theories as well as different practical mathematical applications.

The second goal of the study involved noting and tracking teacher misconceptions and looking for teacher resolution of those misconceptions as well as teacher recognition of misconceptions in their own students.
The third goal was also to see if teachers used inquiry techniques as well as information, lessons/activities, teaching strategies, and science equipment (provided by the course instructors) in their own classrooms.

The quantitative portion of the study employed multiple choice (MC) and constructed response (CR) pre-, post-, and follow-up assessments for both biology courses. The qualitative portion of the study consisted of two things: a teacher questionnaire and classroom observations. Each teacher from both courses was required to complete a questionnaire about their academic background, what courses they have and are teaching, and their teaching pedagogy. Every Biology 1 teacher that was participating in the follow-up class had to be observed for three classes (or the equivalent) and participate in a teacher/research interview after each observation. The researcher observed Biology 1 teachers teaching a minimum of three lessons in their classrooms and completed a classroom observation protocol for every class observed. After each observation, the researcher conducted an interview with the observed teacher for feedback, compliments, suggestions, or any questions concerning strategies, activities, misconceptions, content information and other pertinent matters. All instruments (Biology 1 and 2 MC and CR tests, the teacher survey, and the classroom observation protocol (COP)) used in this study were designed by the researcher.

**Research Questions**

There were four research questions that were the focus of this study.
Research Question 1  Did participating middle school teachers in the Jefferson County School District and other participating districts improve their science content knowledge after a two-week intensive summer science course offered by the RM-MSMSP?

Hypothesis 1  There will be no statistically significant differences in Biology 1 pretests, post tests, and follow-up assessments for:

a) Biology 1 multiple choice tests (MC),

b) Biology 1 constructed response tests (CR),

H<sub>O</sub>:  Biology 1 MC and CR pretest scores will equal Biology 1 MC and CR post test scores which will equal Biology 1 MC and CR follow-up test scores.

H<sub>A</sub>:  Biology 1 MC and CR pretest scores will not equal Biology 1 MC and CR post test scores which will not equal Biology 1 MC and CR follow-up test scores.

Hypothesis 2  There will be no statistically significant differences in Biology 2 pretests, post tests, and follow-up assessments for:

a) Biology 2 multiple choice tests (MC),

b) Biology 2 constructed response tests (CR),

H<sub>O</sub>:  Biology 2 MC and CR pretest scores will equal Biology 2 MC and CR post test scores which will equal Biology 2 MC and CR follow-up test scores.

H<sub>A</sub>:  Biology 2 MC and CR pretest scores will not equal Biology 2 MC and CR post test scores which will not equal Biology 2 MC and CR follow-up test scores.

Research Question 2  Which science misconceptions/errors do participating middle school science teachers bring to the two-week intensive summer institute course and are they able to resolve these misconceptions/errors?
Research Question 3 Will the teachers impart any misconceptions/errors to their students and will they notice and correct student misconceptions/errors in the classroom?

Research Question 4 Will the teachers from the Biology 1 class incorporate lessons, laboratory exercises, inquiry activities, or teaching strategies from the Biology 1 course? Will they use the equipment provided by the course instructors to each district?

Methodology

Quantitative Studies

Guskey (2000) stated that to measure specific learning or cognitive goals, the most efficient, and least expensive way to gather evidence on participants in professional development courses is through the use of assessments. The two most popular formats are multiple choice (MC) and constructed response (CR) (Bennet et al., 1991) MC tests are depicted as assessing simple, factual recognition (Rogers et al., 1999) and CR tests are portrayed as evaluating higher order thinking skills. These views are of concern because they imply that MC tests may be inappropriate for measuring the higher level thinking skills that school districts hope to be imparting to their students, yet many large-scale student assessments are either multiple choice or at least have a multiple choice component. Research indicates that the overwhelming majority of MC items do overlap with CR questions and measure similar constructs (Bennet et al., 1991, Rodriguez, 2002, Thissen et al., 1989), so MC questions can be confidently used
for testing purposes. The recommendation; however, is to use both formats to obtain comprehensive assessment information about scholastic achievement (Rodriguez, 2002, Martinez, 1999). Both MC and CR formats were used for this study.

Good MC questions are more difficult and time-consuming to write than other types of questions because effort must be made to not word them ambiguously, give clues to the answer, or to write them for an inappropriate objective (Burton et al., 1991, (Dodd et al., 2000). An important factor to consider when writing MC questions is how many distractors should be used for the response choices. A three option (one correct answer and two distractors) is optimal (Haladyna et al., 1993, 2002, Haladyna, 1997, 2004). When more than two distractors are used, one or more is generally nonfunctioning (chosen by less than 5% of the test takers) or one of the distractors serves as a testwise clue to the student. Bruno et al. (1995) reported that the reliability of a three-choice MC test was found to be statistically equivalent or superior to those of tests with two or four distractors per MC test item. Rogers et al. (1999) found that MC tests with fewer than four choices were far more discriminatory than those with four or more choices. Landrum et al., (1993) noted that students perform slightly better with 3-option items than with 4-option items (even when the test item difficulty was increased) which may be due to improved validity of the test items.

For the purposes of this dissertation, the focus was on the written assessment (although both courses employed a variety of other forms of evaluation for triangulation and for course grades). After a comprehensive
review of the literature on MC versus CR tests, the decision was made to use both MC and CR tests types to evaluate the teachers in both the Biology 1 and Biology 2 courses. The MC questions were paired such that teachers had to know the correct answer for the content question and the “because” or second question (Maunder, 2002, Lawson, 1978, 1995). An advantage was that the scores from both test types could be compared since both tests covered the same material. It could be seen whether or not teachers (as a group) correctly interpreted a multiple choice question if they indicated complete understanding on CR questions over the same topics.

For this study, it was important to know if teachers came to the course with the knowledge of the science content already part of their knowledge base. This information could be used to adjust the content information or activities of the overall course or to target teachers who might need additional information or help with specific material. A pretest indicates what a participant knows before the course, so if the same assessment is used as a post test, then specific gains can be measured (Guskey, 2000). Cizek, (1994) found that the best results are gotten when the exact same instrument is used for the pre-, post-, and follow-up tests. Even changing the order of the distractors can significantly affect the results. To avoid negative consequences, the multiple choice portions of the tests were kept anonymous so that teachers starting out with low scores would not be embarrassed – especially if they did not improve their scores to any great extent after taking the course. To further document knowledge gain, the exact same test could be re-administered at a specified later date as a follow-up test to
see if the participants retained what they learned over time (possibly a better indication of true learning).

**Qualitative Studies**

The first qualitative portion of the study consisted of a teacher survey (Appendix I) about the teachers’ educational preparation and background, their teaching situations, their pedagogical beliefs, the activities they do in their classrooms and their importance. The second qualitative section was information gathered from a classroom observation protocol (Appendix J) that was used for every teacher observation and interview. The information from this instrument was used to corroborate what teachers had written as responses on their surveys, to see if teachers were presenting accurate information to their students, if they used any of the lesson ideas or equipment from the summer course, and to see if they either imparted misconceptions or were able to recognize their students’ misconceptions during their teaching observations. Even though the questions were subjective, conclusions could still be made from the data. The same was true of the classroom observation protocol used by the researcher to observe the teachers, but in that case, personal bias was something that had to be carefully noted.

**Teacher Sample Population**

To qualify for entrance into one of the biology classes, the applicant had to be a teacher or work in the school system in the Jefferson County School district.
or in one of the other participating districts in the RM-MSMSP grant. Accurate information describing the participating teacher population was gathered by using a teacher survey (Appendix I).

There were two courses, so there were two teacher sample populations. Seven of teachers in the Biology 1 course also took the Biology 2 course. Those seven were considered as part of the population for each class separately. The Biology 1 course had 21 teachers – one high school teacher, 17 middle school teachers, and 3 elementary school teachers representing one high school, ten middle schools, and three elementary schools. One teacher did not take the follow-up course, so those data were excluded from the study because there would be no follow-up test and no COP for that person.

A general characterization of the Biology 1 class teachers based on their survey responses, shows that 67% of the teachers were females and 90% of all the teachers had taught for 15 years or less. Eighty one percent had taken a science class within the last five years. All teachers are supposed to have a bachelor’s degree and all of them did. The areas in which they had their degrees were quite varied from international business to forestry. Sixty seven percent of the teachers had master’s degrees, but none of those were in a science discipline. Sixty seven percent of the master’s degrees had been earned since the year 2000. Three fourths of the teachers were highly qualified in science and 80% of those not highly qualified wanted to become highly qualified. Only two of the 21 teachers in the Biology 1 class had ever worked in science-related job other than teaching.
The biology 2 class had 20 teachers – one high school teacher, 14 middle school teachers, and five elementary school teachers representing one high school, ten different middle schools, and two elementary schools. Twenty-three teachers took the summer course, but three did not take the follow-up course so their data were not included in this study. Seventy five percent of the teachers were female and 85% of all the teachers had taught for 15 years or less. Eighty five percent also had taken a science course in the last five years. All the teachers had a bachelor's degree and the areas in which they earned their degrees were quite varied. Three fourths of the class had master’s degrees and none of them were in science. Sixty percent of the master’s degrees had been earned since the year 2000. Only 15% of this class was working towards a science degree of any kind (one person) and the other two were working on a master’s degree in education. Sixty percent of the class was highly qualified in science, only one fourth of the remaining teachers were interested in becoming highly qualified. None of the teachers had worked in a science-related job of any kind other than their teaching.

School Demographic Data

Specific school demographic data were collected on schools in which classroom observations were made. The classroom observations were made on the teachers in the Biology 1 class only, so only those schools are included in the demographics. Fourteen different schools - elementary (3), middle (10), and high (1) schools from four different districts were represented in this study. Grades
taught by participating teachers ranged from 5th grade to 10th grade. The average number of students per school academic level was 335 for elementary schools and 643 for middle schools. The high school student population was 1530. Demographic information was further collected to give a more exact picture of the student populations in these different schools. The average percentage of minority students overall was 28.4 with the range from 5.1% to 82%. Schools reported an average attendance rate of 94.3 % with a fairly tight range from 89.2 to 98% (Appendix K).

Colorado schools are placed on an academic rating system based on Colorado Student Assessment Program (CSAP) tests taken every year by Colorado public school students. One school in the study was rated as being a low performer with seven schools rated as average, five rated as high and one rated as excellent. Across all the participating schools, the average reading score was 66 ± 14.84, the writing score was 55.29 ±17.01, the math score was 46.14 ± 17.86, and the average science score was 54.36 ± 19.60. Not all schools reported a science score – research into this revealed that schools not reporting science scores had not instituted the science CSAP tests as of the reporting time (the 2006 test results).

The Two Biology Courses

Both Biology 1 (Cells, Human Systems, and Heredity) and Biology 2 (Ecology, Biodiversity, and Adaptation) classes were taught during the summer of 2006. The Biology 1 class began on June 5, 2006 and ended on June 16,
2006. The pre- and post- tests were given on those two dates. The Biology 1 follow-up class consisted of four Saturday classes ending on December 1, 2006 and the follow-up assessment was administered on that day. The Biology 2 class started on June 19, 2006 and ended on June 30, 2006. The Biology 2 follow-up class consisted of four Saturday classes and ended on April 16, 2007. The pre-, post-, and follow-up tests were given on those three dates.

The Biology 1 class instructors were Dr. Jim Platt, Dr. Phil Danielson, Dr. Karen Johnson, Linda Morris, and the researcher – Linda Cepeda. Most preparation work was done by the researcher. The follow-up classes were taught by Dr. Karen Johnson, Linda Morris, and Linda Cepeda. The Biology 2 course instructors were Dr. Jim Platt, Dr. Mike Monahan, Dr. Karen Johnson, and Linda Morris. Drs. Monahan and Platt did the majority of the prep work and Linda Cepeda helped with some of it.

Developing the Instruments

The Assessments

There were a total of six instruments needed and used for this study. It was decided that a pretest, post test, and a follow-up test would be given to participating teachers. Each of these assessments would consist of the same two individual type of tests: one multiple choice (MC) test and one constructed response (CR). The purpose of the tests was to measure the level of biology knowledge of the participating teachers both before and after completing a biology content course and again after the course follow-up class. Another
purpose of the tests (especially the pretest) was to give the instructors an idea of how much background the teachers in each class had so that extra help or course modifications could be made in a timely fashion. All data used for this study were collected from teachers who took both the summer content course and the fall or spring follow-up course.

The concepts taught in the two courses were those specified in the Colorado Model Content Standards for Science (2005), Science: Assessment Frameworks at a Glance (1995) and the Curriculum Matrices for Geography, History, Mathematics, Reading and Writing, and Science, (Denver Public Schools, 2000). The topics chosen for testing were the main concepts covered by each of the two courses. For the Biology 1 course, the main topics were specified in the Goals section of this chapter. The questions were formulated directly from the course materials since the course had been taught before and were written such that answers required demonstration of comprehension (Dewey, http://www.psywww.com/selfquiz/aboutq.htm ). The Biology 2 course main topics were also specified in the Goals section, but since the course had not been offered before, there was less insight into potential problematic areas.

Each participating teacher in each class was required to take a multiple choice and a constructed response pretest and the same test two weeks later as a post test. The two tests covered the same material, but two different formats were employed. When a teacher was through with that multiple choice test, it was turned in and a constructed response test was given next. Teachers were not allowed to review their MC test to help them with answers to the CR tests.
The MC tests were designed following closely the two-distractor, multiple choice formats recommended by Haladyna (1997, 2004), Martinez (1999), Kehoe (2005) and the paired question format recommended by Lawson (1978, 1995) and Maunder (2002). Each MC question had one correct answer and two distractors. All the questions on the Biology 1 test were paired (18 pairs) except the last four questions since the content of those questions did not lend itself to that format (Appendix L). All the questions in the Biology 2 MC test were paired (22 pairs) (Appendix P). The two distractors for each question on the MC assessments for both courses consisted of either content misconceptions or answers that teachers frequently confuse with the correct answers when possible. The second part of the question pair also had two distractors, but the focus of the question was to demonstrate an understanding of the justification for picking the chosen response in the first question of the pair. The second statement in each of the pairs began with the word “because” so the teacher would understand that he/she was to select the reason why they chose the answer to the previous question on the test.

The Biology 1 constructed response test was written so that the participant had to write a short essay answer either explaining a process, propose an experimental design along with drawings, or to make a chart to differentiate between two distinctions within a concept (Appendix M). There were seven questions worth 42 points. Six science and education specialists evaluated the tests using the Writing Multiple Choice Test Matrices (Appendices N,O).
The Biology 2 multiple choice and constructed response tests (Appendices P, Q) were constructed the same way as the Biology 1 ones were. The tests were reviewed by only two members of the University of Denver Department of Biological Sciences due to time constraints. The Biology 2 constructed response test was fifteen questions worth 42 points (some questions had several parts) (Appendix Q).

The test formats were scored differently. The multiple choice questions were paired. They were scored such that if either the first or second question of the pair of questions was incorrect, no points were awarded. If both answers in the pair were correct, then two points were given. Therefore, the chance of teachers getting questions correct solely by guessing was reduced from one third to one ninth. Teachers getting the first part of the question correct, but not knowing the correct reason did not receive any points under the assumption that if they did not know why their answer was correct, then they may have just guessed the answer to the first part of the question. Total scores were calculated and the number of pairs with both answers correct divided by the total point value.

The constructed response tests were graded using an answer key produced by the researcher and partial credit was given for any part that was correct. Questions were worth different point values and were awarded in 0.5 point increments so that scores ranged from zero points to full credit for each question. The total scores were simply calculated as the total points earned
divided by the total number of points. All pretests, post tests, and follow-up tests were graded by the researcher.

The intent of the assessments was to serve as pre-, post, and follow-up assessments to see if the teachers learned any of the material after a two-week course and then determine whether or not they retained what they learned after a six month period for Biology 1 and a ten month period for Biology 2. The reason for the different time periods is that the Biology 1 course was offered during the first round of summer institute course offerings and those classes had a follow-up class offered during the first semester in the fall following the summer. The Biology 2 course was offered during the second round of class offerings and the follow-up courses for those classes were offered during the second semester.

Test reliabilities were assessed by using Cronbach’s alpha. For both the multiple choice and constructed response portions of the two tests, Cronbach’s alpha was calculated using the SPSS Graduate Student Pack software.

The Teacher Survey

To better describe the participating teacher population, accurate information had to be gathered by using a teacher survey. Background information on teachers’ academic coursework in biology, math, physics, earth science, and education, their preparation on different topics in those specific areas, which learning strategies they use, their beliefs about different pedagogical and assessment practices, and their access to adequate science equipment, and textbooks (Appendix I). Teachers were given the survey to
complete on the first follow-up class day and they were collected either on successive follow-up days, at the time of their observations, by mail, or by e-mail.

The Classroom Observation Protocol

One final item considered in this study is what teachers do in their classrooms – are they able to present the material they received in the courses to their own students, and if so, it is accurate and free from errors or misconceptions? It was also important to know if they were able to recognize misconceptions stated by their students or present material in such a way they do not impart additional misconceptions to them. Since a portion of the course was about pedagogy, observations were made to see if they employed any of the pedagogical practices they were shown in the courses and note their methods.

An additional benefit of teachers taking the Biology 1 or 2 course was to enhance their teaching efficacy so that their students could participate in some unique laboratory activities. Part of the observation checklist (Appendix J) was to see if teachers used any of the science equipment that was made available to them. This was only appropriate for Biology 1 teachers currently teaching in the areas covered by the course agenda. To keep track of this information, a classroom observation protocol was developed to provide information on the design of the lessons the teachers presented for observation, how they implemented the lesson, rating of the science content knowledge they presented, the opportunities they presented to their students to engage in logical and thoughtful methods of investigating some science phenomenon (scientif
method and process), and some interview questions over the physical environment of the room, their textbooks, the amount of preparation time and the resources they used to prepare their lesson. Much of the format and intent of this document closely models similar documents developed by Horizon Research, Inc. (2005) and Piburn et al. (Technical Report No. IN00-3) in the context of their external evaluation of the RM-MSMSP.

The idea of using a mixed-method approach (quantitative and qualitative) was done so that results could be triangulated. That is, for the pre-, post-, and follow-up assessments being given in both MC and CR format, the pooled results can be quantitatively compared. Teacher questionnaire results could be compared with classroom observation results.

**Quantitative Data Collection**

The quantitative design for this study was a pre-/post-/follow-up design. Assessments were given to every teacher in the beginning hour of the first day of the course, again on the last day in the afternoon, and on the last day of the follow-up course in the fall or spring. The researcher scored all the tests for the benefit of consistency. The validity of this study would have been increased had a completely random selection of teachers been possible, but only those teachers who signed up for a biology course and the follow-up course were included in the study.

The pre-/post-/follow-up design uses each teacher's initial assessment as a baseline so that their progress can be numerically charted and analyzed.
Every teacher took both the MC and CR tests with the MC test taken first followed teachers received the same treatment (the exact same test each time they took it) and by the CR test. The data were analyzed using repeated measures ANOVA.

**Qualitative Data Collection**

The second research question concerned teacher misconceptions and their resolution or retention. The data were analyzed to see which misconceptions were present at each test-taking time and if they were resolved or not. Both the multiple choice and the constructed response editions of the tests were analyzed. Many of the MC tests’ distractors were misconceptions, so charts with the misconceptions were made to chart teacher progress. For the constructed response portions, the misconceptions/errors stated on the tests were listed to see if the same ones appeared on later editions of the test.

Teachers were also observed to see if they imparted any misconceptions/errors to the students in their classes or if their students mentioned any. If they did, notes were made on how the teacher handled them in class (third research question).

The fourth research question concerned the teachers’ practices in their classrooms. Every attempt was made to provide useful activities during the course that teachers could incorporate into their teaching, and equipment was made available for teachers in every participating district. The classroom observation protocol was used for every observation (61 observations in all) and
close attention was given to the types of lessons teachers used, what they said to their students, what their students said aloud in class, and the number and types of activities the teachers did in class during the observations. Particular attention paid to whether or not they were able to incorporate any of the activities/labs from the summer Biology 1 course (however, not all teachers were teaching that content at the time of their observations). The observations were made for these purposes and to track misconceptions of both teachers and students. Some of the data collected were descriptive in nature and some were converted into charts so the trends would be easier to see and describe.

Only the Biology 1 class teachers underwent the observation process. During the first follow-up class, teachers were asked to sign up for three observations (preferentially sequentially). The observations were to be over lessons they prepared that covered either the course material, or, where it was not possible for the teacher to teach that content, they were to teach a lesson in which “science process or methods” were incorporated. Teachers not in the classroom during the fall semester (computer skills, library duty, etc.) worked with some other teacher in their school or district to “borrow” their classroom for the observations. This created an artificial teaching situation; however, if the teachers incorporated science processes, content, labs or other creative activities, they could see how easy it is to teach science using teaching reforms and how satisfying for their students science inquiry lessons could be.

Teachers were rated by a number of different criteria (Appendix J), but these observations were not factored into their course grades. These data were
used for research purposes only and also as resources so that course instructors could get feedback on anything that might be remedied or clarified with adjustments to course content.

Upon receiving the University of Denver Internal Review Board approval and Jefferson County School District review board approval of the proposed research, the principals of the participating schools in each district were notified that the researcher would be observing the teachers in their classrooms on the agreed upon dates. The teachers were given the opportunity to sign up for their observation times during the first follow-up class. Starting in October, teachers were contacted individually to confirm observations dates and arrangements were made to get security passes at each of the elementary, middle, and high schools in which teachers were to be observed. There were four participating districts with 14 different schools. Information about student and school demographics was also collected to account for all possible factors influencing teaching and learning.

Each teacher was to be observed while teaching three lessons and all except one was observed for a minimum of four hours. During that time, what they did, how they did it, what inquiry techniques they used, whether their delivery of the science content was accurate, if they noticed misconceptions voiced by their students, how they handled misconceptions in the classroom, if they used any of the lessons or labs from the summer course, if they used either the equipment we provided for them or their own, and how they controlled their classes were all observed/noted. The classes were audio-recorded and notes
were made while the observations took place. The tape recordings were to help in remembering specific things or in case something needed to be rechecked.

After each of the observations, the researcher met with each teacher for thirty to sixty minutes to ask them further questions, clarify some of what they said, to discuss the accuracy of their information, and to discuss misconceptions, and any other thing that had come during the observation. A Classroom Observation Protocol was filled out for each observation for each teacher during the observation. For the most part, the observations were done on different days so the progression of a lesson theme could be observed, but teaching schedules did not always permit that. There were some situations where a teacher had to be observed teaching in the morning and again later on the same day due to block schedules, school meetings, assemblies, rotating class schedules, special activities for the students, and other distractions. At the time the teachers were observed, most of the Teacher Surveys were collected. On the last follow-up meeting in December, all teachers were again given the both parts of the Biology 1 course assessment. Any additional teacher demographic surveys were collected.

The Biology 2 follow-up course began in January and ended in April, 2007. This class also was for review of science content and discussions of pedagogy around the various evolution and ecology topics taught during the summer. Twenty of the original 23 teachers took the follow-up course. Teachers were given the teacher surveys to fill out, but these teachers were not observed in their classrooms; therefore, there was no study of whether what they learned
in the course affected their classroom teaching or not. On the last day of follow-up class, Biology 2 teachers were given both Biology 2 course assessments and the teacher demographic surveys were collected.

**Validity**

An assessment is said to be valid if it tests what it was designed to test (Lambert & Lines, 2000). There were several types of validity to consider for this study. Construct validity is the idea that a test is valid if it tests what it sets out to test. These tests were written to test the teachers over the content of the course, so for these instruments, construct and content validity were the same. As far as content validity, these assessments were written specifically to cover the course material so they match the course curriculum very closely. Every topic taught was covered by portions and questions on both the multiple choice and the constructed response tests for the Biology 1 test. There was just one purpose of these tests and that is to see if the teachers learn the course material. The tests were written in an attempt to make them as “trick-free”, unambiguous, and straightforward as possible with direct wording.

To test the validity of these assessments, the Biology 1 test was reviewed by a panel of six experts: Dr. James Platt, Dr. Philip Danielson, and Dr. Judith Snyder from the University of Denver Department of Biological Sciences, Dr. Kathy Green of the University of Denver Department of Education, Dr. Karen Johnson of the Adams 12 School District, and Linda Morris, Jefferson County School District Science Coordinator. The multiple choice tests were written using
the specific guidelines of Haladyna (1997, 2004) (Appendix N). The test raters completed a matrix/questionnaire based on the specifications of good multiple choice test item writing by Haladyna (1997, 2004) (Appendix O) for the multiple choice portion of the test and they read the constructed response test questions and made comments. Some changes were made based on their comments and suggestions.

Reliability

A test can be considered reliable if the result is exactly the same across all occasions, tasks, observations, and settings - if it measures what it is supposed to measure consistently. The biology assessments were used for the first time in the 2006 Biology 1 and 2 courses, so they were not tested on other similar populations of middle school teachers to check for reliability. Reliability can be measured by test and retest scores for the same individuals, which was done in this case, but between the test and the retest, the teachers received the biology course intervention, so this measure could not be used to determine reliability.

Cronbach’s alpha is often used in educational research to determine the reliability of a test by computing correlation values among the questions on the instruments that are split in every possible combination. That statistic was less useful in this case since the questions covered a wide variety of topics and were not written to be compared with each other. The other reason that the Cronbach’s alpha was not useful here is that the questions were paired (each odd-numbered question asked about some topic covered in the course, while the
even-numbered questions were questions asked why the answer to the question paired with it was correct. These questions were not related to each other by topic content, but rather by reasoning ability.
CHAPTER 4 RESULTS

Chapter four describes the results of this study, which examined the learning, retention of information, resolution of misconceptions and errors, teacher preparation and the teaching practices of middle school science teachers after participating in a two-week summer course followed by a one-semester follow-up course. Analysis of the data, research results and other information are discussed in order by each of the research questions.

Research Question 1

The first research question was “Did participating middle school teachers in the Jefferson County School District and other participating districts improve their science content knowledge after a two-week intensive summer science course offered by the RM-MSMSP?”

Four assessments were used to evaluate the results of the teachers’ efforts in the Biology 1 and 2 classes. A Cronbach’s alpha was obtained for each of them to determine the reliability of each test (Table 2) (Benson et al., 1982).

Table 2. Cronbach’s Alpha Values

<table>
<thead>
<tr>
<th>Kind of test</th>
<th>Biology 1</th>
<th></th>
<th></th>
<th>Biology 2</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pre</td>
<td>post</td>
<td>FU</td>
<td>pre</td>
<td>post</td>
<td>FU</td>
</tr>
<tr>
<td>Multiple Choice (MC)</td>
<td>.77</td>
<td>.89</td>
<td>.85</td>
<td>.64</td>
<td>.79</td>
<td>.80</td>
</tr>
<tr>
<td>Constructed Response (CR)</td>
<td>.62</td>
<td>.83</td>
<td>.89</td>
<td>.78</td>
<td>.85</td>
<td>.75</td>
</tr>
</tbody>
</table>
A Cronbach’s alpha of 0.6 to 0.8 or higher is adequate for a test to be considered reliable (Simon, 2008). For the purposes of this study, these four instruments are reliable.

The mean test scores for each Biology 1 and 2 MC and CR assessments and the results of the repeated measures ANOVAS are shown in Table 3.

**Table 3. Repeated Measures ANOVA Results**

<table>
<thead>
<tr>
<th>Test</th>
<th>Tot. Pts</th>
<th>Pretest mean</th>
<th>Post test mean</th>
<th>Follow-up test mean</th>
<th>F value</th>
<th>p</th>
<th>Effec t Size</th>
<th>Huyn-Feldt Epsilon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio1 MC</td>
<td>40</td>
<td>18.7 ± 6.2</td>
<td>28.7 ± 7.5</td>
<td>24.7 ± 8.2</td>
<td>66.8</td>
<td>≤ .001</td>
<td>.769</td>
<td>.836</td>
</tr>
<tr>
<td>Bio1 CR</td>
<td>40</td>
<td>5.7 ± 5.5</td>
<td>28.5 ± 5.6</td>
<td>22.1 ± 9.5</td>
<td>26.1</td>
<td>≤ .001</td>
<td>.867</td>
<td>.857</td>
</tr>
<tr>
<td>Bio2 MC</td>
<td>44</td>
<td>19.2 ± 7.3</td>
<td>28.5 ± 7.1</td>
<td>25.2 ± 7.9</td>
<td>30.6</td>
<td>≤ .001</td>
<td>.879</td>
<td>1.00</td>
</tr>
<tr>
<td>Biol 2 CR</td>
<td>42</td>
<td>13.3 ± 5.7</td>
<td>29.9 ± 7.7</td>
<td>23.3 ± 6.8</td>
<td>82.1</td>
<td>≤ .001</td>
<td>.812</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Means are listed with standard deviation

The results of the statistical analyses indicate that there were significant differences among the means for the different tests at different times for all four assessments.
Pairwise comparisons for the Biology 1 MC and CR test scores found significant differences between all possible pretest, post test, and follow-up test pair combinations (Table 4).

**Table 4. Follow-up Pairwise Comparisons for Biology 1**

<table>
<thead>
<tr>
<th>Time</th>
<th>Time</th>
<th>Biology 1 MC</th>
<th></th>
<th>Biology 1 CR</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Difference</td>
<td>p</td>
<td>Mean Difference</td>
<td>p</td>
<td></td>
</tr>
<tr>
<td>Pretest</td>
<td>Post test</td>
<td>10.05</td>
<td>≤ 0.001</td>
<td>22.79</td>
<td>≤ 0.001</td>
</tr>
<tr>
<td></td>
<td>Follow-up test</td>
<td>5.95</td>
<td>≤ 0.001</td>
<td>16.41</td>
<td>≤ 0.001</td>
</tr>
<tr>
<td>Post test</td>
<td>Follow-up test</td>
<td>-4.10</td>
<td>≤ 0.001</td>
<td>-6.38</td>
<td>≤ 0.001</td>
</tr>
</tbody>
</table>

In the Biology 1 course, MC results increased by about ten points from the pretest to the post test. There was approximately a four point decrease between the post test and the follow-up test. The overall gain from the pretest to the follow-up test was about six points. The CR results showed a larger gain from the pretest to the post test (nearly a 23 point mean increase) with about a six point loss between the post test and the follow-up test. The gain from the pretest to the follow-up test was about 16 ½ points.

Pairwise comparisons using the biology 2 MC and CR test scores found significant differences between all possible pretest, post test, and follow-up pairs for each of the two Biology 2 tests (Table 5).
Table 5. Follow-up Pairwise Comparisons for Biology 2

<table>
<thead>
<tr>
<th>Time</th>
<th>Time</th>
<th>Biology 2 MC</th>
<th></th>
<th>Biology 2 CR</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Time</td>
<td>Mean Difference</td>
<td>p</td>
<td>Mean Difference</td>
<td>p</td>
</tr>
<tr>
<td>Pretest</td>
<td>Post test</td>
<td>9.30</td>
<td>≤ 0.001</td>
<td>16.63</td>
<td>≤ 0.001</td>
</tr>
<tr>
<td>Follow-up test</td>
<td>Follow-up test</td>
<td>6.00</td>
<td>≤ 0.001</td>
<td>9.95</td>
<td>≤ 0.001</td>
</tr>
<tr>
<td>Post test</td>
<td>Follow-up test</td>
<td>-3.30</td>
<td>≤ .015</td>
<td>-6.68</td>
<td>≤ .015</td>
</tr>
</tbody>
</table>

For the Biology 2 course, the MC results showed slightly more than a nine point increase from the pretest to the post test and a loss of three points from the post test to the follow-up test. The overall gain from the pretest to the follow-up test was six points. The CR data showed an increase from pretest to post test scores of slightly more than 16 points with about a seven point loss from the post test to the follow-up test. Overall gain from the pretest to the follow-up test was nearly ten points.

Biology 1 MC Results

Table 6 shows the Biology 1 class teachers’ collective responses to each question for each of the three test administrations. Results showed that 77.5% (31/40) of the questions showed an increase in the number of correct responses from the pretest to the follow-up test while 22.5% (9/40) remained the same or decreased.
### Table 6. Comparison of Biology 1 MC Question Responses

<table>
<thead>
<tr>
<th>Q#</th>
<th>Content</th>
<th>Answers</th>
<th>Response Choices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>1</td>
<td>What is a theory</td>
<td>B</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>Because</td>
<td>C</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>Id of variables</td>
<td>B</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Because</td>
<td>A</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>Diffusion</td>
<td>A</td>
<td>18</td>
</tr>
<tr>
<td>6</td>
<td>Because</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Measurement</td>
<td>A</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>Because</td>
<td>C</td>
<td>7</td>
</tr>
<tr>
<td>9</td>
<td>Diffusion</td>
<td>B</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>Because</td>
<td>A</td>
<td>17</td>
</tr>
<tr>
<td>11</td>
<td>Osmosis</td>
<td>B</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>Because</td>
<td>B</td>
<td>12</td>
</tr>
<tr>
<td>13</td>
<td>Proc of Photosynthesis</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>Because</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>Photosynthesis</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>Because</td>
<td>A</td>
<td>16</td>
</tr>
<tr>
<td>17</td>
<td>Proc of Respiration</td>
<td>C</td>
<td>2</td>
</tr>
<tr>
<td>18</td>
<td>Because</td>
<td>A</td>
<td>13</td>
</tr>
<tr>
<td>19</td>
<td>Respiration</td>
<td>B</td>
<td>6</td>
</tr>
<tr>
<td>20</td>
<td>Because</td>
<td>B</td>
<td>9</td>
</tr>
<tr>
<td>21</td>
<td>Nucleic acids</td>
<td>A</td>
<td>8</td>
</tr>
<tr>
<td>22</td>
<td>Because</td>
<td>B</td>
<td>7</td>
</tr>
<tr>
<td>23</td>
<td>Meiosis</td>
<td>B</td>
<td>9</td>
</tr>
<tr>
<td>24</td>
<td>Because</td>
<td>B</td>
<td>2</td>
</tr>
<tr>
<td>25</td>
<td>Mitosis</td>
<td>A</td>
<td>13</td>
</tr>
<tr>
<td>26</td>
<td>Because</td>
<td>C</td>
<td>6</td>
</tr>
<tr>
<td>27</td>
<td>Compare meiosis/ mitosis</td>
<td>A</td>
<td>12</td>
</tr>
<tr>
<td>28</td>
<td>Because</td>
<td>C</td>
<td>3</td>
</tr>
<tr>
<td>29</td>
<td>Semi-conservative Replica</td>
<td>B</td>
<td>9</td>
</tr>
<tr>
<td>30</td>
<td>Because</td>
<td>A</td>
<td>11</td>
</tr>
<tr>
<td>31</td>
<td>Structure of DNA</td>
<td>A</td>
<td>16</td>
</tr>
<tr>
<td>32</td>
<td>Because</td>
<td>C</td>
<td>9</td>
</tr>
<tr>
<td>33</td>
<td>Transcription</td>
<td>B</td>
<td>10</td>
</tr>
<tr>
<td>34</td>
<td>Because</td>
<td>C</td>
<td>10</td>
</tr>
<tr>
<td>35</td>
<td>Electrophoresis</td>
<td>A</td>
<td>10</td>
</tr>
<tr>
<td>36</td>
<td>Because</td>
<td>B</td>
<td>10</td>
</tr>
<tr>
<td>37</td>
<td>Protein Structure</td>
<td>A</td>
<td>11</td>
</tr>
</tbody>
</table>
The responses for the three test administrations were examined to see if there was any pattern such as a concentration of incorrect responses for questions on specific concepts. There were five pairs of questions and one single question for which there was no apparent improvement in understanding the material.

The first question pair that showed no improvement in understanding was the identification of variables (Q# 3/4). There was a decrease both on the content and the “because” questions. It was expected that the teachers would know this information coming into the Biology 1 course. Seventy six percent (16/21) of the class answered these two questions correctly on the pretest, but that number dropped back to 57% (12/21) on the follow-up test. The reasoning for their answers went from 71% (15/21) correct on the pretest to 63% (13/21) on the follow-up test. These results indicate that a little less than one third of the teachers did not understand how to identify the independent variable by the end of the course.

The second question with which the teachers had difficulty was a question on measurement and proportions (Q# 7/8). The content part of the question pair decreased by only one teacher from the beginning of the class, but less than 50% of the class demonstrated the ability to solve the simple proportional
problem on the pretest and the post test. The “because” portion asked the teachers to pick the correct mathematical equality. While only seven of the 21 (33%) teachers knew the equality on the pretest, 71% (15/21) knew it on the follow-up test.

The third question pair for which numbers of correct responses stayed the same or decreased was the question pair on diffusion (Q# 9/10). Two thirds of the class (14/21) answered the content question correctly on both the pretest and the follow-up test, and 81% (17/21) answered the “because” portion correctly on the pretest and the follow-up test. While most of these teachers correctly answered these questions, no progress was made even though there were several diffusion activities done during the summer course.

The fourth question pair for which correct responses stayed the same or decreased was a question on what the results of meiosis would be concerning numbers of chromosomes in diploid and haploid cells (Q# 23/24). Fifty three percent (11/21) of the teachers chose the correct response on the content question on the pretest and 43% (9/21) did on the follow-up test, but 86% correctly responded to the “because” questions on the pre- and the number rose to 90% (19/21) on the post test.

The last question pair (of those that showed the same number or a decrease in number of correct answers chosen) (Q# 29/30) dealt with semi-conservative replication of DNA. There were problems with this question in the wording of the proposed experiment which was not caught during the test evaluation, so these results were not considered.
There was one single-part question (Q# 10) for which the number of teachers answering correctly decreased by one teacher between the pretest and the follow-up test and that was the question on comparing genes, DNA, and chromosomes - fundamental knowledge for understanding discussions about genetics. With such a low number of teachers in the study, a difference of just one teacher does not truly a trend in any direction.

Another way of looking at these data is shown in Table 7 where the data are presented so that the number of teachers choosing the correct answer for each of the 40 individual questions from the time of the pretest to the follow-up test is shown. The numbers are listed individually so that it can be seen whether or not the difficulty lay with the question (content material) or the “because” statement (reason the answer for the first question of the pair). The increase in correctly answered question pairs (13) was a little more than three times the number of question pairs that stayed the same or decreased (4). There was one question pair for which the content portion of the question was incorrect (decreased) and the “because” portion that was correct (increased).

Table 7. Comparison of Biology 1 Multiple-Choice Question Responses

<table>
<thead>
<tr>
<th>Q #</th>
<th>Content Question Pairs</th>
<th>ANS</th>
<th>Response Choices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pre</td>
</tr>
<tr>
<td>1</td>
<td>What is a theory</td>
<td>B</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>Because</td>
<td>C</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>Diffusion</td>
<td>A</td>
<td>18</td>
</tr>
<tr>
<td>6</td>
<td>Because</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>Osmosis</td>
<td>B</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>Because</td>
<td>B</td>
<td>12</td>
</tr>
<tr>
<td>13</td>
<td>Proc of Photosynthesis</td>
<td>B</td>
<td>1</td>
</tr>
</tbody>
</table>
Because

Photosynthesis
Because
Respiration
Because
Process of Respiration
Because
Nucleic acids
Because
Mitosis
Because
Comp meiosis/mitosis
Because
Structure of DNA
Because
Transcription
Because
Electrophoreses
Because
Measurement
Because
Id of variables
Because
Diffusion
Because
Meiosis
Because
Semi-conservative Repli
Because

Single Questions

Protein Structure
Mutation
Random Assortment
Compare gene, DNA, CHXs

Legend: All colored squares indicate the correct answer for that question.

□ indicates a decrease or no change in score from pretest to follow-up test

□ indicates an increase in score from pretest to follow-up test
Biology 2 MC Results

The Biology 2 class results show a similar trend (Table 8). Results showed that 70% (31/44) of the questions showed an increase in the number of correct responses from the pretest to the follow-up test while 30% (13/44) remained the same or decreased.

Table 8. Comparison of Biology 2 MC Question Responses

<table>
<thead>
<tr>
<th>Q #</th>
<th>Content</th>
<th>ANS</th>
<th>Response Choices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pre</td>
</tr>
<tr>
<td>1</td>
<td>Evolution dendograms</td>
<td>B</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>Because</td>
<td>C</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
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<td>B</td>
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<td>8</td>
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<td>Ecosystem energy sources</td>
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<td>28</td>
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<td>C</td>
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</tr>
<tr>
<td>29</td>
<td>Spatial distribution factors</td>
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There were two question pairs and seven questions from different pairs that decreased in the number of incorrect responses. This might indicate that even though the teachers had some familiarity with these concepts, they did not know them thoroughly. One of the two question pairs that showed a decrease in the number of teachers responding correctly was one on the differences between a theory and a fact (Q# 3/4). The example used plate tectonics as an example which may have interfered with the intent of the question pair in that the teachers may not have understood the theory of plate tectonics rather than the relationship between theory and facts.

The second question pair for which the number of incorrect responses increased from the pretest to the post test was on spatial distribution of living organisms (Q# 29/30). Slightly more teachers (1) thought that the distribution of living organisms was controlled by either biotic or abiotic factors alone. Ninety
five (19/20) percent of the teachers responded to the question correctly, but that number went down to 90% (18/20) on the follow-up test. The “because” portion decreased from 80% (16/20) to 60% (12/20).

The question on homologous versus vestigial traits (Q# 7/8) showed a very large increase in teachers understanding of what a vestigial structure is, but a very slight decrease in understanding why a structure would be vestigial rather than homologous. When these data were analyzed for increases or decreases, the sample size became important. For this question and others, there were instances where the difference between a decrease or increase in percentages of correct answers was only one teacher making it less accurate to make a blanket statement concerning teachers’ knowledge of a concept. That is the case with this question. In general, teachers did understand the concept, but one teacher may have gotten confused as to the reason.

Questions for which the number of incorrect answers decreased by only one answer or those for which the number of teachers with the correct answer is 75% or more will just be mentioned rather than analyzed for reasons why the numbers decreased since the decrease is small and may not truly reflect a significant difference. The questions on fossil ages (Q# 11/12), genetic resistance (Q# 17/18), and trophic level energy transfer (Q# 31/32) fall into this category.

There was a question on speciation (Q# 23/24) – an important concept covered in great detail in the class. Fifty five percent (11/20) of the teachers responded correctly on the pretest, which was unexpectedly high. However, on
the post test, a few less chose the right answer and on the follow-up test only
40% did. They did not learn the information.

The “because” portion of questions dealing with logarithmic growth (Q# 34) and factors affecting biomes (Q# 36) decreased by only zero to one teacher each, but those questions along with the content parts of the pair were correct for only 50% of the class. The correct responses from the “because” question on soil nutrition also decreased which left only 25% percent of the class demonstrating understanding by the time of the follow-up test.

There was one question pair on population cycles (Q# 43/44) that only one teacher chose the correct response for the pretest and the post test. Clearly the concept was not understood by the teachers. The “because” portion increased from one to two, so basically no one truly understood the material. Certainly these results were unexpected, but the fact that even by the time of the follow-up test, the teachers did not correct their misconceptions around this topic.

Another way of looking at these data is presented in Table 9 where the data are ordered so that the number of teachers choosing the correct answer from the time of the pretest to the follow-up test is shown. The number of correctly answered question pairs (11) was more than the number of question pairs that stayed the same or decreased (2). The question pairs for which the content was correct and the “because” statement was incorrect (4) were separated from the others as were the question pairs in which the content statement was incorrect, but the “because” statement was correct (5). The
The number of correctly answered question pairs (11) was also more than the question pairs in which either question in the pair was incorrect (9).

Table 9. Comparison of Biology 2 Multiple-Choice Question Responses

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<th>Q #</th>
<th>Content</th>
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<th>Response Choices</th>
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<td>Post</td>
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<td>Because</td>
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<td>1</td>
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<tr>
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<td>Diff between theory/fact</td>
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<td>4</td>
<td>Because</td>
<td>C</td>
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<td>9</td>
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<td>C</td>
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<td>DNA homology</td>
<td>B</td>
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<td>Because</td>
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<td>18</td>
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<td>A/C</td>
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<td>17</td>
<td>Genetic Resistance</td>
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</table>
Because

Speciation

Because

Trophic level energy trans

Because

Population cycles

Because

Theory of plate tectonics

Because

Spatial distrib factors

Because

**Legend:** All colored squares indicate the correct answer for that question.

\[\square\] indicates a decrease or no change in score from pretest to follow-up test

\[\square\] indicates an increase in score from pretest to follow-up test

**Biology 1 CR Results**

Table 10 presents the data from the CR tests. The pretest results show that more than 50% of the class received no points on six out of the seven questions on the Biology 1 CR pretest. There were two questions on which teachers received full points while more than half of the class received no points (differences between prokaryotes and eukaryotes and differences between plant and animal cells).
Table 10. Frequency of Scores for Biology 1 CR Test Responses

<table>
<thead>
<tr>
<th>Point Values</th>
<th>Biology 1 CR Pretest</th>
<th>Biology 1 CR Post Test</th>
<th>Biology 1 CR Follow-up Test</th>
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<td>41A.Procaryote/Eucaryote</td>
<td>41B.Plant/Animal cells</td>
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<td>Tot Pts</td>
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</table>

Legend: Maximum point values for each question are listed across the bottom, how many points teachers received on a question is listed along the left side of the chart. Squares colored green (□) indicate the number of teachers scoring full points for that question.

On the post test, there were only two questions on which teachers received zero points (Q# 41A and 44B) and three questions on which a total of
19 answers for which full points were awarded (Q# 41A, 41B, 44C). The topic that teachers still had difficulties with was DNA transcription.

By the time of the follow-up test, there were three topics that teachers received full points for: the difference between prokaryotes and eukaryotes (6/21), the differences between animal and plant cells (13/21), and DNA replication (1/21). Some teachers did receive zero points on questions on the follow-up test, but nowhere near as many did as at the beginning of the course. On the question about the difference between plant and animal cells, thirteen teachers scored full points. While the shape of the histogram for all three tests is basically the same, it is readily apparent that the numbers of correct answers shifted the scores considerably with many fewer students at the lower point value end of the graph and many more in the middle and at the higher point value end of the histogram (Table 10).

**Biology 2 CR Results**

Table 11 presents Biology 2 CR results. On the pretest, one or more teachers scored full points for nine of the questions and there were four questions on which more than 50% of the class scored zero points (Q# 4, 7, 8, 10b). There were nine questions on which teachers scored full points and three questions on which 50% or more of the teachers received full points (Q# 5a, 5b, 11c). The topics that were the most troublesome for them were the fossil timeline, use of the population equation, speciation, natural selection, and quality of water. The topics that the teachers were most familiar with were phylogenetic
trees showing interrelationships between animals, stream diversity, and factors affecting populations.

Table 11. Frequency of Scores for Biology 2 CR Test Responses

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**Legend:** the topic of the question is listed for each of the tests followed by the number of teachers receiving that score out of the possible scores for each question. The number of possible points for each question is listed down the column of the right side of the page. Light orange indicates the number of teachers receiving full points for that question.

The post test results showed that question on water contamination (Q# 10b) was the only question on which 50% or more the teachers scored zero points. All of the 15 questions had some teachers that scored maximum points and for seven of the questions, 50% or more of the teachers scored maximum points.

The follow-up test follow-up test showed some relapse in that for 13 of the 15 questions at least some teachers received zero points, and for three of them (Q# 4, 10a, 10b), more than 50% of the class earned zero points. On all of the questions, at least one teacher received total points, and for four of them, 50% or more of the class received full points. The trouble spots were still difficulties with
the population equation and problems with the river diversity and contamination problem. This was not anticipated, but neither was a missing page with question #10 from the follow-up test. Even though the page was put up on the overhead for the teachers to read, many did not answer that question on the back of the preceding page, or if they did, they did not label the parts, so it was difficult to grade. This oversight was very likely the cause of the low scores for that question.

**Biology 1 Course Results**

Table 12 shows the scores for the Biology 1 MC and CR tests together. The results indicate improved scores on each of the three administrations of the tests. While not every teacher increased his/her learning, overall the Biology 1 class of teachers did.

**Table 12. Biology 1 MC & CR Pre-, Post- and Follow-up Test Scores**

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On the multiple choice tests, two teachers did not improve their overall scores and three scored lower on the follow-up test than they did on the pretest, but each of these three teachers showed improve their post test scores. The greatest net point gain from the multiple choice pretest to the follow-up test was fourteen points.

All Biology 1 teachers’ scores increased significantly on the constructed response post test and all increased significantly on the follow-up test except for one student. That student only answered part of the first question on the follow-up test and decided to not take any more of the test so as to "not waste his/her time and that of the researcher grading a test on which he/she did not know the material that well since he/she did not teach that material in his/her grade level.” That score of four points is not really an accurate test score because it only contains the score of one question; however, it is still an increase from the pretest score. Otherwise there was a significant increase between the pretest scores and the follow-up scores which indicates learning on the part of the teachers. The smallest gain was eight and one half points (disregarding the
uncompleted test) and the greatest point gain from the constructed response pretest to the follow-up test was thirty one points. This is more than twice the net gain seen from the MC tests.

**Biology 2 Course Results**

Table 13 shows the scores for the Biology 2 MC and CR tests. The results indicate improved scores on each of the three administrations of the tests. Not every student increased his/her learning, but overall the class did.

**Table 13. Biology 2 MC & CR Pre-, Post- and Follow-up Test Scores**

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<td>36</td>
<td>36</td>
<td>8</td>
<td>14</td>
<td>11.0</td>
<td>30.5</td>
<td>12.0</td>
<td>1</td>
</tr>
<tr>
<td>6993</td>
<td>20</td>
<td>28</td>
<td>20</td>
<td>0</td>
<td>15</td>
<td>6.5</td>
<td>30.0</td>
<td>15.5</td>
<td>9</td>
</tr>
<tr>
<td>7208</td>
<td>20</td>
<td>36</td>
<td>24</td>
<td>4</td>
<td>16</td>
<td>15.5</td>
<td>37.0</td>
<td>15.0</td>
<td>-5</td>
</tr>
<tr>
<td>7474</td>
<td>24</td>
<td>28</td>
<td>28</td>
<td>4</td>
<td>17</td>
<td>18.5</td>
<td>37.5</td>
<td>21.0</td>
<td>2.5</td>
</tr>
<tr>
<td>7501</td>
<td>8</td>
<td>28</td>
<td>20</td>
<td>12</td>
<td>18</td>
<td>2.0</td>
<td>14.0</td>
<td>10.0</td>
<td>8</td>
</tr>
<tr>
<td>9087</td>
<td>12</td>
<td>12</td>
<td>22</td>
<td>10</td>
<td>19</td>
<td>14.0</td>
<td>27.0</td>
<td>24.5</td>
<td>10.5</td>
</tr>
<tr>
<td>9179</td>
<td>34</td>
<td>36</td>
<td>32</td>
<td>-2</td>
<td>20</td>
<td>4.5</td>
<td>25.0</td>
<td>21.5</td>
<td>17</td>
</tr>
</tbody>
</table>

**Legend:** The list of teachers for the multiple choice questions is not in the same order as the teachers for the constructed response tests. The two tests cannot be compared teacher-by-teacher across test types. The scores in red indicate
that the teacher scored the same or lower score on the follow-up test than on the pretest. Numbers in blue indicate the greatest point gain from pretest to follow-up test.

These results show that for the multiple choice tests, all Biology 2 teachers increased their scores between the pretest and the post test except for one student whose score remained the same. That student started out with a fairly high score (comparatively), so there was not as much room for improvement. However, the goal of the course was to impart some new knowledge to every student. There was one student who increased his/her score by only two points and that student also started out with a fairly high score. Five teachers’ scores remained the same or decreased from the pretest to the follow-up test. While there were some teachers that increased their scores by only a few points, many increased their scores by a lot more and two teachers increased their score by 18 points from the pretest to the follow-up test.

All Biology 2 teachers’ scores increased significantly on the constructed response post test and all increased their scores on the follow-up test except for two teachers. One of those two teachers was disinterested in the class and the other student was very conscientious so his/her score was unexpected. Otherwise, there was a significant increase between the pretest scores and the follow-up scores which may indicate learning and retention on the part of the teachers. The greatest point gain from the constructed response pretest to the follow-up test was 17.5 points. The smallest net gain on the post test was only 1 point, followed by one student with a two and a half point gain. There was one
student with a four point net gain and two with a five net point gain. While the teachers in the Biology 2 course were less serious and more prone to taking less time or care with their responses on the assessments, these low increases scores were not necessarily from the less able or conscientious teachers.

**Comparison of Biology 1 and 2 Assessment Results**

Table 14 shows the mean MC and CR scores for both biology 1 and 2 classes. The mean scores for the MC assessments are nearly the same for the two classes. For the CR tests, the pretest mean score for the Biology 1 class was about one half that of the Biology 2 pretest mean score. The means for the post test and the follow-up tests; however, were almost the same.

**Table 14. Biology 1 & 2 Mean MC & CR Pre-, Post-, &Follow-up Test Scores**

<table>
<thead>
<tr>
<th>Test</th>
<th>Biology 1</th>
<th>Biology 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC Pretest</td>
<td>18.7 ± 6.2</td>
<td>19.2 ± 7.3</td>
</tr>
<tr>
<td>MC Post Test</td>
<td>28.7 ± 7.5</td>
<td>28.5 ± 7.1</td>
</tr>
<tr>
<td>MC Follow-up</td>
<td>24.7 ± 8.2</td>
<td>25.2 ± 7.9</td>
</tr>
<tr>
<td>CR Pretest</td>
<td>5.7 ± 5.5</td>
<td>13.3 ± 5.7</td>
</tr>
<tr>
<td>CR Post test</td>
<td>28.5 ± 5.9</td>
<td>29.9 ± 7.7</td>
</tr>
<tr>
<td>CR Follow-up</td>
<td>22.1 ± 9.5</td>
<td>21.5 ± 6.8</td>
</tr>
</tbody>
</table>

Numbers in red = mean scores, the numbers in black= standard deviations

The comparison of the largest net gain between the Biology 1 MC and CR tests (Table 12) showed that the net gain for the CR test was more than twice that of the MC test (14 points on the MC and 31 points on the CR assessments). For the Biology 2 MC and CR assessments (Table 13), it was nearly the same net gain (18 points on the MC and 17.5 points on the CTR).

Both class results also show that the means for the MC pretests were higher than the means for the CR pretests, but post test and follow-up test scores
(MC and CR) were similar. There were significant differences for all tests at all times which provides evidence that the teachers did learn some content and retained some of what they learned.

Both classes had five teachers who either had the same follow-up or lower test scores than their pretest scores. In both classes, two of these students were very high scoring and therefore could not gain many more points. The three other students in both classes were low scoring and either kept the same scores or decreased them.

**Research Question 2**

The second research question was “Which science misconceptions/errors do participating middle school science teachers bring to the two-week intensive summer institute course and are they able to resolve these misconceptions/errors?”

**Biology 1 Multiple Choice Assessments**

MC questions were, for the most part, written so that one or more of the distractors were misconceptions. Table 15 presents data that address this question. Each question-pair topic is listed along with the percentage of teachers correctly answering it.

**Table 15. Percent of Correct Biology 1 MC Questions**

<table>
<thead>
<tr>
<th>Q#</th>
<th>Content Material</th>
<th>Pretest</th>
<th>Post test</th>
<th>FU test</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Simple diffusion vs. temperature</td>
<td>91</td>
<td>100</td>
<td>98</td>
</tr>
<tr>
<td>6</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Membrane diffusion of starch and sugar</td>
<td>74</td>
<td>88</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Process of photosynthesis</td>
<td>71</td>
<td>76</td>
<td>76</td>
</tr>
<tr>
<td>14</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Photosynthesis requirements</td>
<td>81</td>
<td>98</td>
<td>100</td>
</tr>
<tr>
<td>16</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Respiration with/without C sources</td>
<td>60</td>
<td>81</td>
<td>76</td>
</tr>
<tr>
<td>18</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Cells in which mitosis occurs</td>
<td>60</td>
<td>71</td>
<td>71</td>
</tr>
<tr>
<td>26</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>End results of meiosis and mitosis</td>
<td>62</td>
<td>81</td>
<td>81</td>
</tr>
<tr>
<td>28</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Structure of double-stranded DNA</td>
<td>67</td>
<td>98</td>
<td>93</td>
</tr>
<tr>
<td>32</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Transcription of DNA</td>
<td>29</td>
<td>95</td>
<td>74</td>
</tr>
<tr>
<td>34</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>Protein structure and function</td>
<td>52</td>
<td>86</td>
<td>71</td>
</tr>
<tr>
<td>38</td>
<td>DNA base sequence in mutation</td>
<td>57</td>
<td>71</td>
<td>71</td>
</tr>
<tr>
<td>1</td>
<td>What is a theory</td>
<td>43</td>
<td>76</td>
<td>62</td>
</tr>
<tr>
<td>2</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Osmosis across RBC membrane</td>
<td>38</td>
<td>76</td>
<td>62</td>
</tr>
<tr>
<td>12</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Nucleic acid processes involving mRNA</td>
<td>38</td>
<td>76</td>
<td>55</td>
</tr>
<tr>
<td>22</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Random assortment of chromosomes</td>
<td>43</td>
<td>91</td>
<td>48</td>
</tr>
<tr>
<td>40</td>
<td>Relationship of genes, DNA, chromos</td>
<td>62</td>
<td>86</td>
<td>57</td>
</tr>
<tr>
<td>35</td>
<td>DNA separation in electrophoresis</td>
<td>36</td>
<td>60</td>
<td>76</td>
</tr>
<tr>
<td>36</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>ID of independent variables</td>
<td>74</td>
<td>81</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Measurement of cell structures</td>
<td>38</td>
<td>64</td>
<td>55</td>
</tr>
<tr>
<td>8</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Respiration products</td>
<td>38</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>20</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Chromosome numbers in gametes</td>
<td>69</td>
<td>69</td>
<td>64</td>
</tr>
<tr>
<td>24</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Semi-conservative replication</td>
<td>50</td>
<td>55</td>
<td>31</td>
</tr>
<tr>
<td>30</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend:** The numbers in each box are an average of the percents of teachers answering the two questions of the pair correctly. Grey boxes indicate 70% or greater than 70% of the teachers answering the question pair correctly.
The pretest results show that only four of the question pairs were answered correctly by 70% or more of the teachers which indicates that most of the teachers initially held a lot of misconceptions/errors about this material.

After two weeks of intensive coursework, laboratory activities, and class discussions and tasks, 70% of the teachers were able to answer multiple choice questions correctly on every topic except proportional reasoning, products of respiration, chromosome numbers in gametes, semi-conservative respiration, and electrophoresis (thirteen pairs of questions and all four single questions were correct). The numbers changed from four pairs of questions answered correctly on the pretest, to 13 pairs and all of the four single questions were answered correctly by 70% or more of the teachers on the post test – more than double the correctly answered questions from the beginning of the class.

Five months later these five same topics that were missed on the post test along with questions about what a theory is, how to identify variables, osmosis, and nucleic acid processes. Nine question pairs and two single questions were answered correctly by 70% or more of the teachers on the follow-up test.

Additionally, there were five question pairs and two single questions that were answered correctly by 70% or more of the teachers on the post test and the follow-up test. There were three question pairs and two single questions that were answered correctly only on the post test. There were two questions that were in categories by themselves – one was answered correctly on the pretest and post test only and the other one was answered correctly only on the follow-
up test. There were four question pairs that were not answered correctly by at least 70% of the teachers on any of the test administrations.

Table 16 shows the misconceptions for each question pair and the number of teachers choosing those misconceptions/errors for answers on each question on the pretest, post test, and follow-up test. Pretest results showed that there were eight questions on which more than 50% of the teachers chose a specific misconception for their answer. Of those eight questions, only one had 50% or more of the teachers choosing it as a response on the follow-up test. There were six questions that demonstrated an increase in the number of teachers choosing misconceptions rather than the correct answer from the pretest to the follow-up test. For three of those, more than 50% of the teachers chose the misconception.

There were 38 misconceptions that the Biology 1 MC test addressed. There were two which showed a marked increase in the number of wrong answers chosen and three others in which the number of wrong answers increased by one teacher. There were 18 that appeared to be resolved from the pretest to the follow-up test and 13 misconceptions/errors that decreased slightly from the pretest to the follow-up test. There was a concentration of misconceptions/errors in the DNA content area, but the assessment had more questions in that topic area than any other. It was difficult to see any other trend because the number of participants was small and the numbers of questions on each concept were small as well.
<table>
<thead>
<tr>
<th>#</th>
<th>Content</th>
<th>Response Choices</th>
<th># chosen</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Misconceptions</td>
<td>Pre</td>
<td>Post</td>
<td>FU</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>What is a theory</td>
<td>All scientific statements are facts</td>
<td>11</td>
<td>2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Because</td>
<td>If scientists agree, then it is a fact</td>
<td>11</td>
<td>8</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Measurement</td>
<td>When dividing by 1000, move the decimal point to the right.</td>
<td>13</td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Osmosis</td>
<td>Cell contain water instead of saline, so RBC volume not affected by water</td>
<td>12</td>
<td>4</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Transcription</td>
<td>Produces strand with same base sequence with U in place of T</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Because</td>
<td></td>
<td>5</td>
<td>0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Electrophoresis</td>
<td>DNA mixtures can be separated by DNA sequencing</td>
<td>10</td>
<td>4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>Because</td>
<td></td>
<td>10</td>
<td>11</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Random Assortment</td>
<td>Chromosomes blend to produce new traits</td>
<td>12</td>
<td>2</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Meiosis</td>
<td>Haploid cells have half the pairs of chromosomes</td>
<td>9</td>
<td>11</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Because</td>
<td>All cells of species have same number of chromosomes</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Semi-conservative Replication</td>
<td>Only 1 daughter cell would be radioactive if parent DNA was radioactive</td>
<td>9</td>
<td>8</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Because</td>
<td></td>
<td>9</td>
<td>9</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Process of Respiration</td>
<td>CO2 is the only gas exhaled</td>
<td>6</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Because</td>
<td>Glucose broken down to energy and H2O</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Compare gene, DNA, chromosomes</td>
<td>Genes contain chromosomes made of DNA</td>
<td>8</td>
<td>3</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>ID of variables</td>
<td>If there is more than one variable, it must be independent</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Because</td>
<td></td>
<td>4</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Diffusion</td>
<td>Temperature does not affect the rate of diffusion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Diffusion</td>
<td>When a substance diffuses, then it all diffuses</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Process of Photosynthesis</td>
<td>CO2 reacts with H2O to make sugar</td>
<td>8</td>
<td>8</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Because</td>
<td>Energy source for plants is sugar</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Photosynthesis</td>
<td>H2O not required for photosynthesis</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Because</td>
<td>Plants get their carbon from soil</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Respiration</td>
<td>Yeasts do not need carbon source</td>
<td>7</td>
<td>0</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Because</td>
<td>Yeast will respire without carbon source in sunlight</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Nucleic acids</td>
<td>mRNA is not involved in translation, mRNA is involved in transcription</td>
<td>8</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Question</td>
<td>Response</td>
<td>Score 1</td>
<td>Score 2</td>
<td>Score 3</td>
<td></td>
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<td>---</td>
<td>-----------</td>
<td>-----------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Because</td>
<td>mRNA not involved in coding molecule</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Mitosis</td>
<td>Spore formation in plants is asexual since spores are identical</td>
<td></td>
<td>6</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>26</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Compare</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>meiosis/mitosis</td>
<td></td>
<td></td>
<td>6</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>28</td>
<td>Because</td>
<td>All body cells need all genetic information to reproduce</td>
<td></td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tissue cells have ½ genetic info so they combine</td>
<td></td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>31</td>
<td>Structure of DNA</td>
<td>Opposite strand of DNA in double strand is base sequence in reverse</td>
<td></td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>32</td>
<td>Because</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>Protein Structure</td>
<td>Protein function based on site of synthesis</td>
<td></td>
<td>7</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>38</td>
<td>Mutation</td>
<td>Mutation changes AA sequence of protein. Mutation changes protein structure</td>
<td></td>
<td>4</td>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>

**Legend:** For some questions, there were two distractors that were misconceptions, or two or more different misconceptions were addressed by the question and/or the “because” statement, thus, two or more sets of scores are reported. Questions that showed an increase in the number of teachers choosing a misconception are the light grey boxes. Yellow highlights indicate that 50% or more of the class chose the misconception as the correct answer. Boxes with no numbers indicate question with declarative knowledge and no misconceptions were written into those questions.

**Biology 2 Multiple Choice Assessments**

Like the Biology 1 MC assessments, MC questions on the Biology 2 assessment were also written whenever possible so that one or more of the distractors were misconceptions. Table 17 presents data that address this question. Each question-pair topic is listed along with the percentage of teachers with the correct response. Only six question pairs were answered correctly by 70% or more of the teachers in the class on the pretest.
Table 17. Percent of Correct Biology 2 MC Questions

<table>
<thead>
<tr>
<th>Q#</th>
<th>Content subject</th>
<th>Pretest</th>
<th>Post Test</th>
<th>FU Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>DNA homology of humans and apes</td>
<td>70</td>
<td>90</td>
<td>83</td>
</tr>
<tr>
<td>14</td>
<td>Because</td>
<td>83</td>
<td>100</td>
<td>98</td>
</tr>
<tr>
<td>15</td>
<td>Theory of common descent</td>
<td>78</td>
<td>93</td>
<td>87</td>
</tr>
<tr>
<td>16</td>
<td>Because</td>
<td>78</td>
<td>93</td>
<td>87</td>
</tr>
<tr>
<td>21</td>
<td>Identification using taxonomy keys</td>
<td>75</td>
<td>85</td>
<td>90</td>
</tr>
<tr>
<td>27</td>
<td>Ecosystem energy sources</td>
<td>80</td>
<td>90</td>
<td>98</td>
</tr>
<tr>
<td>29</td>
<td>Spatial distribution factors</td>
<td>88</td>
<td>80</td>
<td>75</td>
</tr>
<tr>
<td>31</td>
<td>Trophic level energy transfer</td>
<td>60</td>
<td>83</td>
<td>78</td>
</tr>
<tr>
<td>39</td>
<td>Water quality indicators</td>
<td>50</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>41</td>
<td>Evolution mechanisms</td>
<td>68</td>
<td>93</td>
<td>90</td>
</tr>
<tr>
<td>1</td>
<td>Interpreting evolution cladograms</td>
<td>50</td>
<td>88</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>Because</td>
<td>50</td>
<td>88</td>
<td>60</td>
</tr>
<tr>
<td>11</td>
<td>Timelines and fossils</td>
<td>60</td>
<td>70</td>
<td>63</td>
</tr>
<tr>
<td>35</td>
<td>Factors affecting biomes</td>
<td>45</td>
<td>73</td>
<td>53</td>
</tr>
<tr>
<td>3</td>
<td>Identifying fact/theory/opinion</td>
<td>40</td>
<td>58</td>
<td>63</td>
</tr>
<tr>
<td>23</td>
<td>Speciation requirements</td>
<td>53</td>
<td>58</td>
<td>53</td>
</tr>
<tr>
<td>25</td>
<td>Zero population growth</td>
<td>43</td>
<td>58</td>
<td>63</td>
</tr>
<tr>
<td>33</td>
<td>Logarithmic growth</td>
<td>35</td>
<td>65</td>
<td>53</td>
</tr>
<tr>
<td>37</td>
<td>Soil nutrients/limiting factors</td>
<td>48</td>
<td>55</td>
<td>48</td>
</tr>
</tbody>
</table>
Because Population cycles 3 5 5
44 Because

**Legend:** The numbers in each box are an average of the percents of teachers answering the two questions of the pair correctly. Grey boxes indicate 70% or greater than 70% of the teachers answering the pair correctly.

The number of correctly answered question pairs increased from six on the pretest to 15 on the post test, and then decreased again to 12 on the follow-up test. Additionally there were 12 question pairs that 70% or more of the teachers answered correctly on the post test and the follow-up test and three that were answered correctly *only* on the post test.

There were six question pairs that were answered correctly by 70% or more of the teachers on all three test administrations and seven question pairs on which less than 70% of the teachers were able to answer correctly on *any* of the test administrations.

Table 18 presents more information about the teachers’ misconceptions. There were forty four misconceptions/errors written into the test. There were six questions for which 50% or more of the teachers chose misconceptions for answers on the pretest, three on the post test, and four on the follow-up test. There were eight questions for which the number of misconceptions/errors chosen for answers stayed the same, and 13 questions for which the number of misconceptions/errors chosen for answers was decreased slightly. There were twelve misconceptions/errors that appeared to be resolved for most, if not all teachers. There were nine misconceptions for which the number increased slightly and two for which the numbers of teachers choosing them increased
considerably. The topic for which most teachers chose a misconception was population topics (ZPG, population cycles). The concept for which the most teachers changed their misconception/error to the correct conception was water quality indicators. There were also a number of “because” questions for which the teachers improved their understanding of why their answers were correct on the content portion of the question.

Table 18. Misconceptions Chosen for Biology 2 MC Questions

<table>
<thead>
<tr>
<th>Q#</th>
<th>Content</th>
<th>Ans</th>
<th>Response Choices</th>
<th># choosing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Misconceptions</td>
<td>Pre Post FU</td>
</tr>
<tr>
<td>1</td>
<td>Evolution dendograms</td>
<td>B</td>
<td>Organisms that look similar are more closely related</td>
<td>6 2 4</td>
</tr>
<tr>
<td>2</td>
<td>Because</td>
<td>C</td>
<td>Misconceptions in reading dendograms</td>
<td>5 2 4</td>
</tr>
<tr>
<td>15</td>
<td>Theory of Common Descent</td>
<td>A</td>
<td>Living species arose from separate, unrelated lines</td>
<td>4 0 0</td>
</tr>
<tr>
<td>16</td>
<td>Because</td>
<td>C</td>
<td>Life is too complex to arise by mutation/selection</td>
<td>3 0 1</td>
</tr>
<tr>
<td>21</td>
<td>Tree taxonomy tree</td>
<td>B</td>
<td>Need to be able to read taxonomy tree/interpret descriptions</td>
<td>5 3 0</td>
</tr>
<tr>
<td>22</td>
<td>Because</td>
<td>A</td>
<td></td>
<td>2 0 0</td>
</tr>
<tr>
<td>23</td>
<td>Speciation</td>
<td>C</td>
<td>Two species have to look different from each other so they can tell each other apart</td>
<td>6 0 2</td>
</tr>
<tr>
<td>24</td>
<td>Because</td>
<td>A</td>
<td>Different species live in different habitats</td>
<td>5 1 2</td>
</tr>
<tr>
<td>33</td>
<td>Logarithmic growth</td>
<td>C</td>
<td>Do not understand logarithmic expansion</td>
<td>12 4 6</td>
</tr>
<tr>
<td>34</td>
<td>Because</td>
<td>B</td>
<td>Do not understand how “doubling time” affects total numbers</td>
<td>10 8 8</td>
</tr>
<tr>
<td>39</td>
<td>Water quality indicators</td>
<td>B</td>
<td>Best way to evaluate water quality is water chemistry tests and pollution tests</td>
<td>10 0 0</td>
</tr>
<tr>
<td>40</td>
<td>Because</td>
<td>C</td>
<td>Chemistry gives precise info</td>
<td>2 0 0</td>
</tr>
<tr>
<td>41</td>
<td>Evolution Mechanisms</td>
<td>A</td>
<td>Sexual repro is mechanism for evolution, acquired characteristics is mechanism for evolution</td>
<td>1 0 0</td>
</tr>
<tr>
<td>42</td>
<td>Because</td>
<td>B</td>
<td>gene modification by environment or chromosome blending</td>
<td>7 3 2</td>
</tr>
<tr>
<td>17</td>
<td>Genetic Resistance</td>
<td>C</td>
<td>Organisms pass on same</td>
<td>0 0 2</td>
</tr>
<tr>
<td></td>
<td>Because</td>
<td></td>
<td></td>
<td>susceptibilities</td>
</tr>
<tr>
<td>---</td>
<td>---------------------------------------------</td>
<td>---</td>
<td>---</td>
<td>------------------------------------------------------</td>
</tr>
<tr>
<td>18</td>
<td>Because</td>
<td>A</td>
<td>18</td>
<td>organisms change genetics because of environmental</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>19</td>
<td>affects, mutations in organism can help it survive</td>
</tr>
<tr>
<td>25</td>
<td>Zero Population Growth</td>
<td>A/C</td>
<td></td>
<td>Family size of 1.9 to 2 means population is increasing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>slowly.</td>
</tr>
<tr>
<td>26</td>
<td>Because</td>
<td>A</td>
<td>21</td>
<td>ZPG rates do not consider divorce rates or family size</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>22</td>
<td>of previous generation</td>
</tr>
<tr>
<td>35</td>
<td>Factors affecting biomes</td>
<td>C/A</td>
<td></td>
<td>Humans have most effect on biomes because they are very</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>23</td>
<td>invasive</td>
</tr>
<tr>
<td>36</td>
<td>Because</td>
<td>C</td>
<td>24</td>
<td>Biomes become dominated by invasive species</td>
</tr>
<tr>
<td>43</td>
<td>Population cycles</td>
<td>B</td>
<td>25</td>
<td>Animal populations are cyclical and predictable</td>
</tr>
<tr>
<td>44</td>
<td>Because</td>
<td>C</td>
<td>26</td>
<td>Cycles are the rule for physical and biological</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>27</td>
<td>processes on Earth</td>
</tr>
<tr>
<td>3</td>
<td>Diff between theory/fact</td>
<td>A</td>
<td>28</td>
<td>Factual statement about fossils is opinion or theory</td>
</tr>
<tr>
<td>4</td>
<td>Because</td>
<td>C</td>
<td>29</td>
<td>Statements by experts are theories</td>
</tr>
<tr>
<td>5</td>
<td>Theory of plate tectonics</td>
<td>A</td>
<td>30</td>
<td>Fact, not theory because of evidence</td>
</tr>
<tr>
<td>6</td>
<td>Because</td>
<td>A</td>
<td>31</td>
<td>Fact level is higher than theory</td>
</tr>
<tr>
<td>7</td>
<td>Homologous/vestigial</td>
<td>B</td>
<td>32</td>
<td>Homologous is derived from same feature in ancestor</td>
</tr>
<tr>
<td>8</td>
<td>Because</td>
<td>A</td>
<td>33</td>
<td>Structures evolve to help whales adapt to land life</td>
</tr>
<tr>
<td>9</td>
<td>Acquired traits vs. genetics</td>
<td>B</td>
<td>34</td>
<td>Environment causes acquisition of new genetic traits</td>
</tr>
<tr>
<td>10</td>
<td>Because</td>
<td>C</td>
<td>35</td>
<td>Dark environment will cause change in organisms’ DNA</td>
</tr>
<tr>
<td>11</td>
<td>Fossil ages</td>
<td>C</td>
<td>36</td>
<td>More fossils from earlier times because more things</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>37</td>
<td>have become extinct</td>
</tr>
<tr>
<td>12</td>
<td>Because</td>
<td>A</td>
<td>38</td>
<td>Large or small # of fossils found at site determine</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>39</td>
<td>age</td>
</tr>
<tr>
<td>13</td>
<td>DNA homology</td>
<td>B</td>
<td>40</td>
<td>Humans &amp; gorillas look more alike so they are more</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>41</td>
<td>closely related</td>
</tr>
<tr>
<td>14</td>
<td>Because</td>
<td>B</td>
<td>42</td>
<td>Humans evolved from apes</td>
</tr>
<tr>
<td>19</td>
<td>Biological Species Concept</td>
<td>C</td>
<td>43</td>
<td>BSC requires all members to descend from same</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>44</td>
<td>individuals</td>
</tr>
<tr>
<td>20</td>
<td>Because</td>
<td>B</td>
<td>45</td>
<td>Similarities of individuals determines</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>46</td>
<td>relationship</td>
</tr>
<tr>
<td>27</td>
<td>Ecosystem energy sources</td>
<td>B</td>
<td>47</td>
<td>Ultimate source of energy is chemical</td>
</tr>
</tbody>
</table>
Because Organisms need nutrients, vitamins, and minerals most

Spatial distribution factors

Because Potential distribution, always more than actual distribution

Trophic level energy transfer

Because Orgs. at high trophic levels go extinct due to toxic buildup, trophic levels depend of evolutionary time frame

Soil nutrition

Because No misconceptions, just errors. Direct knowledge question

Because Direct knowledge question on soil.

Legend: For some questions, there were two distractors that were misconceptions, or two different misconceptions were addressed by the question and the “because” statement, thus, two sets of scores. Questions that showed an increase in the number or the same numbers of teachers choosing a misconception are highlighted in grey boxes. Yellow highlighting indicates that 50% or more teachers in class accepted the misconception as correct for that test administration.

Comparing MC Test Results

More question pairs on the Biology 1 (13) test were answered correctly even though there were more question pairs on the biology 2 test (11). There was only one question pair on the Biology 1 test that had just one part of the question pair incorrect (content or “because” portion), while the Biology 2 results showed nine question pairs with one or the other part incorrectly answered. The number of question pairs for which both questions of the pair had incorrectly answered questions was about the same (4 for Biology 1 and 3 for Biology 2).

Biology 1 Constructed Response Questions

The numbers of misconceptions/errors on the constructed response tests could not be quantified because it was not possible to tell if the
misconceptions/errors were held by a teacher unless they were specifically stated in the answer. Therefore, whether or not they were resolved is not possible to state. The trend that can be seen is similar for both courses in that the number of teachers increasing their scores on the post- and follow-up tests can be seen to increase.

The responses on the MC tests were either correct or incorrect, but with essay questions, there were different ranges of points for answers that a teacher wrote depending on how well they knew the information.

**Individual Questions from the Biology 1 CR Test**

The first question (Table 19) dealt with the difference between prokaryotes and eukaryotes. There were four basic student misconceptions on the pretest and they are listed in Table 19. There were three on the post test and four on the follow-up test. None of the misconceptions/errors listed are the same for each test administration.
Table 19. Biology 1 CR Test Question 41A
Discuss at least five characteristics that distinguish prokaryotes from eukaryotes.

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Prokaryotes have asexual reproduction, eukaryotes have sexual reproduction.</td>
<td>1. Prokaryotes are always bacterial cells.</td>
<td>1. Prokaryotes divide by mitosis.</td>
</tr>
<tr>
<td>2. Eukaryotes are carnivores, prokaryotes are not.</td>
<td>2. All prokaryotes are smaller than eukaryotes.</td>
<td>2. Eukaryotes cannot be single-celled.</td>
</tr>
<tr>
<td>3. Prokaryotes are nitrogen fixers, eukaryotes are not.</td>
<td>3. Prokaryotes have no cell walls, eukaryotes do.</td>
<td>3. Plant cells are prokaryotic and animal cells are not.</td>
</tr>
<tr>
<td>4. Prokaryotes are autotrophic, eukaryotes are heterotrophic.</td>
<td></td>
<td>4. Prokaryotes contain RNA, eukaryotes contain DNA.</td>
</tr>
</tbody>
</table>

The teachers wrote responses that sounded like wild guesses. The misconceptions listed were different for all three test administration. The misconceptions written for the post test were closer to being correct than those from the pretest, and those for the follow-up test were a little more sophisticated various facts from the class were mentioned.
The second question (Table 20) dealt with the differences between plant and animal cells. Some of the misconceptions/errors carried over from the pretest to the post test or the post test to the follow-up test. The main topics of these misconceptions were the type of reproduction, the kinds of organelles in the cells, and respiration. There were misconceptions/errors about whether mitosis or meiosis were sexual or asexual processes.

**Table 20. Biology 1 CR Test Question 41B**
Discuss at least three characteristics that separate plant cells and animal cells.

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Animal cells have nuclei, plant cells do not.</td>
<td>1. Chlorophyll captures energy from sunlight.</td>
<td>1. Only animal cells divide by meiosis.</td>
</tr>
<tr>
<td>2. Plants consume energy for fuel.</td>
<td>2. Animal cells are larger than plant cells.</td>
<td>2. Do not make the distinction that sex cells divide by meiosis and somatic cells by mitosis.</td>
</tr>
<tr>
<td>3. Plants do not give off carbon dioxide.</td>
<td>3. Animal cells do not have organelles.</td>
<td>3. Plant cells have only one shape.</td>
</tr>
<tr>
<td>4. Do not understand that mitosis is asexual reproduction and meiosis is sexual reproduction.</td>
<td>4. Plants do not have mitochondria.</td>
<td>4. All plants grow straight because they have rigid cell walls.</td>
</tr>
<tr>
<td>5. Animal cells do not need energy to divide.</td>
<td>5. Plants do not respire.</td>
<td>5. Mitochondria are not present in plant cells.</td>
</tr>
<tr>
<td>6. Plant cells are asexual and animal cells are sexual.</td>
<td></td>
<td>6. Only animal cells carry out aerobic respiration.</td>
</tr>
</tbody>
</table>

The third question (Table 21) asked teachers to design a lab for their students to help them learn the concepts of photosynthesis or respiration. The expectation was that labs would be designed with appropriate controls and would have all variables accounted for. Teachers were to include opportunities to analyze and interpret data, and to indicate some understanding of a scientific
process or method. Eighteen out of 21 teachers missed most of the available points on this question on the pretest. A number of misconception/errors were revealed in their pretest responses. Teachers also did not understand the word “ambient” which referred to the temperature of the room.

A number of the responses indicated some important misconceptions/errors around homeostasis, respiration, and photosynthesis on the pretest. The content portion of the Biology 1 class covered all these points, but the most surprising misconceptions that were listed had to do with what constitutes a testable question, which variables are dependent or independent, what controls should be used, how to state an hypotheses, and other concepts about the NOS. It was not anticipated that the teachers would have such a low level of understanding of the processes of science and designing inquiry laboratory activities.

After the teachers completed the class, they did not list so many misconceptions/errors about the content material, but still had serious problems with the NOS and science processes. Even with explicit teaching about the NOS, teachers still did not truly understand these concepts and indicated that some of them did not yet understand the difference between independent and dependent variables.

After the follow-up class, teachers were still making serious errors in the design of an investigation for their students.
Table 21. Biology 1 CR Test Question 42

Using readily available materials, design an experiment for your class that involves testing the respiration rate of an organism against the ambient temperature. Be sure to include a hypothesis, the independent and dependent variables, controls, exact steps in the procedure, etc. You should be able to use this experiment in your class, so design it around the level of the students you teach.

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Higher temperature increases the metabolic rate up to 100°C.</td>
<td>1. Did not identify the independent or dependent variables, or missed points on controls, and/or other aspects of a scientific method. They had problems with choosing a question to answer, stating a hypothesis instead of a prediction, and setting up controls.</td>
<td>1. Listed predictions in place of hypotheses and made other errors in conjunction with designing an experiment using some sort of scientific process.</td>
</tr>
<tr>
<td>2. Yeasts produce oxygen when they ferment sugar.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Do not consider homeostasis as part of respiration.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Have incomplete concept of homeostasis is and its implications in the body.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. If respiration increases, a body temperature increase always occurs.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The fourth question (Table 22) required an explanation of the two reactions of photosynthesis (light dependent and light independent reactions).

The answers on the pretest were minimal with most teachers leaving this question blank. Fourteen out of 21 teachers remained confused by this question at the time of the post test; even after the class, they did not know the content material on photosynthesis. Teachers seemed confused by the request for discussion of the two reactions as though they did not realize that there were two types of reactions. A number of teachers did not even mention chlorophyll in their answers. There was no real way of answering correctly without discussing
the role of chlorophyll in the process of photosynthesis. The results on the follow-up test were the same as for the post test. The teachers apparently never really learned and understood this material.

**Table 22. Biology 1 CR Test Question 43**

Describe how photosynthesis occurs in two separate types of reactions.

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
</table>
| 1. Plants do not respire.  
2. Chlorophyll turns green when it is ready to provide food for plants. | 1. Fourteen out of twenty one teachers were still confused by the question asking for the two reactions.  
2. Five teachers did not even mention chlorophyll in their answers for this question. | 1. Many teachers did not know the mechanisms of photosynthesis.  
2. Four teachers did not mention chlorophyll or chloroplasts in their answers. |

The responses on the follow-up test suggested that this is a very difficult set of concepts and this question indicated that many teachers never learned the mechanisms of photosynthesis.

The last three questions on this test dealt with processes involving DNA. It was anticipated that some teachers would know something about DNA replication, but that most would have inaccurate information. This was the case on the pretest. Most of the teachers left these questions blank on the pretest.

The first question on how DNA can replicate itself indicated a basic lack of knowledge about this process. The post test showed that the teachers had learned a lot about the process, but they had misconceptions/errors about the many details of DNA replication. The misconceptions/errors were more sophisticated on the post test. One of the misconceptions that was mentioned
several times was that DNA can only produce one new molecule at a time. This misconception was important in that if that were the case, then our bodies and cells would cease to function since so much more information from the DNA molecule is necessary.

By the time of the follow-up test, teachers not actually teaching this material had forgotten a lot of the specific information about DNA replication, but were able to discuss it in a rudimentary fashion.

**Table 23. Biology 1 CR Test Question 44A**

Explain (with drawings) how DNA can replicate itself

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. When DNA replicates, it splits and then grows its other side back. Adenine will “grow” another adenine, guanine will “grow” another guanine, etc.</td>
<td>1. mRNA is involved in replication. 2. Trouble remembering which direction DNA polymerase builds strands. 3. Think that the end of the DNA is 5’ or 3’ – not that each end has a 5’ and a 3’ strand and both are at each are at each end running opposite to each other. 4. Think that mRNA replicates DNA.</td>
<td>1. One DNA molecule makes only one new DNA molecule. 2. mRNA is involved in replication. 3. Some still think that replication on the leading strand starts at the 5’, but that on the lagging strand it starts on the 3’ end.</td>
</tr>
</tbody>
</table>

No teacher wrote any answer for the next question on transcription of DNA on the pretest (Table 24). Fifteen out of 20 teachers had difficulties explaining transcription and lost points on this question on the post test. The only misconception/error that stood out was the mistaken idea that tRNA is involved in transcription. Mistakes were mainly lack of pertinent information in their answers.
or lack of answers and mixing up information about this process with the process of translation. This complicated process may be more difficult to learn, and many of the teachers did not remember a lot about it by the time of the follow-up test.

**Table 24. Biology 1 CR Test Question 44B**

Explain with drawings how DNA is transcribed.

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No one wrote any answer for this question.</td>
<td>1. Fifteen out of twenty teachers had difficulties explaining transcription. 2. Think that tRNA is involved.</td>
<td>1. Teachers did not remember much about it.</td>
</tr>
</tbody>
</table>

No one wrote any answer for the last test question of the Biology 1 pretest (Table 25) on translation. The information was presented on the next to the last day of the course, so there was not a lot of time before the post test to learn this content. The post test and follow-up test responses revealed many misconceptions/errors with little understanding.
Table 25. Biology 1 CR Test Question 44C

Explain how translation occurs with drawings, etc.

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. No one wrote any answer for this question.</td>
<td>1. Trouble with the direction translation occurs.</td>
<td>1. Think that translation takes place in the mitochondria.</td>
</tr>
<tr>
<td></td>
<td>2. Think that translation occurs such that the polypeptide chain forms inside the ribosome.</td>
<td>2. Still think that rRNA transfers the amino acid to the ribosome.</td>
</tr>
<tr>
<td></td>
<td>3. Think that rRNA carries the amino acid to the ribosome.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Think that RNA replicates and makes the proteins.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Do not understand that tRNA picks up the amino acid that matches its code.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Think that mRNA carries copies of DNA to ribosomes for translation instead of being the transcript itself.</td>
<td></td>
</tr>
</tbody>
</table>

Twelve teachers completely forgot what translation was on the follow-up exam even though these processes were discussed in the follow-up course with activities where the teachers had to act out the processes.

Biology 1 Constructed Response Assessment Results

A question-by-question examination revealed several things. First, for some questions, initial misconceptions/errors were replaced by different misconceptions/errors as the course proceeded. For concepts that were originally unfamiliar to the teachers, some of the misconceptions became more sophisticated as the teachers took in more knowledge and details about the
topics. Second, for some topics, initial misconceptions/errors were corrected by
the course’s end, but teachers reverted back to their original misconceptions by
the end of the follow-up course. Third, for some topics, the misconceptions
apparently were resolved. And fourth, there were a number of important
concepts that the teachers did not know before the class and they really never
were learned by the teachers.

Biology 2 Constructed Response Questions

The Biology 2 exam did not have the same type of questions on the CR
test as the Biology 1 exam. There was not as much overt emphasis on the
scientific method – it was demonstrated in class, but the onus was put on
learning specific kinds of information on biodiversity/ecology and material on how
the modern theory of evolution came to be. The class activities were not
experiments as much as they were exploratory exercises from which the
teachers could learn – such as dissecting owl pellets, comparing skulls from
different apes and anthropoids, collecting water samples and identifying
organisms present, and learning and identifying different evergreen trees.

Individual Questions from the Biology 2 CR Test

The first CR question on the Biology 2 exam (Table 26) required the
teachers to explain why decomposition was necessary. There were no specific
misconceptions/errors listed on the pretest, but neither was there any mention of
recycling of nutrients or the consequences of not having any decomposers.
Some teachers wrote something other than what was asked for, so they did not receive full points for their answers. There were no misconceptions/errors on the follow-up test.

**Table 26. Biology 2 CR Test Question 1**

Explain why decomposers are necessary for life on earth.

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Teachers did not explain why decomposition was necessary, just said how it was done.</td>
<td>1. The prime reason for their importance is to get rid of unwanted wastes.</td>
<td>1. No misconceptions were noted.</td>
</tr>
<tr>
<td>2. Teachers did not mention the recycling of nutrients or the consequences of not having decomposers.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The second question (Table 27) asked teachers why two organisms could share the same habitat, but not the same niche. On the pretest, teachers were unclear about the difference between a habitat and a niche.

On the post test, there seemed to be confusion over whether two species could have the same role or the same niche, but at least eight teachers received full points for their answer. By the time of the follow-up test, most of the misconceptions/errors stated in the previous assessments seemed to be cleared up.
Table 27. Biology 2 CR Test Question 2

Explain why two different species in an ecosystem can share the same habitat, but not the same niche.

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post Test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Teachers confused about the difference between habitat and niche.</td>
<td>1. Believe that no two species can have the same role in a habitat.</td>
<td>1. No misconceptions were noted.</td>
</tr>
<tr>
<td>2. Many teachers wrote nothing down.</td>
<td>2. Confusion over terms – role vs job, role of food or other terms.</td>
<td></td>
</tr>
</tbody>
</table>

Misconceptions around the third question (Table 28) of whether Cambrian or Cenozoic fossils would be more similar to living things today centered around confusion over which period was closer to present times. At the time of the pretest, not all teachers knew which period was older, but aside from that, many teachers speculated that more recent fossils would be more similar to organisms living today. On the post test, 60% of the class received full credit and the other 40% received 50% of the credit or more. The follow-up test did show that there were really no misconceptions, just teachers forgetting which period was more recent, but they understood that fossil remains from the more recent period would be more similar to contemporary organisms.
A paleontologist prepared a display of Cambrian fossils and another of Cenozoic fossils. Student discussions in a classroom centered around a comparison of these two groups of fossils to living species. Which group of fossils would be more similar to living species and for what reasons?

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post Test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Living things today have not changed since the Cenozoic period.</td>
<td>1. Most teachers got this answer correct.</td>
<td>1. Many teachers forgot which period is the more recent one, but they reasoned that the more recent of the two would have characteristics more closely related to us.</td>
</tr>
<tr>
<td>2. Understand that whichever is closer time-wise will be more similar, but do not know which period is closer.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Teacher answers “Cenozoic”, but does not explain why.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The fourth question was problematic (Table 29) and was one of the two most difficult questions for the teachers. The teachers did not understand how to use the population equation. No teacher wrote the correct answer on the pretest and many put down nonsense answers. Even on the post test, many teachers did not demonstrate that they knew how to use the population equation. Only six teachers calculated the correct answer. This material was presented in class along with the use of the population equation to calculate future population numbers. Some of the teachers were able to do the first part of the problem and calculated the doubling time, but then succumbed to the misconception/error that once the doubling time is known, all they had to was double it to get the correct answer. By the follow-up test, nearly all the teachers had reverted back to
misconceptions/errors or made a random guess and therefore did not receive much, if any credit for their answers.

**Table 29. Biology 2 CR Test Question 4**

The population of the United States is about 300,000,000 and is growing at the rate of 1.3% per year. How many years until the population reaches 12,000,000,000? Show your work.

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post Test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Do not understand when and how to use the population equation.</td>
<td>1. Most teachers still do not know how to use the population equation. Some did first part, but could not do the rest.</td>
<td>1. Teachers do not know how or when to use the population equation.</td>
</tr>
<tr>
<td>2. Wrote nothing down or nonsense answers.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The next two questions were part of a set that was to test teacher knowledge of determining relationships between vertebrates by interpreting a phylogenetic tree (Appendix Q) Table 30). It was expected that the teachers would know how to interpret a phylogenetic tree. A variety of incorrect answers were written down on the pretest which made it apparent that some did not. Some of those who did write a correct response got their answer by faulty reasoning. Some of the teachers did not know what the term “common ancestor” meant. On the post test, many teachers did write the correct answer, but they did not justify them. There were misconceptions written on the follow-up test; some were the same ones that appeared on the pretest.
Table 30. Biology 2 CR Test Question 5a

Use the drawing below to answer this question. Which group of reptiles gave rise to modern birds? Justify your choice.

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post Test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Did not know how to read a tree.</td>
<td>1. Chose Archaeopteryx thinking that it was an ancestor to modern birds since it branched off earlier, rather than looking at the earlier organism as being the common ancestor.</td>
<td>1. Some still think that the horizontal distance in the tree makes a difference in the relationship.</td>
</tr>
<tr>
<td>2. Did not know what a common ancestor means.</td>
<td></td>
<td>2. One teacher believed that Pterosaurs gave rise to modern birds because they both had wings.</td>
</tr>
<tr>
<td>3. Think that if the ends of the branches are closer together, then the relationship is closer, rather than where the branches originate.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Think that the number of subsequent branches determine the closeness of the relationship rather than the location of the branches.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The second question in the set of questions concerning phylogenetic trees was whether crocodilian DNA would be more similar to modern birds or to turtles (Table 31). On the pretest, there were many misconceptions/errors.

Again, teachers indicated that they did not understand how to interpret the tree.

On the post test, there were still teachers that did not show complete understanding of how to interpret a tree showing the interrelationships of different groups of animals. There was one main misconception carried over to the follow-up test and that is that if animals have similar characteristics, they are more closely related than animals that have a common ancestor.
Table 31. Biology 2 CR Test Question 5b

Use the drawing below to answer these two questions. Would you expect the DNA of crocodilians to be more similar to the DNA of modern birds or the DNA of turtles? Explain your reasoning.

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post Test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. If the branches of the tree are closer, then the animals at the end of the branches have a closer relationship.</td>
<td>1. Students think that a branch off of a larger branch means that that line of organisms gave rise to others higher up on the branch.</td>
<td>1. Some teachers have retained their misconception that if animals have similar characteristics, they are more closely related than animals with a common ancestor.</td>
</tr>
<tr>
<td>2. Animal morphology determines the relationship.</td>
<td>2. The closer the ends of the branches, the closer the relationship between the organisms at the ends of the branches.</td>
<td></td>
</tr>
<tr>
<td>3. Where the animals live, locomotion, etc., determine how closely related they are.</td>
<td>3. Morphology determines the closeness of the relationship.</td>
<td></td>
</tr>
<tr>
<td>4. If two organisms on the tree are reptiles, they are more closely related than two animals that are not reptiles.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Think that if common branching comes earlier, then the animals must be more closely related.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. It is the number of in-between branches and placement of their bases that determines the closeness of the relationship rather than the location of the branching!</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The sixth question (Table 32) asked teachers to describe the differences in the jaw structures of carnivores and herbivores. They were supposed to write some obvious differences and they did. There was little specific information given. Although the teachers had to draw and describe the two types of jaws and label each part for one of the lab exercises, they did not remember specific information and their post test answers were not very different from their pretest.
answers. The teachers’ follow-up test answers closely resembled their post test answers. They listed very little specific information.

**Table 32. Biology 2 CR Test Question 6**

How do jaws of carnivores and herbivores differ and how to these differences reflect adaptation to their respective diets?

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post Test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
</table>
| 1. Teachers know that the jaws of herbivores and carnivores are different, but have little knowledge about the specifics.  
2. Think the jaws of carnivores are made of bone and the jaws of herbivores are made of cartilage. | 1. Answers similar to pretest answers | 1. Answers similar to pretest answers |

For question seven (Table 33), teachers were asked to explain the process of speciation with diagrams. On the pretest, most teachers did not know anything about the process of speciation. Those that did venture a response confused speciation with natural selection. A common misconception was revealed: speciation is a result of need so that if animals need different traits to survive changing conditions, they evolve the new trait to survive.

On the post test, more teachers gave correct answers, but a few thought that organisms could change their genetic traits at will and evolve into what they need to survive – indicating that they still hold a Lamarckian view of evolution.

On the follow-up test, some teachers did not remember anything about the process of speciation. There was the persistent misconception that organisms can change their genetics at will and evolve to survive. This would imply another
misconception – that organisms themselves evolve rather than populations of organisms evolving over time.

**Table 33. Biology 2 CRC Test Question 7**

Explain the steps in the process of how species form. Use diagrams or drawings if possible.

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post Test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Confused speciation with natural selection.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Think that speciation is a result of need and that animals will evolve to the new environment.</td>
<td>1. Organisms can change their genetic traits at will – they evolve into what they need to stay alive.</td>
<td>1. Teachers wrote very little in the way of answers, but the misconception concerning the Lamarckian process as evolution remains.</td>
</tr>
</tbody>
</table>

The eighth question (Table 34) required teachers to explain how natural selection caused changes in the populations of peppered moths in England during the Industrial Revolution. Most teachers did not answer this question on the pretest. This was a surprise since this example of natural selection is covered in high school and college biology texts.

After taking the class, many teachers responded that species could change their genetics at will – that since conditions for survival had changed in England, the moths had to evolve to survive in the new conditions. They seemed to be confused about this issue, especially if they tried to explain the mechanism for how this might happen. They thought that the moths mutated to survive the Industrial Revolution. This same misconception was present again on the follow-up test.
Table 34. Biology 2 CR Test Question 8
How did natural selection cause changes in the populations of peppered moths?

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post Test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. If light colored moths are getting eaten by birds, then a mutation could happen to make their wings darker so they can survive.</td>
<td>1. Some think that the pollution in England got so bad that the moths developed spots on them. As more white moths were eaten, the spotted ones “took over” and eventually the moths became black.</td>
<td>1. Many teachers felt that species could change their genetics at will in response to environmental pressure.</td>
</tr>
<tr>
<td>2. Moths turn a darker color to match their new environment – camouflage themselves.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Changed color due to being covered with soot and then when industry cleaned up, the moths changed to a lighter color again because the new moths born did not get soot on them.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The next question (Table 35) asked teachers to describe the likely food chain for a stretch of the Platte River. Most teachers made some attempt to describe a possible food chain for a river on the pretest and were able to do this on the post test. They did not list any misconceptions on the post test.
Table 35. Biology 2 CR Test Question 9

To the best of your knowledge, describe the likely “food chain” or trophic structure for a stretch of the Platte River above Chatfield Reservoir in Waterton Canyon. Spell out the likely “steps” in the food chain.

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post Test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The sun starts the food chain off with the sun providing energy to plants.</td>
<td>1. Most teachers did not have any problem with this question.</td>
<td>1. Teachers forgot specifics for the Platte Canyon population, but most could put down some schematic.</td>
</tr>
<tr>
<td>2. Listed “producers, first level consumers, second level consumers, etc.”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. State that plants are at the bottom of the food chain.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

By the time of the follow-up test ten months later, teachers had forgotten the details of the food chain for the section of the Platte River they studied, but they could give a general river food chain and most received points for this question.

The following set of questions was written (in part) to test the skills of teachers in reading charts, graphs, histograms, and other methods of data presentation. Question ten presented two histograms representing two stream populations and the teachers had to identify which had the greater diversity and explain why. (To see the histograms for these questions, please refer to Appendix Q.)

The first part of the question was to discuss which river site had higher diversity and why (Table 36). Most teachers wrote incorrect answers. There was little difference on the post test or the follow-up test.
Table 36. Biology 2 CR Test Question 10A

Examine the data in the histogram and answer the questions that follow. Which site has the higher diversity and why?

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post Test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. A teacher thought the size of the space on the histogram bar referred to the sizes of the insects in the water.</td>
<td>1. Teachers either did not answer the question or got it wrong.</td>
<td>1. Teachers did not know the answer.</td>
</tr>
</tbody>
</table>

There were two issues here: 1) knowing how to read and interpret graphs, charts, and other data representations, and 2) knowing how stream water quality is determined. One of the teachers was under the impression that the size of the bars in the histogram indicated the size of the insects collected. A teacher with low math skills such that they could not understand a bar graph would have no idea how to answer these questions. They would be unqualified to be teaching science in the upper elementary/middle school level.

Teachers were taken to collect water samples from two very different stream sites to collect water samples. The stream organisms were separated, various types counted, viewed under a dissecting scope, and compared from the two sites. There were obvious differences not only in the numbers of different insects, but also in the different types of insects isolated. No water chemistry was done, so the differences between the streams were only determined by the organisms in the samples. The idea that the two stream populations were different (the turbidity of the water was noticeably different as well) was obvious...
to the teachers, but the idea of using indicator organisms to gauge the quality of the water did not get across to them, or if it did, they did not mention it.

The second question about the histogram (Table 37) asked the teachers to tell which site was contaminated by heavy metals and why. Answers showed a wide variety of mistaken beliefs/misconceptions on the pretest. On the post test, teachers restated some of their misconceptions/errors. Little reference was made to indicator organisms and when it was, the organisms mentioned were the wrong ones. However, a few of the teachers had some idea about indicator organisms.
Table 37. Biology 2 CR Test Question 10B

Examine the data in this histogram and answer the questions that follow. Which site would you predict is contaminated by heavy metals? Defend your answer.

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post Test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Domination by one species indicates contaminated water.</td>
<td>1. Since mayflies grow better in sample #1, they must have adapted to heavy metal contamination.</td>
<td>1. Problems with the test missing a page affected whether or not an answer was written down or not.</td>
</tr>
<tr>
<td>2. If there are about the same number of each kind of organism in the water, then that indicates poor water quality.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. No mention of stone flies which indicate water purity, or true flies which indicate poor water quality.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. If caddis flies die off and mayflies take over, then that indicates contamination.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. A lack of caddisflies indicates contamination.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. A healthy ecosystem would have a variety of species rather than a variety of specific kinds (indicator organisms) of species.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The last set of questions on the Biology 2 CR test consisted of three questions about data provided about the relationship between lynx and hare populations. There was a graph (see Appendix Q) showing the nature of the populations over a 75 year period. The graph had two scales on the y axis – one on each side of the graph. The left side showed the numbers of hare and on the right side were the numbers of lynx. The line depicting the number of hare was black and the line for the lynx was red. The teachers did not understand the
graph and they made incorrect interpretations of the results. They stated they saw a correlation between the lynx and hare numbers, but their explanations indicated that they did not have good data interpretation skills. The skills to correctly interpret these data are so basic, that the researcher wondered if they somehow got the black and red animal lines on the graph mixed up. These backward results occurred on the pretest, post test, and follow-up test (Table 38).

**Table 38. Biology 2 CR Test Question 11A**

Do the data above provide proof that lynx control the number of hare?

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post Test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Think that there is no correlation between an increase or decrease of either population.</td>
<td>1. Some teachers still think that lynx control hare even though the higher hare numbers precede the higher lynx numbers.</td>
<td>1. Some still think that the lynx control the hare population.</td>
</tr>
<tr>
<td>2. Think that as hare populations go up, it means that the lynx control them.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Think that when the lynx population increases, then the hare population does also.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The second question in this three-question set (Table 39) asked if the hare numbers were cyclic. Most teachers believed that the hare numbers were cyclic, although some had faulty reasoning as to why. On the post test, nearly all teachers stated that the hare numbers were cyclic. The results were the same for the follow-up test.
Table 39. Biology 2 CR Test Question 11B

Are the hare numbers cyclic?

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post Test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Numbers are cyclic if they go up and down, not that they have the same period or frequency.</td>
<td>1. No misconceptions stated.</td>
<td>1. No misconceptions stated.</td>
</tr>
<tr>
<td>2. Think that fluctuating and cyclic are mutually exclusive.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The last question (Table 40) asked the teachers to list factors other than lynx numbers that might affect hare populations. There were no misconceptions/errors listed for this question – even on the pretest, many teachers knew the answer. The errors that were made generally were due to them not answering the question in the way they were asked to. Most teachers listed some other appropriate factors affecting the ability of a population to survive other than prey numbers on all three test administrations. On the follow-up test, all but one teacher were able to respond correctly and the one teacher who did not had left the question blank.
Table 40. Biology 2 CR Test Question 11C

What other factors besides lynx numbers might affect either of these populations? Make a list.

<table>
<thead>
<tr>
<th>Pretest Misconceptions</th>
<th>Post Test Misconceptions</th>
<th>Follow-up Test Misconceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Most teachers could answer this.</td>
<td>1. All teachers were able to answer this.</td>
<td>1. All teachers were able to answer this (all but one).</td>
</tr>
</tbody>
</table>

**Biology 2 Constructed Response Assessment Results**

The Biology 2 course concepts were conceptually less demanding than those for the Biology 1 course (for which an understanding of chemistry was needed.) Corroboration between the two test formats showed that for Biology 1, MC test questions over topics that were also on the CR response indicated that initially, the teachers knew the specific facts on the MC test better than the type of information CR tests required, but that evened out by time of the post test and the follow-up test. For the Biology 2 course, since the teachers started out with some general content knowledge, the gains made as evidenced by the MC tests were not as great. There was also not as much corroboration between concepts on the two tests, so test data corroboration was not possible. The CR test did inform course instructors that there were a number of concepts that were not known at the time of the pretest, were not known at the course’s end, and were still not understood or known by time of the follow-up test. This information, while not helpful for this first Biology 2 class, was helpful to course instructors since they could make course adjustments for successive Biology 2 classes.
Unlike the Biology 1 teachers who were very conscientious and answered every question they could, the Biology 2 class teachers did not seem to try as hard to answer the questions with detail and accuracy. The evidence for this was in the parsimonious wording of answers, the nearly illegible writing and the failure for some of them to even answer all the questions: some answered in such a way that it seemed as though they had not read the question carefully and did not realize that there was something to answer there. Many points were missed due to factors not necessarily associated with knowledge of the material.

**Research Question 3**

The third research question was “Will the teachers impart any misconceptions/errors to their students and will they notice and correct student misconceptions in the classroom?

**Misconceptions Noted from the Classroom Observations**

Each teacher was observed for three class periods to see if the teachers were imparting accurate information to their students. One goal was to see if misconceptions were expressed in the classroom either by the teachers or the students in their classes.

These errors/misconceptions that were noted in the classes are listed by category. Not all the teachers that were observed were teaching biology; so some of the misconceptions listed are not biology misconceptions/errors. There were six categories of misconceptions noted with 53 different
misconceptions/errors. The categories and the misconceptions in each category are listed below:

**Misconceptions/Errors**

1. Microbiology

   - While presenting some information to the class, a student claimed that Parkinson’s disease is caused by bacteria.
   - A student asked about a microorganism (fungi) that might be visible to the naked eye. Fungi are not all microscopic and the distinction should be made.
   - Bacteria in the stomach have been implicated in causing ulcers, but not in breaking down food.
   - Bacteria do have ribosomes, but do not have other cell organelles like the endoplasmic reticulum, Golgi bodies, etc.
   - The organisms that cause flu are not bacteria, they are viruses.
   - A strep infection is bacterial, not viral.
   - Viruses are much smaller than bacteria.
   - Bacteria do not have nuclear membranes nor do they have nuclei.

2. Physical Science

   - Water “bulging” out over the top of a container is not a bubble, but a concave meniscus.
   - A student asked about “smashed” or compressed water when it cannot escape the pressure. The properties of water/liquids should be reviewed.
   - One student remarked that heat does not matter when discussing gases, but it does.
A student thought that a substance with a density greater than one would float. It would float in water if its volume displaced at least an equivalent weight of water as its mass. The shape of an object as well its mass has everything to do with whether it floats or not.

The words cycle and cyclical were used interchangeably, but they mean different things. In other words, something that was three cycles was called a cycle rather than being cyclical.

One cubic centimeter does equal one gram which equals one milliliter of water, but this does not hold true for all liquids.

Diving is NOT sliding between the attractions between water molecules, it is just that with the shape of your hands and body streamlined, there is less surface area to break the surface tension of the water than a belly flop.

Air does not get “sucked up”. It gets pushed up by concentration and pressure differences in the media around it.

3. Scientific Methods

The word “hypothesis” was used when the meaning really was “prediction”. Apparently no distinction was made in the district materials.

A lab was given to students that really investigated two different principles: density of different gases and effects of temperature on gases. The experiment consisted of using balloons with different gases rising with heat or no heat, but it was discussed as though there was only one variable. Introducing the scientific method with a lab with two variables could be confusing, especially if the lesson was an introduction to science methods, identifying and isolating variables, etc.

There is not only one way to do a “scientific method”.

A hypothesis is not an educated guess; it provides a causal explanation of an observed phenomenon by invoking entities that cannot be directly observed.
• There can be more than one variable taken into consideration in an experiment. More controls may have to be set up to make sure the results are caused by which variable.

• If the thermometers being used only measure to the whole degree, then the measurement you make (by eyeballing it) cannot be stated in fractions of a degree if significant figures have to be considered.

• There are two types of observations: qualitative (involving the senses) and quantitative (numerical).

4. Chemistry

• The textbook states that the water molecules that are present today are the exact same water molecules that were present during times of the dinosaurs. That is not necessarily correct. Water molecules do undergo rearrangement due to their polarity and water molecules are split during photosynthesis. This type of statement should just be left out of texts to avoid confusion.

• Confusion about the rate of diffusion – there are several factors that are involved in the decrease/increase of the rate. The shape, size, and charge of the diffusing substance make a difference.

• Vinegar is not 100% acid – only about 3% acetic acid.

• Red chili does not “burn” because of acid, but rather because of a chemical called capsaicin.

• Sodium chloride dissolved in water is not an example of chemical change.

• Dry ice is not frozen water, but rather frozen carbon dioxide.

• Molecules are not “constant things.” They change, they vibrate, interact with other molecules, etc.

• Components of molecules can recombine with other elements, but the atoms remain the same atoms. Carbon atoms do not change into another type of atom when they change from being combined with oxygen atoms to other carbon and hydrogen atoms. However, radioactive decay
elements does occur and an element does change into another one until it reaches the end of its decay.

- Carbon dioxide gas is acidic when in water because it combines with the hydrogen in water to make $\text{HCO}_3^-$ and $\text{H}^+$ which is slightly acidic. Hydrogen ions must be present for something to be acidic and CO$_2$ in the air has no hydrogen.
- There is caffeine in chocolate.
- Dissolving and breaking down are not the same thing.

5. Biology

- Students were looking at slides of cardiac muscle cells which were very thick and the nuclei could not be easily seen. They were questioned about how many nuclei were in the cells and the cell boundaries were very indistinct. It looked as though some cells had nuclei, some had more than one nucleus, and some cells did not have one. All intact cardiac cells have a nucleus, but it may not be visible in a particular section or slide preparation.
- BTB in water will not harm plants directly, but plants grown under a blue light filter do have their growth affected.
- Plant cells also have mitochondria in addition to chloroplasts.
- The cell nucleus is not the “brain” of the cell although this analogy could be used with middle school students.
- DNA is not the “messenger” in your body. If an analogy is used, then “blueprint” would be more appropriate.
- Green beans are not legumes.
- When a person breathes in, the air goes into their lungs, not the stomach.
- Stomach acid does not “melt” food, but contains enzymes that break down the components of food.
• Saliva is not the only thing that moves food down the esophagus to the stomach. The esophagus has muscle contractions that help move food down.
• Plants do not get their oxygen from the carbon dioxide they take in – they split the water molecules to get it.
• Some parts of plant life cycles have cells that have cilia.
• Every cell in the body has a blood supply.

6. Earth Science

• One student remarked that the sun circles the earth. The misconception was discussed and hopefully cleared up.
• A student asked if there is the same amount of water now as there was then. During earth’s formation, the amount of water has changed from nearly covering the globe to the amount present in the oceans, lakes, etc. today.
• People do not breathe out mostly carbon dioxide – there are other gases such as nitrogen, oxygen, different noble gases, and so on in the atmosphere. Carbon dioxide is only 0.003% of the gas in our atmosphere.
• Teaching about the water cycle means that it is a cycle and that it does not end in any particular place, but the cycle continues via a number of different pathways.
• The reason we have seasons is because of the tilt of the earth on its axis, not the distance from the sun.
• The equator is an imaginary line and it does not change position.
• Magma from volcanoes is not the reason it is hotter at the equator, but the tilt of the earth on its axis.

Each misconception in these six categories occurred in class – either verbalized by a teacher or a student. When said by a student, generally (but not
always) the teacher noted the misconception and directed the students in the
direction of the correct conception. If that did not occur, it was discussed in the
teacher-researcher conference after each observation. Misconceptions/errors
were not noted in every teacher’s classroom, which does not mean that there
were none; just that they were not caught or recognized during that particular
class.

**Research Question 4**

The fourth research question was “Will the teachers from the Biology 1
class incorporate lessons, laboratory exercises, inquiry activities, or teaching
strategies? Will they use the equipment provided by the course instructors to
each district?”

At least five hours (observation and interview) were spent with each
teacher, and for most, much more time was spent due to teachers teaching more
than one subject, class scheduling, lunch breaks, and subjects being taught. It
was not always possible to observe the teachers teaching consecutive classes
as there were different teacher/class arrangements and activities (such as
assemblies, fire-drills, and shortened-school-day) which interrupted the normal
teaching schedule. In those instances, teachers had to be observed teaching the
same lesson twice in a row or for a two-hour block.

The classroom observations were done while filling out an observational
protocol and the results were compared with the teachers’ responses from the
Teacher Questionnaire. Information on the teachers’ science and educational
backgrounds was obtained because teachers’ science content knowledge and their pedagogical background and practices would likely influence their choices in using hands-on, content-rich, inquiry science activities in their classrooms.

**Classroom Observation Protocol Data**

Data from the Classroom Observation Protocol (COP) was divided into four basic compartments: 1) lesson design, 2) lesson implementation, 3) science content of lessons, and 4) using science process knowledge in lessons.

The lessons that the teachers designed for observation were, for the most part, well-designed Table 41. The teachers had several weeks before being observed to prepare their lessons, and most of them did a thorough job.

**Table 41. COP Lesson Design**

<table>
<thead>
<tr>
<th>The design of the lessons</th>
<th>1 = no</th>
<th>2 = sometimes</th>
<th>3 = yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria:</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1  incorporated tasks, activities, and interactions consistent with investigative, inquiry-based science</td>
<td>3</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>2  involved fundamental concepts of the subject</td>
<td>0</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>3  included instructional strategies and activities to activate students’ prior knowledge</td>
<td>1</td>
<td>1</td>
<td>19</td>
</tr>
<tr>
<td>4  included strategies and activities that addressed student learning styles</td>
<td>0</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>5  included strategies and activities that took into account student levels of cognition</td>
<td>0</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>6  encouraged a collaborative approach to learning and allowed for talk among students</td>
<td>2</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td>7  made connections to topics the students have already studied or will study</td>
<td>*1</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>8  provided adequate time and structure for “sense-making”</td>
<td>2</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td>9  included assessments of students that were consistent with investigative science</td>
<td>**0</td>
<td>**0</td>
<td>3</td>
</tr>
<tr>
<td>10 provided adequate time and structure for wrap-up</td>
<td>2</td>
<td>4</td>
<td>15</td>
</tr>
</tbody>
</table>
*0 – this was a drop-in lesson for a teacher not in the classroom this semester of observations and it was not connected to the current unit being taught. **0 – very few teachers scheduled assessments of their students during the observations since the goal was not to watch teachers assessing, but to watch them teaching. However, three of the teachers had worked in some creative assessments into their lessons.

These data clearly show that the lessons presented for observation incorporated inquiry-science tasks, consisted of standards-required content material, required students to utilize prior content knowledge, and made connections to topics the students have been studying. Teaching inquiry-based lessons implies that different learning styles and levels of cognition are addressed, and that students work together on investigative science projects. The most difficult thing for most of the teachers was to design appropriate lessons that fit into fifty minutes or less science classes that included time for students to think about what they are doing and why and for there to be time to wrap-up lessons. Teachers with block-scheduling were able to do this more consistently. Many middle school classrooms are plagued by constant interruptions from the office, announcements, or other school-related things which made it even more difficult to complete the lesson on time.
The lesson implementation (Table 42) was also done very well by most of the teachers. Some of the teachers had been teaching for a long time, but many of them had been teaching for five years or less. There were some instances where classroom management or questioning strategies were weak, but overall, the lesson implementation was of high quality.

Table 42. COP Lesson Implementation

<table>
<thead>
<tr>
<th>How the lessons were implemented:</th>
<th>1= no</th>
<th>2 = sometimes</th>
<th>3 = yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria:</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1 The instructional materials supported the instructional approach.</td>
<td>0</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>2 The pace of the lesson was appropriate for the developmental levels/needs of the students.</td>
<td>0</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>3 The pace of the lesson was appropriate for the number and types of activities.</td>
<td>0</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>4 Students were given time to discuss topics and concepts and help each other understand them.</td>
<td>1</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>5 Students were encouraged to generate ideas, questions, and/or propositions over the material.</td>
<td>2</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>6 The activities and tasks were appropriate for the focus of the lesson.</td>
<td>0</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>7 The teacher’s questioning strategies enhanced the development of student conceptual understanding.</td>
<td>1</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>8 The teacher’s questioning strategies emphasized higher order questions.</td>
<td>6</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>9 The teacher’s questioning strategies identified student misconceptions.</td>
<td>6</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>10 The teacher’s classroom management style enhanced the lesson quality.</td>
<td>1</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>11 The teacher moved around to answer questions to enhance student investigations.</td>
<td>0</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>12 The teacher appeared confident in his/her ability to teach science.</td>
<td>0</td>
<td>1</td>
<td>20</td>
</tr>
</tbody>
</table>
Colorado has state standards mandating that certain science topics be taught at each grade level (Table 43). The teachers were aware of this and designed their lessons for observation to meet state requirements. The science content was appropriate and age-level, and there were new ideas to challenge the students. Nearly 80% of the teachers did not connect science topics to other subjects, none of the teachers portrayed science as a dynamic discipline, and 60% did not use any symbolic representations. There was also some lack in checking for understanding – an important teaching technique.

**Table 43. COP Science Content Knowledge**

<table>
<thead>
<tr>
<th>Science Content of the Lessons</th>
<th>1 = no</th>
<th>2 = sometimes</th>
<th>3 = yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 The science content was significant and worthwhile.</td>
<td>0</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>2 The science content was appropriate for the developmental levels of the students in this class.</td>
<td>0</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>3 The content was aligned with district standards.</td>
<td>0</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>4 Students were intellectually engaged with important ideas relevant to the focus of the lesson.</td>
<td>1</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>5 Teacher-provided content information was accurate.</td>
<td>0</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>6 Teacher-provided content and responses to student questions were free of misconceptions.</td>
<td>2</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>7 Teacher noted/identified students’ misconceptions/errors, arranged for further discussion to clarify/correct them.*</td>
<td>7</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>8 The teacher displayed an understanding of science concepts.</td>
<td>0</td>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td>9 Appropriate connections were made to other areas of science, to other disciplines, and/or to real-world contexts.</td>
<td>16</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>10 Science was portrayed as a dynamic body of knowledge subject to new evidence, analysis, and reinterpretation.</td>
<td>20</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>11 Elements of science abstraction (symbolic representation) were included when it was important to do so.</td>
<td>12</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>12 The degree of “sense-making” of the content was appropriate for students’ developmental levels/lesson purposes.</td>
<td>2</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>13 The teacher checked for understanding of complex concepts.</td>
<td>5</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>
These data have been quantified for three observations for each teacher, so even though it seems that nearly one third of the teachers missed student misconceptions/errors, there were two teachers who were not teaching science, one of which was not even a science teacher, two elementary education teachers with very little science background, one teacher who had been a P.E. teacher and was in the science classroom for the first time, and two teachers who were special education teachers with no science background.

New science teaching (Table 4) calls for science process knowledge – an important part of the science curriculum and a hallmark of inquiry science. There are twenty four characteristics listed with several glaring deficiencies. The fact that no teacher even mentioned the difference between quantitative and qualitative data was problematic. When teaching students about observations, there are two kinds and this important fact was not mentioned. Most students were not given the opportunity to repeat experiments (time was a factor), take their experiment a step further, or evaluate and critique their classmates’ work (although they were, in some instances, able to compare their results to their classmates). The last six questions had to do with using some actual science equipment. That was very limited. Glassware was the main equipment used and some students had microscopes (where appropriate), measuring and weighing devices, timers, and a few were able to use live plants or insects. Even schools in “wealthier” neighborhoods had mundane science equipment. A number of teachers did use equipment provided by the Biology 1 instructors.

Making inferences, predictions, designing and completing data tables, writing down observations in notebooks/journals, and discussion of results (expected and unexpected) with each other were done in nearly every classroom. There was, however, a general skirting of the issue when it came to
identifying the variables and setting up controls (presumably since the teachers themselves were unsure of this information).

Table 44. COP Science Process Knowledge

<table>
<thead>
<tr>
<th>Activity utilizing science process knowledge was part of the lessons</th>
<th>1=less than 50%</th>
<th>2=50% of the time</th>
<th>3=more than 50%</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students were:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 presented with a problem, data, etc. to think about</td>
<td>4</td>
<td>7</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>2 required to analyze data from scientific literature</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>3 given an opportunity to learn and distinguish between qualitative and quantitative observations</td>
<td>15</td>
<td>1</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>4 required to ask a question they could investigate</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>5 able to make predictions about what would happen before doing lab activities or experiments</td>
<td>1</td>
<td>4</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>6 required to test hypothesis or questions in experiments</td>
<td>4</td>
<td>1</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>7 able to identify/control variables when doing experiments</td>
<td>8</td>
<td>0</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>8 able to design and set up their own experiments</td>
<td>1</td>
<td>6</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>9 drawing inferences</td>
<td>3</td>
<td>6</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>10 required to fill in a data table with experimental results</td>
<td>2</td>
<td>4</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>11 required to write down information from observations of their experiments in a notebook or journal</td>
<td>1</td>
<td>1</td>
<td>18</td>
<td>1</td>
</tr>
<tr>
<td>12 required to construct a chart or data table</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>13 required to create a graph and graph data generated from their experiments</td>
<td>2</td>
<td>1</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>14 required to discuss the results and data from their experiments with each other</td>
<td>0</td>
<td>0</td>
<td>19</td>
<td>2</td>
</tr>
<tr>
<td>15 required to discuss reasons for outcomes that were different than what they predicted</td>
<td>1</td>
<td>1</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>16 encouraged to repeat experiments to check results</td>
<td>2</td>
<td>1</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>17 given the opportunity to critique, judge, evaluate other experiments or work</td>
<td>0</td>
<td>2</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>18 able to take it “a step further” and design additional experiments to further their research</td>
<td>4</td>
<td>0</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>19 using balances, scales, or thermometers</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>20 using magnifying lenses, microscopes, dissecting scopes</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>17</td>
</tr>
<tr>
<td>21 using meter sticks, timers, or stopwatches</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>22 using graduated cylinders, beakers, flasks for liquids/fluids</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>10</td>
</tr>
</tbody>
</table>
Table 45 summarizes the findings for Research Question 4.

Table 45. Teaching Practices from Biology 1 Class

<table>
<thead>
<tr>
<th>Strategies</th>
<th>1 = little</th>
<th>2 = some</th>
<th>3 = lot</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Teachers demonstrating the use of inquiry in their classrooms</td>
<td>1</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>2 Teachers demonstrating the use of a scientific process</td>
<td>7</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>3 Teachers implementing hands-on lab exercises</td>
<td>1</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>4 Teachers incorporating content from the Biology 1 class</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>5 Teachers incorporating lab activities from the Biology 1 class</td>
<td>10</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>6 Teachers using Bio 1 donated lab equipment/supplies</td>
<td>10</td>
<td>4</td>
<td>7</td>
</tr>
</tbody>
</table>

Most of the teachers (20/21) used some elements of inquiry in their classrooms. More than half of the teachers had students using some aspect of a scientific method during the observations (14/21). All but one teacher had the students working with hands-on activities, and that one teacher did an interesting demonstration in which the students participated heavily. These first three teaching practices are consistent with inquiry teaching.

Corresponding data from the teacher questionnaire is that all of the teachers stated that they consider inquiry to be fairly important to very important and this was corroborated by the observations: 20 out of 21 teachers did inquiry activities during the observations. Seventeen out of 21 teachers stated that they...
felt prepared to teach about the scientific process, and 14 out of 21 teachers actually demonstrated teaching that required using a scientific process. All the teachers stated that they consider hands-on activities to be important, and twenty of twenty-one teachers had the teachers doing hands-on activities during the observations.

The second three teaching practices listed in Table 48 would only apply to those who were teaching subjects that coincided with the topics in the Biology 1 course. Ten teachers received a score of 1 for the last three practices as they were not teaching Biology 1 material, but they were using inquiry, science methods, and had good science content.
CHAPTER 5  CONCLUSIONS, INTERPRETATIONS, LIMITATIONS, AND IMPLICATIONS

Results and Interpretations

Research Question 1.

Did participating middle school teachers in the Jefferson County School District and other participating districts improve their science content knowledge after a two-week intensive summer science course offered by the RM-MSMSP?

The major goal of the biology courses was to increase the overall science content knowledge of participating teachers. The results of the pre-, post-, and follow-up assessments provided insights into the science backgrounds of middle school science teachers in this study and clearly showed the teachers’ content knowledge gains.

Biology 1 Assessment Results

Both the Biology 1 MC and CR pretests indicated that these middle school science teachers did lack a basic understanding of photosynthesis, respiration, the nature of science (NOS), and concepts concerning genetics and DNA although many of them were currently teaching some of these subjects. All of the teachers did improve their content knowledge during the course and scored
higher on the MC post test. Seventy six percent of the teachers in the Biology 1 class scored higher on the MC follow-up test than on the pretest indicating a significant increase in their biology content knowledge as measured by these assessments. The Biology 1 CR assessments showed that all teachers increased their post test and follow-up scores and therefore their content knowledge.

Biology 2 Assessment Results

The Biology 2 MC and CR pretests indicated that these teachers had limited background knowledge about ecology, paleontology, taxonomy, speciation, natural selection, and adaptation, but needed more in-depth knowledge of these topics. All of the teachers improved their content knowledge during the course as shown by the post test scores. Seventy five percent of the teachers scored higher on the MC follow-up test than on the pretest, indicating an increase in their science content knowledge as measured by these assessments. All but two teachers increased their CR follow-up score above pretest levels and those two had slightly lower follow-up scores than pretest scores.

Some of the teachers in both biology classes who had lower MC follow-up scores than their original MC pretest scores or who had lower CR follow-up scores than CR pretest scores offered the explanation that since they were not teaching this material to their current students, they either forgot the material, or they did not attempt to remember it as they did not need it for their students that
year. They also stated that the course manual, the handouts, labs and other activities, the course supplemental CD, and other materials were of such high quality that they felt that if they did need to teach this material at a later time, they would be able to use these resources to review and relearn the course information well enough to teach it at the middle school level.

There were two hypotheses that addressed this research question. Both stated that there would be no statistical differences between the Biology 1 or 2 MC and CR course pretests, post tests, and follow-up tests. Both of these hypotheses were rejected as the differences in the scores for all tests for all times were statistically different.

Differences between the Biology 1 and 2 Courses

Even though the trend in both biology courses was the same basic pattern (low pretest average, high post test average, and follow-up test average lower than the post test, but higher than the pretest), the way the teachers performed on them was different. The data from the MC assessments were charted according to individual questions in the question pairs and coded for each question pair based on whether the “content” part or the “because” part or both parts of the question pair were answered correctly. This information indicated that Biology 1 teachers came to the course knowing very little about the course content topics. They improved on the post test and retained a significant amount of the information by the time of the follow-up test. They had to learn the material from the very bottom up and their responses on the MC questions reflected that
they when they knew the correct answers, they also knew the reasons why. Their responses on the CR test showed that they indeed started out knowing almost nothing about the topics and in all cases, their post test and follow-up test scores were higher than the pretest scores.

The Biology 2 class came to the course with some knowledge of the topics (specific ones like ecology and environmental topics). They improved their content knowledge. The MC questions showed that for ten of the question pairs, the teachers knew the correct content and 'because' portions, but there were nearly as many (nine) question pairs for which they did not know one of the answers for the question pair - either the content part or the 'because’ portion. This suggests that the teachers did not really understand the material and that they might be guessing the answers. Perhaps they felt confident with the material since they had prior exposure to it or not taught it and they did not study it to score well on the test. On the MC test, guessing incorrectly worked against the teachers because if they missed either part of the two question pair, they did not receive any points for those two questions. The CR questions showed that for all teachers except one, their post test scores were higher than their pretest CR scores, but there were two teachers for whom the follow-up scores were lower than the pretest scores.

The teachers in the Biology 2 class were much more laconic with their answers on the CR test - they wrote minimal responses – even when they were supposed to explain their answers. The scores for these tests would have been higher if the teachers had followed instructions and explained “why and how”
when they were instructed to do so. The impression was that these tests were taken hurriedly and with less care than the Biology 1 class.

A significant increase in scores can be misleading. A low score can be doubled and what is known is less than 50% of the material. However, that still means more is known at the end of the class than at the beginning. An individual starting out with a high score can only increase it a little, but again, he/she increased his/her knowledge. For both Biology 1 and 2 classes, the mean score for all four pretests (MC and CR) was less than 20 points out of 40 or more points, which is less than 50%. The post test means ranged from 28 to 29 points, which is less than 70%. The follow-up scores were all below 60%. These class averages are not considered to be good scores, but they are significantly higher than the pretest scores, indicating that some of the individuals did retain a significant amount of the information they learned.

When the number of participants is small, as it is in this study, the scores of one person can affect the results. One high or low score can affect the results and give the erroneous impression of a trend. The misconception/error data for this study is problematic in that for individual misconceptions/errors in Tables 16 and 18 are hard to interpret because for many of the misconceptions/errors, the “trend” of increasing or decreasing resolution of misconceptions/errors is caused by one or two individuals and is not a trend.
Research Question 2

Which science misconceptions/errors do participating middle school science teachers bring to the two-week intensive summer institute course and are they able to resolve these misconceptions/errors?

The Biology 1 and 2 assessments indicated that the participating middle school science teachers did have misconceptions/errors in their biology content knowledge. The term “misconception/errors” is used rather than “misconception” because within the scope of this study, it was not possible to determine whether incorrect answers were chosen due to a misconception or an error.

Biology 1 Misconception Results

Different types of cells

Middle school curriculum includes information about the differences between plant and animal cells. High school curriculum includes information about the differences between prokaryotic and eukaryotic cells. These two sets of differences, each distinguishing between two major categories of organisms, are fundamental to many biology concepts. The Biology 1 teachers began the class with a lack of information on these topics (two-thirds of the teachers scored zero points) and they had many misconceptions/errors. After the class, there were still misconceptions/errors, but they were different than those with which they started. Some of the misconceptions/errors were on specific details mentioned during the class. The teachers did not understand the information about prokaryotic and eukaryotic cells as well as the information about the
differences between plant and animal cells. Therefore, they did not completely understand classification schemes and the full ramification of being an organism in any of the groups.

Reproductive processes

Responses from different questions on both the MC and CR tests show that these teachers had misconceptions/ errors about reproductive processes. Some of these teachers did not understand that meiosis is a sexual reproductive process and mitosis is not. The responses from several of the teachers indicated that they did not know that organisms like plants can reproduce an entirely new organism employing either process, while organisms like mammals can reproduce another organism by sexual means. The teachers did not know that somatic cells from higher organisms (both plants and animals) are reproduced by asexual means (mitosis). They were under the impression that every organism (other than bacteria and viruses) could reproduce itself or its tissues by only one process (i.e. plants utilize mitosis while animals use meiosis). Nor did they understand that meiosis results in genetic recombination while mitosis does not. These are major deficiencies in their background knowledge. While genetics at the middle school level is not covered in great depth, students do ask questions and they need the background to prepare them for high school science classes.

Respiration

The question on designing an experiment about respiration was intended to test how much teachers know about cellular respiration (answers with
experiments on breathing were accepted). The teachers did not completely understand this concept – many teachers held the misconception/error that respiration referred only to the act of breathing. While respiration does refer to the act of breathing, it is not the only respiration that occurs in the body: every cell respires. At the middle school level; however, respiration information is very rudimentary, does not include chemistry or biochemistry, and often entails studying the pulmonary system and breathing. Cellular respiration may be taught under the topic of “cells” with some mention of mitochondria and little connection to the actual complicated metabolic process. Cellular respiration was not something with which most of these participating middle school teachers were familiar. In the Biology 1 class, little time was spent on the pulmonary system and breathing, but considerable time was spent on cellular respiration. Even though their content knowledge increased, test responses and classroom observations indicated that they still struggled with the fundamental processes that respiration involves. The difficulty with this topic is not that teachers have so many misconception/errors, but that they lack in-depth knowledge of this topic. Those teachers with little biology and no chemistry background found the topic intimidating and had difficulty with understanding these difficult concepts.

Photosynthesis

Of all the topics covered in the Biology 1 course, the one that appeared to be the most difficult for the teachers to learn and to retain were concepts of photosynthesis. This is another concept where the problem was not so much
with misconception/errors, but just a fundamental lack of knowledge. The question on photosynthesis required some knowledge of the two types of reactions that take place during the different processes of photosynthesis, and it also involved some knowledge of chemistry. Only one teacher in the class scored any points on that question on the pretest. Even on the post test, the teachers did not seem to understand that there were two types of reactions that occur – one in sunlight and one that does not require sunlight directly. There were misconceptions/errors stated about these, but most of what was seen was lack of comprehension. Twenty five percent of the class did not even mention the essential words “chlorophyll” and/or “chloroplast” in their answers. The follow-up test scores showed the same thing. While the scores were better than those from the pretest, it appeared that the teachers learned some facts about photosynthesis, but they were not able to integrate them for good understanding of the processes.

DNA processes

Structure and replication

Biology 1 MC and CR test data indicate that teachers had considerable difficulty with misconceptions/errors on different DNA processes. At the start of the course, they had virtually no content information about DNA structure, replication or other processes. Some indicated that DNA “grows” another purine or pyrimidine base (like an ameba budding) to fill the place that the original base. Another idea was that once the DNA helix “unzips,” it searches for another
complete strand with which to reattach. On the post test, the teachers had the
information fresh in their minds and they knew the information on DNA structure
and replication, but they still had a few misconceptions/errors. Most of these had
to do with specific details of the structure or of processes - ideas such as at the
end of the DNA double helix, the strands are either both 5’ or 3’ rather than one
5’ and one 3’ strand together. These errors lead into teacher responses
indicating that they thought that replication proceeds in the same direction on
both the lagging and the leading strand. Some teachers ended up with a
fundamental lack of knowledge or a misconception of how the molecule works
and the elegance of the replication process.

Transcription and translation

By the time of the follow-up test, the teachers still knew about structure
and replication, but had difficulties with the more complex concepts of
transcription and translation. There were fewer misconceptions/errors stated
about transcription in that most of the teachers really did not understand the fact
that mRNA is a transcript itself and that it is the molecule that is translated to
form amino acids which eventually form proteins. Because of the difficulties with
understanding transcription, their understanding of translation was faulty as well.
Most of the incorrect responses about translation had to do with where it occurs,
which molecules are involved, and misunderstanding how the codons work.
Again, this level of information is not likely to be used at the middle school level,
but it would be helpful for teachers so they can field questions.
Genetic recombination

Perhaps as a direct result of their lack of knowledge about the details of meiosis and other processes involving DNA, the teachers showed evidence of incomplete understanding of genetic recombination of chromosomes, dominant genes, and that fact that some traits are controlled by more than one gene. Chromosomes are randomly assorted (thus they can produce traits in offspring that are not the same as their parents’ traits), but the teachers subscribed to the misconception/error that chromosomes blend together somehow to produce melded traits. While the concept of random assortment of chromosomes is not necessarily new to teachers, full understanding of how it works probably is.

Overview

A question-by-question examination of the Biology 1 MC test revealed several things. First, for some questions, initial misconceptions/errors were replaced by different misconceptions/errors as the course proceeded. Second, for some topics, the misconceptions apparently were resolved. Third, for some topics, initial misconceptions/errors were corrected by the course’s end, but teachers reverted back to their original misconceptions by the end of the follow-up course. And fourth, there were a number of important concepts that the teachers did not know before the class and they did not learn them.
Biology 2 Misconception Results

Speciation

An important concept covered in the Biology 2 course was speciation and its role in the evolutionary process. There were numerous misconceptions/errors around this topic. The mechanism for speciation was meticulously presented and illustrated with a number of specific examples. The teachers did increase their scores on the questions on speciation on the MC assessment, but on the CR test, they did not. They were to explain speciation using a diagram. Their ability to do this had improved by the post test, but at the time of the follow-up test ten months later, fifty percent of the teachers received one point or less out of five points. The misconceptions/errors centered around the teachers’ confusing speciation with natural selection and stating that speciation occurred as a result of need. This was unexpected in that some of these teachers were teaching about this topic in their classrooms, yet they demonstrated a low proficiency themselves even after the class.

Natural Selection

Another topic covered in detail was natural selection. The example used was peppered moths, a common example used in high school texts. Seventy five percent of the teachers received zero points for this question on the CR pretest. Numbers much improved for the post test and they were higher on the follow-up test than the pretest, but some of the teachers adhered to a
Lamarckian view of evolution which is that evolution proceeds as a result of environmental pressure or need. This is a common misconception. They stated that if conditions were harmful to the moths, then the moths would simply change their genetics so that they could survive the new conditions. Another misconception/error that surfaced in the responses to the same question was that individuals adapt rather than populations. The teachers seemed to believe that individuals change their genetics to survive adversity. These teachers did not subscribe to the idea that there is natural variation within a population and that survival of certain individuals who reproduce results in a physical change in the population. They modified their views somewhat by the time of the post test, but they did not retain the more accurate views - on the follow-up test these misconceptions showed up again. While the number of correct responses on the MC test did increase, the misconceptions on this topic were seen on the CR follow-up test.

Population cycles

All but one teacher held the misconception that population fluctuations occur in specific cycles. One set of MC questions directly asked the teachers if animal populations were cyclical and predictable and only one teacher responded with the correct answer. Nearly every teacher got this wrong on all three MC assessments. Some of the examples discussed in the class did appear to be cyclical which may have given the teachers the wrong impression and influenced their perceptions, plus there was an example on the CR test.
where the population shown in a graph was cyclical. This topic must not have been presented clearly because so many of the teachers missed it.

Phylogenetic Relationships

Initially when the teachers were given a phylogenetic tree to interpret, a number of misconceptions/errors were revealed. Rather than looking at where the lines connect to organisms and their predecessors, the teachers disregarded lines denoting relationships and stated that a number of different things determine the relationship: morphology, habitat, and locomotion of the organisms determine the relationship, and that the number of branches rather than the location of the branching determines the relationship. More than half of the class answered these questions correctly on the post test, but there were still some that thought that morphology and other factors determine the relationship between organisms. This carried through to the post test indicating that these misconceptions are firmly held.

Indicator organisms

Half of the teachers in the Biology 2 class knew some things about stream water diversity and quality at the beginning and end of the course, but one concept that was rarely verbalized on any of the assessments was the idea of indicator organisms – organisms that are present in either good quality water samples or organisms that indicate poor water quality. When they had to answer questions about it, a number of misconceptions were seen. The idea that living organisms could be used to rate water quality (as opposed to chemical tests) is
an important one and it was not firmly established. The teachers did check their water samples for organisms, isolated, and identified them. They were very interested in seeing which ones they found, comparing them with those that other teachers isolated, and preserving them so they would have them for their classes in the fall, but they did not make the connection that the presence or absence of certain organisms could be an indication of the quality of that water. The next day a different activity was started, so there may not have been enough follow-up after with class discussion to check for understanding on the concept of indicator organisms.

**Research Question 3**

Will the teachers impart any misconceptions/errors to their students and will they notice and correct student misconceptions/errors in the classroom?

This portion of the research was done entirely during the classroom observations. The misconceptions stated by the Biology 1 teachers, their students, and any that were noticed in textbooks or district materials were noted. A total of fifty three misconceptions/errors were noted and sorted into six categories: microbiology, physical science, scientific methods, chemistry, biology and earth science. Most of these were brought up or stated by students, but all of the NOS/science process misconceptions/errors were stated by teachers. One misconception/error was noted in the text used for a 6th grade class and one was found in district materials for 7th grade biology (included in the 53).
Students did voice many misconceptions/errors. Oftentimes, it was information from a source outside the classroom such as television. The television news media frequently make errors when discussing topics associated with microbiology, such as incorrect organisms causing diseases. Two students in different schools asked about information they heard on the news. One was an example from a media source that included statements that streptococcal infections are caused by viruses (instead of bacteria) and another was a statement that influenza viruses could be seen with an ordinary microscope (as opposed to an electron microscope). The latter misconception/error also caused another misconception/error in student thinking because if viruses could be seen with a light microscope, they might be in the same size range as bacteria when they are actually much smaller and cannot be seen with a light microscope. Students, their teachers and classmates had short discussions about these misconceptions/errors.

District materials for one of the districts participating in this study included a section after every chapter in the seventh grade biology textbook that listed commonly noted misconceptions/errors over the content in that chapter. That was helpful to teachers so they could resolve their own misconceptions/errors and be proactive about the misconceptions/errors that might be held by their students.

The teachers noted many of the misconceptions and handled them in different ways. One teacher asked a student a question that would cause him/her to reflect on what he/she had said, but with a new viewpoint or focus. A
few guiding questions followed and the student had the opportunity to revise
his/her original statement. Another tactic seen was for teachers to assign the
student to do some research on the topic and report the results back to the class.
In a case where the misconception/error needed to be clarified right then in order
to proceed with the lesson, some teachers asked other students what they
thought or they corrected it in class. All misconceptions catalogued in a
teachers’ classroom were discussed in the teacher interviews after the
observations.

Research Question 4

Will the teachers from the Biology 1 class incorporate lessons, laboratory
exercises, inquiry activities, or teaching strategies from the Biology 1 course?
Will they use the equipment provided by the course instructors to each district?

Ninety five percent of the teachers demonstrated the use of inquiry in their
classrooms either to some extent or to a great extent. Two thirds of the teachers
either used some activity that demonstrated the processes of science or had their
students do a laboratory or other exercise where they could use science
processing skills. Ninety five percent of the teachers had hands-on activities for
their students to engage in, but the one teacher who did not had a class
demonstration in which student participation was very good and the exercise was
an inquiry one with great student interest. All the teachers indicated that they
thought these three things (the use of inquiry, teaching about science processes,
and hands-on activities) were important. Some of them were less skilled with
incorporating activities to show how the science process works, but they expressed a desire to try and do that in their teaching.

It was hoped that all of the teachers would use some of the exercises, teaching strategies, and equipment provided by the course instructors, but that depended on what subjects they were teaching. Nearly half of the teachers were either teaching a different science than biology or were teaching some other class such as library/computer skills, special education, or had a non-teaching job in the district, but took the course because they need a good biology background to do their job effectively. So the fact that those ten teachers did not use course materials or supplies is not because they did not find them useful, but rather because it was not appropriate for the courses they were teaching.

Data from the teachers’ questionnaire and the COP showed that those teachers who were teaching science content from the course did incorporate some of the lessons, laboratory exercises, and activities from the Biology 1 course. They also used science equipment given to each district from grant funds. Some of those teaching science used lessons and activities that they modified for their students, and devised their own materials from their schools’ science departments or their own personal supply of science equipment.

Teachers using course lessons also used a variety of teaching strategies consistent with inquiry. In one case, two teachers from the same school were housed in very small, cramped rooms with more than thirty students in each room. In both cases, there was virtually no room for students to move other than to reach the door to the classroom. Hands-on inquiry science activities are
difficult to do under these conditions. In one of the classes, students went over a portion of a mathematical conversion exercise before starting the hands-on activity which was to build a model of an *Escherichia coli* bacterium to scale (the reason for the mathematical conversions). Under these conditions, once physically moving about became necessary for students to collect materials for their model, the situation in the classroom began to deteriorate. It was very difficult for the teacher to physically reach the students requiring help and students waiting for their teacher began to get off-task. In that instance, the teacher assigned a short passage from their textbooks so the reading could bring the class all to the same place in the lesson. Then the hands-on activities were started again. In the other classroom, using the same lesson, the teacher gave the students a written exercise with math conversions necessary for the students to understand the lesson and they did the first page together as a class. The teacher then asked the students to begin their *E. coli* model activity. If they ran into a problem, they were to work on the math sheet until he/she could get to them to help. As soon as any student began to get off-task, the teacher immediately reminded the class to work on the conversions. Both strategies worked. The lesson was a hard one. Mathematical conversions are something that students have trouble with and these seventh grade classes – one extremely crowded and the other crowded with a large population of special-needs students, proceeded through the lesson successfully and the students enjoyed the activity. This hands-on inquiry lesson was one that most middle school teachers would not attempt, yet these two teachers did just that. When they
were asked whether they would have tried a lesson like that if they had not taken
the course, their response was “Absolutely not!” They indicated that not only
would they not have thought of a lesson like that, they would never have tried it
had they not done it themselves in the Biology 1 class and seen how interesting
and adaptable it was for their students. There are additional benefits to taking
the Biology 1 class. In addition to learning more science content, the teachers
also received ideas for lessons and strategies for teaching that kind of inquiry
lesson.

Conclusions

Test Format

The use of both MC and CR test formats is recommended (Bennet et al.,
1991, Rodriguez, 2002, Thissen et al., 1989), but the CR grading process is
laborious. Both assessment types showed improvement, but the kinds of
information they yielded were different. For example, the CR test was
particularly useful for questions that dealt with processes: the teachers had to
explain the process of various DNA functions or they had to design an
experiment on a specific topic, or interpret data. The teachers got the chance to
explain something and they could receive partial credit if the answer was partially
correct. The MC questions were more useful to query about the product of a
particular process and for asking direct answer questions. Teachers either had
to know the material or know how to complete steps to get the answer. There
was no partial credit – if they did not get both questions of the paired question
sets correct, they received no points for that question pair. The pairing of the questions was an attempt to ask higher order questions that do cover processes, but even when well-written (which is difficult to do), the researcher is of the opinion that they do not test that kind of information as easily as CR questions do. To get a complete picture of just what the teachers did know and how they improved or did not improve, both assessment formats that covered the same material were used. The MC results indicated that the teachers knew information about several topics when the CR test indicated clearly that they did not. It could also be that they MC questions were not as well-written as originally thought.

**Content Knowledge**

The assessments for both classes showed an increase in content knowledge – even ten months after the end of the Biology 2 class. This could be due to a number of different aspects of the course and the instruction. Teachers may have learned and retained the information because the hands-on inquiry nature of the activities in the class helped them anchor the new information to that already learned. The fact that the instructors modeled inquiry techniques, used inquiry lessons, and required the teachers to really think about the material may have been a reason the teachers learned since inquiry has been shown to help with the learning of complex concepts. The follow-up course activities may have been helpful to the teachers. Aside from the pedagogical exercises, there were also activities to reinforce content material and clear up questions. These served to refresh memories and to anchor the concepts more firmly. The
teachers could have taught some of the content presented during the courses thereby reviewing it for themselves. Many of the teachers from both classes were teaching material about some of the topics covered in the biology courses. Some were teaching the same lessons (adjusted for the level of their students) they had themselves during the Biology class. The CD, the course manual and the many handouts could have been used as resources to review the material.

**The Nature of Science**

Understanding of the nature of science is a worldwide science educational goal (Science for All Americans, 1990). The teachers’ responses on the Biology 1 MC and CR indicated they did struggle with understanding the NOS. The MC assessment gave them the opportunity to identify the independent variable of an experiment. Twenty percent of them could not do that at the time of the pretest. That percentage did not change much until the follow-up test where it increased to 40%. Not all of the teachers were able to carry out a logical sequence of steps designed to answer a testable question, collect data and analyze it, and to make conclusions based on their data. Professional scientists have stated that employees entering the science work field lack basic science content knowledge, knowledge of the NOS, skills and useful techniques for investigative science, and the ability to use mathematical tools to help in their investigations (Hurd, 1997). The assessment results corroborate those findings.

On the CR test, teachers were required to design an experiment testing the respiration rate of an organism, write the hypothesis, and list the different
variables, controls, and steps of the experiment. At the time of the pretest, 50% of the class received zero points on this question. The post test and follow-up test showed improvement, but the fact still remains that fully one half of the teachers who had been teaching science for at least one year (and many for much longer), did not know very basic concepts concerning the NOS or science processes while they were teaching science. It was found (Crawford, 2005) that many teachers do not engage in scientific thinking and do not really understand the processes of science. What is more, people do not learn this kind of information with implicit teaching strategies (Abd-El-Khalick et al., 2004, Gess-Newsome et al, 1995). Information on the NOS must be taught explicitly for teachers and students to get the point. Abd-El-Khalick (1998) stated that teacher preparation programs should help prospective teachers understand the rationale behind and to comprehend the importance of the NOS. Contemporary science curriculum demands teacher knowledge of the NOS, and there are likely many experienced teachers who teach science, but lack a basic understanding of the NOS.

The classroom observations substantiated the assessment findings. The teachers did not teach about the NOS explicitly or otherwise, and the misconceptions about the NOS that were noted during the observations were all teacher-generated. Lederman’s (1999, 2003) work indicated that unless a teacher clearly addresses the NOS and follows through with explicit emphasis during their class instruction, students will not develop an understanding of the NOS. The teachers felt well-prepared to teach about the NOS, and they thought
that it was very important to do so; however, they did not. Abd-El Khalick et al. (1998) found that teachers do feel that it is important to teach about the NOS, but they greatly overestimate their teaching of this topic and many think if they model science processes or ask their students about it, then they are teaching it. The Biology 1 teachers did not seem to have NOS instruction as a teaching goal. Perhaps they also felt that by modeling strategies and engaging their students in inquiry activities they were teaching it. That is consistent with prior research.

An example of faulty science methodology was seen in an introductory laboratory exercise for the chemistry students to learn about variables. The experiment that the teacher set up had two variables being tested simultaneously. For an initial lesson on variables, that was confusing, especially when the teacher did not clarify that there were two variables. The controls were inadequate so when the data were collected, there was no way to determine which variable was responsible for the results. The teacher chose one variable to account for any differences in the outcome. This invalidated the entire lesson because it gave the students the idea that you can test for more than one variable simultaneously and choose a variable to account for or be responsible for the results. It also showed the researcher that the teacher was not knowledgeable about the NOS or science processes.

It is possible that the Biology 1 course instructors, even though they modeled inquiry methods, they did not teach the NOS as explicitly as was needed for the teachers to understand it.
Mathematics Abilities

These test data indicate a serious problem with middle school teachers' mathematics skills. Many teaching majors enter their programs with low levels of mathematical content knowledge. There is little mathematics training in their teacher certification programs with no opportunity to develop mathematics skills (Swackhamer, 2006). This discrepancy has not been addressed through teacher education programs or professional development opportunities (Schlang, 2006). The participating teachers did poorly on questions involving mathematics operations. Less than 50% of the teachers answered the proportion portion of the question correctly on the MC pretest (Q# 8), and even fewer than that did on the follow-up test. The second part of that question pair contained an identity (the relationship between a micrometer and a millimeter) and only three teachers knew the how to calculate this information on the pretest. This number improved considerably by the time of the post test, so the teachers were able to work out the relationship or memorize enough basic math identities to calculate what portion of a millimeter a micrometer was, but they were unable to use that information to complete the proportion part of the question relating to how many micrometers there were in 0.6 centimeters. Some of the teachers admitted that mathematics scared them and they were intimidated by situations in which they had to solve mathematical problems. Much of science research is based on quantitative data, and understanding how to interpret mathematical data is essential. It would appear from these data that middle school science teachers would benefit from an increased mathematics requirement for their teacher education.
certification to increase their mathematics skills and clear up misconceptions/errors (Carpenter et al., 2004).

Another finding from these CR assessments is that some of these science teachers have trouble understanding graphs. This skill is required at virtually all grade levels. A few teachers did not understand what the bars on a bar graph meant. A number of teachers did not understand a complex graph with y axes at each side of the graph labeled for different variables and the x axis labeled the same for both of the y variables (Appendix Q). Teachers must have the basic math skills to teach them to their students and not every teacher in this sample of teachers did.

The teachers did not grasp the significance and usefulness of the population equation - a tool for predicting future population figures from contemporary data. On the post test, some of them understood how to get the doubling time of a population, but only six of the teachers understood that the doubling time is not merely doubled, but used in calculations to determine how many times (or in how many years) the population must double to reach the outcome and multiplying the number of times it doubles by the number of years it takes to double.

**Teaching Strategies**

There were a few things noted from the classroom lesson observations that should be addressed. The teachers could have asked the students higher order questions. The teachers did wait for the students to answer the questions
they asked. Along with that skill, some teachers could have used questioning skills to help students resolve a misconception or figure out and answer to a question. This skill takes time to learn and some of the teachers had not been teaching for more than a year or two.

One criticism is that there were few connections or tie-ins with other sciences, math or real-world contexts. This can be a difficult challenge for teachers, but an important aspect of science is how different science, math, and other disciplines are interrelated. Science knowledge was not taught as being dynamic: that is one of the most important aspects of science knowledge – that what is known is continuously scrutinized, re-interpreted, and revised when additional data become available. That was not mentioned in classes.

The teachers did utilize many excellent teaching strategies in innovative ways. For example, one of the teachers was teaching his students about how to set up an investigation (science method). The students got very interested when they decided that the investigation would center around who could eat the most hot dogs. They could hardly wait to list the variables and set up the parameters of the investigation. This was something they could relate to. When the competition expanded to include the science class of another teacher in the Biology 1 class, the students were really excited. When the two teachers decided that they would compete for their classes and everyone was going to be able to eat some hot dogs, the students could hardly wait for the day of the investigation. That “lab” experience will likely be remembered for a long time – it was interesting, fun, academic and they got to eat as well.
Overview

This study found that middle school science teachers with varied academic backgrounds sparse or lacking in science coursework can learn high level science content as a result of an intensive two-week inquiry science content class with an appropriate follow-up course and support. Based on assessment scores, significant content learning can take place in a two-week time period. The Biology 1 and 2 classes did not only offer high level content information, but also labs and activities to help anchor the information in the teachers’ minds and to clarify science concepts. This study found that this format for professional development (two-week intensive course with semester-long follow-up) is successful for teacher learning of science content and can be a stimulus for implementing changes in teachers’ classroom behaviors.

The teaching strategies modeled in the course along with activities and other hand-outs given to the teachers may have had an effect on teaching behaviors in the classroom (there was no baseline or classroom observation done before the Biology 1 class began). The teachers were able to design or revise labs into inquiry learning experiences that were interesting to their students. They had the added benefit of new and different and exciting laboratory equipment and supplies of the type that scientists use that was donated by the RM-MSMSP grant.

Teachers were able to note student misconceptions/errors in class, but found it hard to be aware of their own. This study identified some major misconceptions/errors from the teachers’ classes; many of which have been
noted in the literature (Appendices R and S). While some of them appeared to have been resolved, not all of them were.

**Recommendations**

Since the test results of the course showed significant learning on the part of the teachers, it is recommended that these courses continue to be offered to middle school teachers who do not have a strong science background or took their prerequisite science classes many years ago. The teachers were enthusiastic, positive about the courses and the observations, and they worked hard on the projects and other class requirements. The final projects they delivered in the follow-up classes were of very high quality and must have taken a considerable amount of time to prepare. Generally teachers do not have a lot of extra time to do that kind of thing, but these teachers did a great job.

These two classes filled a very real teacher need. Even though there were some teachers who did not retain the science knowledge at a high level, they felt that by doing scientific process activities that link concepts together for better understanding of an overall unit, they did get a lot out of the classes. Many teachers expressed interest in taking more classes of this type – intensive content and teaching pedagogy courses with reinforcement and more content/pedagogy follow-up classes.

Since the teachers did have a lot of difficulty with the NOS and science processes, it might be useful to develop a course solely on methods of science. A course where the teachers do basic science activities from learning how to ask
a testable question, design appropriate controls, state hypotheses, collect data and put it in a useable form, analyze and draw conclusions from the data, present and discuss their results with other members of the class, critique their own and others work and propose future research work might be immensely helpful to science teachers – not just middle school, but all levels of science teachers. Lawson and other educational researchers also advocated for a course like this (Lawson, 2002, Trowbridge, 2000) to help teachers understand the nature of science better and to see how science really is done. Luft et al. (2007) and Zembal-Saul (2002) both feel that with proper training in content and technology-rich courses taught by inquiry methods, teachers can become effective science teachers who can translate content into learning activities that result in student understanding.

Information obtained from data collected from course assessments, observations and discussions with the teachers point to some specific needs.

**Recommendations for Biology 1 Course**

Emphasis on explicit teaching of the NOS

Research has shown that teachers are ignorant about the NOS and that the NOS cannot be inferred – it must be taught explicitly. The Biology 1 course instructors must take this into account and teach this information with activities or teaching specifically about the NOS. The teachers may not be aware of their deficiencies in this area and they do not have teaching strategies to teach this information to their students. An unexpected result of this study was the inability
of the teachers to correctly design an experiment with knowledge of independent and dependent variables, the proper controls, appropriate data collection plans, or carry out other science method processes even after the course was over. The researchers feel they would benefit from more explicit information.

Topic and activity refinement

Activities associated with photosynthesis and respiration need to be refined. The teachers did not truly learn this information. One difficulty the researcher (as one of the instructors) found with these activities is that there is a shortage of experiments that really work well, that do not require expensive equipment, and that can fit into a teaching schedule. The concepts are very difficult to understand and if the teachers have no background in biology or chemistry they may have trouble understanding this information. When one fourth of the class neglects to mention chloroplasts or chlorophyll in a constructed response on photosynthesis, then it can be inferred that they did not understand the material.

Reduce DNA/forensics information

The information on DNA was fascinating to the teachers, but there was so much of it in such a short period of time that the teachers became overwhelmed. It may be that the amount of information should be limited with some saved to teach during the follow-up course. Test results indicate that the teachers did not retain a lot of the information about transcription and translation, but if they had
received even more additional instruction during the follow-up class to reinforce their newly acquired knowledge, then their retention might have been better.

Retool MC and CR assessments

The assessments need to be fine-tuned so they are more appropriate for the teachers. Several of the MC questions on the Biology 1 test need to be adjusted so they are better stated and do not lead the teachers toward the incorrect answer. Some of the CR test questions need to be changed as well so they are more specific.

Recommendations for the Biology 2 course

Reduce number of activities

One of the main criticisms of this course was too many concepts and activities were scheduled in the two week course and there was not enough time to fully appreciate the activities associated with the concepts. There was not enough follow-up with specific activities like the stream collections or the duckweed experiment. The teachers were very interested in them, but the class did not come together to discuss and compare their findings and what they mean because another activity was started before they had time to make sense of the one they were working on.
Retool Assessments

This was the first time the Biology 2 course had been taught, so there were some problems. Teachers were aware of that and took the problems in stride. One thing that needs to happen is to refine both the Biology 2 MC and CR tests - specifically the questions that require graphing or interpretations of graphs. From the assessments, it would appear that the teachers could not graph or understand the graphs. However, they had several graphing exercises to do in the course (the Paramecium/Daphnia experiment and the duckweed growth experiment) on which they did well. Perhaps the way the questions were presented on the test needs to be changed to read more clearly.

The researcher’s opinion is that certain activities such as dissection of the owl pellets, the Paramecium/Daphnia lab, the comparison of skulls, and some of the field trips should be kept as activities because they were of high interest to the teachers and could be easily modified for different levels of students at the middle school level.

Future Research

This study was limited with only two classes and a total of 41 participating teachers. Future research should include gathering more data a larger number of teachers, using a single, final version of the two tests, and using follow-up class activities based directly on the results of the summer course pre- and post tests (tailored to each class based on content need). If the same assessments
are used each year for the summer courses, then more data extensive data would be available for higher level statistical analyses to yield more information.

Coursework background, years of teaching science, which science subjects the teachers taught, and other data could be analyzed to see if there is any effect of these kinds of traits on the abilities of the teachers to learn and retain the content material. Even though there were a small number of total participants in the two biology classes, it was noted that their science content backgrounds were not the only thing that influenced how well the teachers did in the course because some of the teachers with no science background at all had the greatest increase on the CR assessments. Johnson et al. (1998) and Lawson (1992) found that factors like reasoning ability are more important for learning that the number of courses taken in a specific area. Refinement of the teacher questionnaire would allow for accurate information which could be used to see which factors affect learning.

**Limitations**

**Weaknesses**

The major weakness of this study was the small number of subjects participating. Twenty of the 21 teachers in Biology 1 course and 20 of the 23 teachers in the Biology 2 course were included in the study. It would have been better to have at least 100 teachers for each course, but that was not possible. A problem with small numbers is that one or two teachers can greatly affect results, but those teachers may not be an accurate reflection of the science teacher...
population as a whole. This problem showed up numerous times when data were being analyzed – data from one or two teachers influenced trends (positive or negative). This observation may also indicate that these results may not be generalizable – the teachers in this study show these results, but do these results apply to other groups of teachers? A higher number of participants would also allow for the use of different statistics to analyze the data. A factor analysis might be really revealing, but with only 20 to 21 teachers in a class, it would not be appropriate for use.

Another problem with this study is that the assessment instruments were not tested before use. There was no opportunity for these instruments to be given a “dry run” before their use. Frequently, testing with a sample population is part of the validation of the documents. As that was not possible, validation was done by science and education faculty comments and suggestions for improvement after reading the assessments through and looking at an evaluation matrix. There were a number of changes that needed to be made that were apparent immediately after the administration of the pretest. For example, one of the questions on the Biology 1 CR test asked teachers to design an experiment to be conducted at ambient temperatures. A number of teachers did not know what “ambient” meant. The researcher assumed that everyone would know that term and that was not the case.

The population of teachers was not a random sample. They had to be teaching in specific districts, they were teaching in urban and suburban schools, not all of them were science teachers or had a science background, and a
A generous stipend was allotted to teachers who completed both the course and the follow-up class and that may have been a motivating factor for some of the teachers to take either biology course.

Another weakness of this study is that the researcher not only wrote and administered the assessments, but also graded them. It would have been more appropriate if instructors not involved with the writing of the test had graded them or if several graders compared their grading to see if they did it the same way as the author of the assessments.

Another problem related to survey data collect on teacher academic background. The plan was to look at whether their academic background had any effect of their course assessments. The teacher questionnaire was used to collect a lot of information, but unfortunately some of the most important pieces of data were unable to be used due to difficulties in operationalizing it. Data collected on the coursework background of the teachers were not used because the course hours in elementary education classes and secondary science classes could not be directly compared. The way the course hours are assigned is very different between institutions and between different departments within institutions. These comparisons and the effect of the teachers’ coursework backgrounds could have been compared had it been a course requirement that teachers submit accurate records of their science and mathematics coursework.
**Strengths**

The MC portions of the assessments were anonymous. The reason this was considered to be a strength is that teachers knew what their scores were, but the course instructors did not. The teachers were not stressed by their MC assessment scores because they were not factored into course grades. They could chart their own progress while the course instructors could chart individuals’ progress, but they did not know to which individuals the MC grades belonged.

Another strength in the design was that the teachers were tested by MC and CR test formats. Teachers scored better on the CR tests where they could receive partial credit for their responses. Since both formats were used, the results could be corroborated or compared, although direct comparison student by student was not possible since the MC portions of the test were anonymous. If the class scored low on certain topics of the MC assessment and also scored low on the CR portion of the assessment over the same material (on the post test or the follow-up test), then there would be evidence either that the teachers did not know or understand that particular material and the course instructors could revisit some of the material. There is also the possibility that the MC test questions were not good questions if a majority of the teachers got them wrong.

The choice of a Repeated Measures ANOVA statistic for this research is a strength in that it is a within subjects design which is more powerful since individual differences can be eliminated or at least reduced as a source of between group differences.
A strength is that the researcher who designed the tests was also the one who graded the assessments. This allowed for consistency in grading. The pretest and post test were read and graded more than once so that there would be consistency in grading not only between teachers but also between the times of the test administration. By the time the follow-up test was given (especially ten months later for the Biology 2 course), the researcher felt it was necessary to read through the tests again the make sure the teachers were graded the same way on the final assessment as they were on the pretest.

Another strength was the teacher interviews. They were good sources of information - there were no specific questions that were asked of each teacher; each interview was based on what was seen during the presentation of the lessons. A few of the interviews were thirty minutes or so, but most were longer and many lasted over an hour depending on how many points there were to discuss and if the teacher wanted any additional help with planning activities. The researcher felt that the teachers trusted her and they confided additional information that helped her see their actions in a more insightful way. The teachers' trust enabled the researcher to clarify some of the statements they had made during the lesson presentation in a non-threatening way. The researcher noted that nearly all teachers had gone to a lot of effort to teach very good lessons for the observations.

A final strength of this study is that the researcher was one of the instructors and was also the person who conducted the classroom observations and teacher interviews. As part of a team of instructors, the researcher knew
exactly what was taught and done in class, had a good rapport with the teachers, and became close to the teachers. The teachers trusted the researcher and they knew that the researcher was not there to be critical, but to make careful observations that could be useful to them. During the interviews that followed the observations, most teachers remarked that the observations/interviews had been an enjoyable and helpful experience and they were glad they had taken the Biology 1 course and the follow-up class. Ways in which the observations and interviews had been helpful for the teachers were:

1. they were required to prepare a series of good inquiry lessons over content they were teaching which they could use in the future,
2. they made them think carefully about not only what to teach, but how to best teach it,
3. they made them think about inquiry teaching in general and how inquiry lessons could be used in their classes,
4. compelled them to put hands-on and other inquiry activities into their teaching,
5. they made them happy with the outcome of their lessons so they were more motivated to spend some time planning inquiry lessons
6. they made them think about misconceptions – their students’ misconceptions or their own,
7. they became more aware of how insidious alternate conceptions were and were surprised that they themselves had some
8. they provided an opportunity for the teachers to use high-interest science equipment in their classes.

The literature supports the idea that teachers can learn information from professional development opportunities, but are more likely to retain it when
there is some follow-up action or support on the part of the course instructors (James, 2002, Supovitz et al, 2000). Coursework lasting at least 60 to 80 hours along with additional support results in better knowledge retention of the participants. The results of this study support those findings. The Biology 1 and 2 classes lasted 6 hours and the Biology 1 follow-up class added another 32 hours. The Biology 1 course also had another three to eight hours for observations which brought the total number of hours to about 95 to 100 hours. This amount of PD along with other factors was enough to positively influence the way in which these teachers teach.

James (2002) found two reasons that teachers gave for their continued use of what they learned in PD workshops on inquiry: materials were provided to them, and continued support from workshop or course instructors for at least one semester. The Biology 1 course provided both of these to the teachers by supplying each district taking part in the study with a set of materials to do the experiments that were done in the Biology 1 class and by scheduling the follow-up course with the observations. This was to motivate the teachers to design some inquiry lessons using materials of high students interest and to continue using and refining them.

Bias

A possible source of bias was that all of the course assessments, questionnaires, and protocols were designed, administered, and graded by the researcher. However, the assessments needed to cover the high level course
content material, they needed to include science process skills, and they had to be accurate on science information. The researcher was an experienced teacher (middle school, high school, and college teaching) and had helped teach the Biology 1 course before.

The observations were also completed by the researcher and that provided an arena for bias. It was difficult after knowing and working with each of the teachers to be evaluating them personally. Effort at objectivity was made and not every teacher received top scores for their lessons. However, the observation criteria were written very specifically, so that it would be easy to note the strengths and weaknesses of the presentations (and Implications


Baum, D. A., Smith, Stacy DeWitt, Donovan, Samuel S. (2005). “Supporting Online Material for the Tree-Thinking Challenge, American Association for the Advancement of Science. [www.sciencemag.org/cgi/content/full/310/5750/979/DC1](http://www.sciencemag.org/cgi/content/full/310/5750/979/DC1)


APPENDICES

Appendix A  Summary of national recommendations for education:

1. Education in the sciences should harmonize with life as lived in the real world. Currently students experience their world only after the final bell for the school day has rung.

2. Curricula need to be invented that represent the strategic nature or mission-oriented research of contemporary science. The traditional discipline-bound, science career-oriented courses are too narrow in scope to serve as a base for a citizen's education in the sciences.

3. The educational process for today's knowledge-intensive society needs to begin soon after birth. Goal 1 of the National Education Goals Panel states that children should enter school ready to learn. The family and community bear this responsibility, assisted by schools.

4. An education in the sciences should be in terms of the fulfillment of life, interconnecting the sciences, technology, society, economy, individual development, quality of life, and civic responsibilities. Most current science curricula consist of a chain of facts from page one to the last page of a textbook and fail to meet the educational demands of our changing culture in either purpose or subject matter.

5. Science in the context of life and living recognizes the biological and social developmental levels of individuals from birth throughout life, the reform is focused on making science more productive in the life of students.

6. Congress, in establishing science and technology as an integral part of our democratic society, makes enculturation a new purpose for the teaching of science.
7. School science curricula should be organized in terms of problems that connect science/technology with self, community, society, and the future. This is a curriculum beyond the limitations of traditional disciplines and represents the new civic dimension of science education in helping shape the nation’s social and economic policies.

8. A “science-for-all” context includes a focus on the preparation of all citizens for jobs in our knowledge-intensive world. Today the economic worth of individuals depends upon their ability to acquire, process, and utilize information in different ways. These abilities are different from the traditional concepts of vocational education. Increasingly today, non-knowledgeable persons are being replaced by robots.

9. Social inquiry supplements scientific inquiry in importance as a goal for science teaching. Scientific inquiry is discipline-bound and has little use beyond the classroom. Social inquiry is a process of utilizing science concepts for resolving personal, social, and economic actions. Beyond the laboratory, science concepts take on a different meaning.

10. Laboratory work in the framework of the national science goals is seen as an experience in citizenship. The problems selected for study typically require teamwork characteristic of most scientific research today. Team study of a problem requires developing communication skills essential not only for work, but also for fully participating in a democracy. A modern perception of the science laboratory is that it has no intellectual walls.

11. In science education a perspective of the future is seen as essential not for predicting the future, but for shaping it. This approach is in accord with the way strategic research in the sciences is oriented. The effort is to develop a science curriculum characteristic of the world in which the student lives.

12. To achieve an education in the sciences to meet national goals will require a large measure a national curriculum framework. A central purpose of this curriculum is a citizen’s understanding of a science and technology-oriented culture and democracy.
13. A national science curriculum framework is viewed as an integrated core subject representing the interdisciplinary nature and blending of contemporary research in the sciences. It would vary in emphasis with the developmental level of the student, changes in the practice of science/technology, and current socioeconomic conditions. Science as a core subject is also viewed as a way of connecting the natural sciences to the humanities and social sciences.

14. The nature of knowledge and its relationship to ways of knowing and understanding is still being debated. There is agreement that the goal should be the ability to utilize science knowledge appropriately in resolving problems associated with human welfare and the common good.

15. The assessment of learning would focus on the student’s ability to manage science knowledge in terms of problems and issues one is likely to encounter throughout life. The extent to which science knowledge is usable in everyday affairs is a measure of human capital. By the year 2020 it is expected that almost all the knowledge ever discovered will be available to anyone who knows how to identify, access, process, and utilize the information.

16. National reports on science education stress that it is the quality of science curricula that counts. Quality is defined as a contemporary view of science/technology in terms of its meaning for the welfare of individuals and the social and economic progress of the nation. The National Research Council (1979) asserts that the critical goal of science education is “knowledge useful for one’s own well-being and knowledge useful for good citizenship.”

17. The National Science Foundation notes that current school science education seems to lack a sense of direction, theory, and philosophy that would provide guidance to curriculum development and instruction. What students should learn also remains unclear.
18. Science/technology in personal and civic contexts requires special ways of thinking, recognized as higher order thinking skills. To achieve this goal requires that student be able to distinguish evidence from propaganda, probability from certainty, relevant questions from pseudo-questions, rational beliefs from superstitions, data from assertions, science from myth and folklore, credibility from incredibility, sense from nonsense, fact from fiction, and theory from dogma. Higher order thinking skills are related to the optimal use of science knowledge in personal and social contexts. Higher order thinking skills are qualitative in nature, in contrast to the notion of scientific inquiry, which is quantitative and discipline bound.

19. The proposed view of school matches the natures of contemporary science, with its emphasis on strategic research, designed from the onset to benefit human well-being or social or economic progress. About 75% of the research in the sciences is now identified as strategic or mission-oriented research. In terms of science education, the trend is also described as relating science to the real life or real world of the student. In this context, the student is the curriculum. What is sought is a curriculum that can be experienced and lived by the learner for life in a changing world.

20. Over the past several decades and continuing is the development of the cognitive sciences. Cognitive scientists investigate how human beings learn, remember, and utilize knowledge. What interests the cognitive scientist is a view of how to foster an understanding of science and the optimal utilization of this knowledge in the context of science and society. It has long been recognized that major outcome of conventional science courses has been that of forgetting. Now that knowledge has become the basis of one’s economic success in life, a measure of one’s social capacity, and the principal treasure of our civilization, learning in the sciences takes on new meaning. Some biologists view the birth of a knowledge-intensive society and its influence on human adaptive capacities as making a new phase in
human evolution, a move toward Homo sapiens sapiens, the product of
cognitive adaptive capacities.

21. In an ever-changing knowledge-intensive world, the human mind must constantly be refueled with new information of the proper sort. A National Research Council report in 1978 points out the difficulties of relating knowledge developed in the natural sciences with that produced in the social sciences. The report deplores the “sluggishness” of discussion on this issue. A modern education in the sciences is seen as one that helps connect students with the natural world, the culture, work, society, and most of all, oneself. All of these factors are interconnected in various ways.

22. New assessment and testing practices will be required to harmonize with the new goals and modes of thinking proposed for modern science curricula. Traditionally, tests have been used to determine a student’s reservoir of information on a topic. All students take the same test. Grading is a matter of determining winners and losers at a cutoff at some percentage of right answers. Assessments being sought for the modern curricula are those which recognize every student as a variable. The purposes of the new tests are to indicate the capacity of a student to utilize what has been learned in ways appropriate for responsible living in a knowledge-intensive society.

23. The starting point for a reform of science education should be a study of students and the problems they are facing in this transition period to a new culture. Youths and family structures today are different from those of a generation ago. More live in poverty, more are homeless, more commit suicide, more lack the benefit of health care, and more are having difficulty adapting to a changing society and understanding the changing world of work and themselves.

24. Throughout all topics in science courses there should be the concept of change. The sciences are dynamic fields of study with an “endless frontier”. Students are misinformed when they do not recognize that the topic they are studying today is likely to be different tomorrow. Contrast your knowledge of
the universe before the Hubble Telescope with you knowledge of astronomy today. A primary purpose of science education has become one of connecting students to a changing world.

25. The tone of national efforts for the reform of science education is an integration of science with other school subjects in ways that will increase opportunities for critical thinking and social interaction. The ultimate goal is to expand the interdisciplinary characteristics of contemporary science/technology with social and economic development in ways that recognize that the wealth of a nation and of an individual today are determined by usable knowledge. Current science curricula are mostly a dead end in this context.

26. The National Education Goals Panel sees the need to coordinate all community agencies and others who have a concern for science education (Hurd, 1997).
Appendix B  Guiding principles of constructivist thinking

1. Learning is an active process in which the learner uses sensory input and constructs meaning out of it.

2. People learn to learn as they learn: learning consists both of constructing meaning and constructing systems of meaning.

3. The crucial action of constructing meaning is mental: it happens in the mind. Learning activities must engage the mind as well as the hands.

4. Learning involves language: the language we use influences learning.

5. Learning is a social activity: our learning is intimately associated with our connection with other human beings, our teachers, our peers, our family as well as casual acquaintances.

6. Learning is contextual: we do not learn isolated facts and theories in some abstract ethereal land of the mind separate from the rest of our lives. We learn in relationship to what else we know.

7. One needs knowledge to learn: it is not possible to assimilate new knowledge without having some structure developed from previous knowledge to build on.

8. It takes time to learn: learning is not instantaneous. For significant learning we need to revisit ideas, ponder them, try them out play with them and use them.

9. Motivation is a key component in learning – it is essential. Unless we know the reasons why, we may not be motivated to learn.
Appendix C  Postulates of Modern Learning Cycle Theory

1. Children and adolescents construct personal beliefs about natural phenomena, some of which differ from currently accepted scientific theory.

2. These alternative beliefs (misconceptions) may be instruction resistant impediments to the construction of scientifically accepted beliefs (conceptions).

3. The replacement of alternative beliefs requires students to move through a phase in which a mismatch exists between the implications of the alternative belief and the scientific conception and provokes a “cognitive conflict” or state of mental “disequilibrium.”

4. The improvement of reasoning patterns (procedural knowledge) arises from situations in which students state alternative beliefs and engage in verbal exchanges where arguments are advanced and evidence is sought to resolve the contradiction.

5. Argumentation provides experiences from which particular forms of argumentation (i.e., patterns of reasoning may be internalized).

6. The learning cycle, a method of instruction consistent with the way people spontaneously construct knowledge, provides the opportunity for students to reveal alternative beliefs and the opportunity to argue and test them, thus become “disequilibrated” and acquire more adequate conceptions as well as more powerful and effective reasoning patterns.

Lawson defines the learning cycle as:

- **Exploration** = allows students to investigate new materials and/or ideas so that patterns of regularity can be discovered and questions are raised that students attempt answer.

- **Term introduction** = allows the teacher to introduce terms to label the patterns and to explain the newly invented concepts

- **Concept application** = provokes students to seek the patterns elsewhere and to apply the new concepts to additional examples, often employing abstraction or generalization techniques.
Research has supported the effectiveness of the learning cycle in encouraging students to think creatively and critically. As well as in facilitating a better understanding of scientific concepts, developing positive attitudes toward science, improving science process skills, and cultivating advanced reasoning skills (Lawson, 1995).
## Appendix D  The BSCS Version of Learning Cycle Instruction

<table>
<thead>
<tr>
<th>Phase</th>
<th>Teacher</th>
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| **Engage** | Creates interest  
Generates curiosity  
Raises questions  
Elicits responses that uncover what the students know or think about the concept |
| **Explore** | Encourages students to work together without direct instruction from teacher  
Observes and listens to the students as they interact  
Asks probing questions to redirect students’ investigations when necessary  
Provides time for students to puzzle through problems  
Acts as a consultant for students |
| **Explain** | Encourages students to explain concepts and definitions in own words  
Asks for justification (evidence) and clarification from students  
Formally provides definitions, explanations, and new labels  
Uses students’ previous experiences as basis for explaining concepts |
| **Elaborate** | Expects students to use formal labels, definitions, and explanations provided previously  
Encourages the students to apply or extend the concepts and skills in new situations  
Refers students to existing data and evidence and questions them about what they think and know |
| **Evaluate** | Observes students as they apply new concepts and skills  
Assesses students’ knowledge and/or skills  
Looks for evidence that the students have changed their thinking or behaviors  
Allows students to assess their own learning and group-process skills  
Asks open-ended questions about their thinking, evidence, explanations, etc. |
Phase  | Student
--- | ---
**Engage** | Asks questions about why did things happen, what they already know, how can they find out more
| Show interest in the topic
**Explore** | Think freely, but within the limits of the activity
| Tests predictions and hypotheses
| Forms new predictions and hypotheses
| Tries alternative sand discusses them
| Records observations and ideas
| Suspends judgment
**Explain** | Explains possible solutions or answers to others
| Listens critically to others’ explanations
| Questions others’ explanations
| Listens to and tries to comprehend explanations offered by teacher
| Refers to previous activities
| Uses recorded observations in explanations
**Elaborate** | Applies new labels, definitions, explanations, and skills in new, but similar situations
| Uses previous information to ask questions, propose solutions, make decisions, design experiments
| Draws reasonable conclusions from evidence
| Records observations and explanations
| Checks for understanding among peers
**Evaluate** | Answers open-ended questions by using observations, evidence, and previously accepted explanations
| Demonstrates an understanding or knowledge of the concept or skill
| Evaluates his or her own progress and knowledge
| Asks related questions that would encourage future investigations (Lawson, 2002)
Appendix E  Teacher Role Consistent/Inconsistent with BSCS Model

<table>
<thead>
<tr>
<th>Consistent with Model</th>
<th>Inconsistent with Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engage</strong></td>
<td></td>
</tr>
<tr>
<td>● Creates interest</td>
<td>● Explains concepts</td>
</tr>
<tr>
<td>● Generates curiosity</td>
<td>● Provides definitions/answers</td>
</tr>
<tr>
<td>● Raises questions</td>
<td>● States conclusions</td>
</tr>
<tr>
<td>● Elicits responses to see what students know/think about concept</td>
<td>● Provides closure</td>
</tr>
<tr>
<td></td>
<td>● Lectures</td>
</tr>
<tr>
<td><strong>Explore</strong></td>
<td></td>
</tr>
<tr>
<td>● Encourages students to work together without direct instruction from teacher</td>
<td>● Provides answers</td>
</tr>
<tr>
<td>● Observes and listens to the students as they interact</td>
<td>● Tells or explains how to work through problems</td>
</tr>
<tr>
<td>● Asks probing questions to redirect students’ investigations when necessary</td>
<td>● Provides closure</td>
</tr>
<tr>
<td>● Provides time for students to puzzle through problems</td>
<td>● Tells students they are wrong</td>
</tr>
<tr>
<td>● Acts as a consultant for students</td>
<td>● Gives information or facts that solve problems</td>
</tr>
<tr>
<td></td>
<td>● Leads students step by step to a solution</td>
</tr>
<tr>
<td><strong>Explain</strong></td>
<td></td>
</tr>
<tr>
<td>● Encourages students to explain concepts and definitions in own words</td>
<td>● Accepts explanations that have no justification</td>
</tr>
<tr>
<td>● Asks for justification (evidence) and clarification from students</td>
<td>● Does not solicit students’ explanations</td>
</tr>
<tr>
<td>● Formally provides definitions, explanations, and new labels</td>
<td>● Introduces unrelated concepts or skills</td>
</tr>
<tr>
<td>● Uses students’ previous experiences as basis for explaining concepts</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Elaborate</strong></td>
<td></td>
</tr>
<tr>
<td>● Expects students to use formal labels, definitions, and explanations</td>
<td>● Provides definitive answers</td>
</tr>
<tr>
<td>● Encourages the students to apply or extend the concepts and skills in new situations</td>
<td>● Tells students they are wrong</td>
</tr>
<tr>
<td>● Refers students to existing data and evidence and questions them about what</td>
<td>● Lectures</td>
</tr>
<tr>
<td></td>
<td>● Leads students step by step to a solution</td>
</tr>
<tr>
<td></td>
<td>● Explains how to work through problems</td>
</tr>
</tbody>
</table>
they think and know

Evaluate
- Observes students as they apply new concepts and skills
- Assesses students' knowledge and/or skills
- Looks for evidence that the students have changed their thinking or behaviors
- Allows students to assess their own learning and group-process skills
- Asks open-ended questions about their thinking, evidence, explanations

- Tests vocabulary words, terms, and isolated facts
- Introduces new ideas/concepts
- Creates ambiguity
- Promotes open-ended discussion unrelated to concepts
Appendix F  Myths about Science Education

1. It is easy to change one’s instructional pattern from a current instructional model to a reform-based practice.
2. Students that participate in laboratory investigations will construct their own knowledge about emphasized concepts.
3. Students learn important concepts through well-planned inquiry-based investigations, activities, or laboratories which require minimal teacher assistance.
4. Students will understand the nature of science and develop good habits of mind as they proceed through classroom investigations in which they observe phenomena, collect and analyze data, and draw conclusions.
5. The standard summative science assessment measures student competency (Luft, 1999).

Appendix G  Ten Myths of Science

1. Hypotheses become theories which become laws.
2. A hypothesis is an educated guess.
3. A general and universal scientific method exists.
4. Evidence accumulated carefully will result in sure knowledge.
5. Science and its methods provide absolute proof.
6. Science is more procedural than creative.
7. Science and its methods can answer all questions.
8. Scientists are particularly objective.
9. Experiments are the principal route to scientific knowledge.
10. All work in science is reviewed to keep the process honest (McComas, 1996).
Appendix H  Twenty-two Propositional Knowledge Statements

These are required for understanding diffusion/osmosis at freshman level.

1. All particles are in constant motion.
6. Diffusion involves the movement of particles.
7. Diffusion results from the random motion and/or collision of particles (ions or molecules).
8. Diffusion is the net movement of particles as a result of a concentration gradient.
9. Concentration is the number of particles per unit volume.
10. Concentration gradient is a difference in concentration of a substance across a space.
11. Diffusion is the net movement of particles from an area of high concentration to one of low concentration.
12. Diffusion continues until the particles become uniformly distributed in the medium in which they are dissolved.
13. Diffusion rate increases as temperature increases.
14. Temperature increases motion and/or particle collisions.
15. Diffusion rate increases as the concentration gradient increases.
16. Increased concentration increases particle collisions.
17. Diffusion occurs in living and nonliving systems.
18. Osmosis is the diffusion of water across a semi-permeable membrane.
19. Tonicity refers to the relative concentration of particles on either side of a semi-permeable membrane.
20. A hypotonic solution has fewer dissolved particles relative to the other side of the membrane.
21. A hypertonic solution has more dissolved particles relative to the other side of the membrane.
22. An isotonic solution has an equal number of dissolved particles on both sides of the membrane.
23. Osmosis is the net movement of water (solvent) across a semi-permeable membrane from a hypotonic solution to a hypertonic solution.

24. Osmosis occurs in living and nonliving systems.

25. A semi-permeable membrane is a membrane that selectively allows the movement of some substances across the membrane while blocking the movement of others.

Appendix I Teacher Survey

Please fill out these pages concerning your education and teaching experience.

1. Are you: Female _______ Male _______

2. How many years have you taught prior to this school year? ________

3. When did you last complete a science course for college credit?
   In the last 5 yrs _____ 6-10 yrs ago _____ 11-20 yrs ago _____ More than 20 _____

4. Do you have the following degrees?
   Bachelors _____ Subject your degree is in _____________ Year ______
   Masters _____ Subject your degree is in _____________ Year ______
   Doctorate _____ Subject your degree is in _____________ Year ______

5. Are you currently working towards a science degree? _________

6. Are you highly qualified in science? _____________

7. Have you ever worked in a science field other than teaching? _____
   Which field? ___________________ What type of job? ________________

8. Which of the following courses have you taught in the last 3 years?
   _____ Life Science/Biology       _____ Physical Science
   _____ Advanced Biology          _____ Physics
   _____ Earth/Space Science       _____ Advanced Physics
   _____ Chemistry                _____ Integrated Science
   _____ Advanced Chemistry        _____ Environmental Science
   _____ Technology Education      _____ Other

9. Student Demographics:
   Number of students in class ______
   Number of students for whom English is not their first language _____
   Number of students with learning disabilities _____
   Number of students with other special needs _____

10. Describe the ability level of students in this class:
    a. Represent the lower range of abilities _____
    b. Represent the middle range of abilities _____
    c. Represent the higher range of abilities _____
    d. Represent a broad range of abilities _____
11. For each of the following subjects, please indicate the a) number of semesters of college coursework you have completed, and b) whether you are certified to teach it at the secondary level.

### EDUCATION
- General methods of teaching ______
- Methods of teaching science ______
- Instructional uses of computers ______
- Supervised student teaching in ______
- Science ______
- Other ______
- # of hours in Ed ______

### EARTH/SPACE SCIENCES
- Introductory earth science____
- Astronomy _____
- Geology _____
- Meteorology _____
- Oceanography _____
- Other ____________________
- # of hours in Earth Sci ______

### MATHEMATICS
- College algebra ______
- Trig/Elementary functions _____
- Calculus____
- Differential Equations ______
- Discrete mathematics _____
- Probability/statistics _____
- Other ____________________
- # of hours in Math ______

### LIFE SCIENCES
- Introductory biology _____
- Botany, plant physiology _____
- Cell biology _____
- Ecology ______
- Entomology _____
- Genetics, evolution _____
- Microbiology _____
- Anatomy, physiology _____
- Zoology, animal behavior _____
- Other ____________________
- # of hours in Life Sci ______

### CHEMISTRY
- General introductory chemistry ____
- Analytical chemistry _____
- Organic chemistry _____
- Physical chemistry _____
- Biochemistry _____
- Other ____________________
- # of hrs in Chem ______

### PHYSICS
- Physical science____
- General/introductory physics _____
- Electricity and magnetism _____
- Heat and thermodynamics _____
- Mechanics _____
- Modern/quantum physics _____
- Optics _____
- Other physics _____
- # of hrs in Physics ______
12. Within science, many teachers feel better prepared to teach some topics than others. How well-prepared do you feel to teach each of the following topics at the grade levels you teach, whether or not they are currently included in your curriculum?

<table>
<thead>
<tr>
<th>Subject</th>
<th>Not adequately prepared</th>
<th>Somewhat prepared</th>
<th>Fairly well-prepared</th>
<th>Very well-prepared</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Biology</td>
<td>Cell biology</td>
<td>Structure and function of human systems</td>
<td>Cell respiration</td>
<td>Plant biology (structure and function)</td>
</tr>
<tr>
<td>2 Chemistry</td>
<td>Structure of matter and chemical bonding</td>
<td>Properties and states of matter</td>
<td>Chemical reactions</td>
<td>pH; acids and bases</td>
</tr>
<tr>
<td>3 Environmental and ecology issues</td>
<td>Water pollution</td>
<td>Global warming and environmental effects</td>
<td>Population, food supply, and production</td>
<td>Mutation and natural selection</td>
</tr>
<tr>
<td>4 Scientific methods and inquiry skills</td>
<td>Science process skills</td>
<td>Use math formulas to solve problems</td>
<td>Understand how to do metric conversions</td>
<td>Qualitative and quantitative observations</td>
</tr>
</tbody>
</table>
13. Importance. Please rate the following in terms of its importance for effective science instruction in the grades you teach.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Provide concrete experience before abstract concepts</td>
</tr>
<tr>
<td>B</td>
<td>Develop students’ conceptual understanding of science</td>
</tr>
<tr>
<td>C</td>
<td>Use guided inquiry to help students learn</td>
</tr>
<tr>
<td>D</td>
<td>Take students’ prior understanding into account when planning curriculum and instruction</td>
</tr>
<tr>
<td>E</td>
<td>Engage students in applications of science in a variety of contexts</td>
</tr>
<tr>
<td>F</td>
<td>Listen/ask questions as students work in order to gauge their understanding</td>
</tr>
<tr>
<td>G</td>
<td>Have students prepare project/laboratory research reports</td>
</tr>
<tr>
<td>H</td>
<td>Use calculators/computers to collect and/analyze data</td>
</tr>
<tr>
<td>I</td>
<td>Use the Internet in your science teaching for general reference</td>
</tr>
<tr>
<td>J</td>
<td>Use the Internet in your science teaching for data acquisition</td>
</tr>
</tbody>
</table>
14. **Teacher Opinions.** Please provide your opinion on each of the following statements.

<table>
<thead>
<tr>
<th></th>
<th>Equipment/supplies</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>I have adequate access to computers for teaching science.</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>B</td>
<td>I have internet access for my students.</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>C</td>
<td>I have adequate supplies (glassware, balances, etc.) to teach science.</td>
<td></td>
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<tr>
<td>D</td>
<td>I have enough space in my classroom to conduct lab exercises.</td>
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<tr>
<td>E</td>
<td>I have A/V equipment to augment lessons.</td>
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</tr>
<tr>
<td>F</td>
<td>I have district-approved, current textbooks or lessons for my students.</td>
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<tr>
<td></td>
<td><strong>Assessment</strong></td>
<td></td>
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</tr>
<tr>
<td>G</td>
<td>It is important to find out what students know before starting a unit.</td>
<td></td>
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</tr>
<tr>
<td>H</td>
<td>It is important to use embedded assessments to see if students are getting the material.</td>
<td></td>
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</tr>
<tr>
<td>I</td>
<td>It is important to go over and grade assigned homework.</td>
<td></td>
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<tr>
<td>J</td>
<td>It is important to read through student notebooks and journal writings.</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>K</td>
<td>It is important to assess a lab product or result.</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>L</td>
<td>It is important to give lab “practicals”.</td>
<td></td>
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<tr>
<td>M</td>
<td>It is important to assess the “problem of the day” or opening class problem.</td>
<td></td>
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</tr>
<tr>
<td>N</td>
<td>It is important to give quizzes.</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>It is important to assess a variety of learning styles (MC, T/F, fill-in-the-blank, matching, etc.)</td>
<td></td>
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<tr>
<td>P</td>
<td>It is important to assess by designing tests containing open-ended responses.</td>
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<tr>
<td>Q</td>
<td>It is important to use pre- and post- tests to see how much students learned during a unit.</td>
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</tr>
</tbody>
</table>
15. Aside from assessing science content, the following classroom activities help inform you about student misconceptions. About how often do students in your classroom do these activities?

<table>
<thead>
<tr>
<th>Activity</th>
<th>Never</th>
<th>Rarely (few times/yr)</th>
<th>Some times (1 or 2 times/month)</th>
<th>Often (1 or 2 times/week)</th>
<th>Always (or nearly always)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Listen and take notes during presentation by teacher</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>B Watch a science demonstration</td>
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</tr>
<tr>
<td>C Participate in student-led discussions</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>D Participation in discussions with teacher to further science understanding and resolve misconceptions</td>
<td></td>
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</tr>
<tr>
<td>E Work in cooperative learning groups</td>
<td></td>
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<tr>
<td>F Make formal presentations to class</td>
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</tr>
<tr>
<td>G Read from textbook in class</td>
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<td></td>
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</tr>
<tr>
<td>H Answer textbook worksheet questions</td>
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</tr>
<tr>
<td>I Work on solving a real-world problem</td>
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<tr>
<td>J Share ideas or work on problems in small groups</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K Explain concepts to one another</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>L Engage in hands-on science activities or investigations</td>
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<tr>
<td>M Follow specific instructions in an activity or investigation</td>
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</tr>
<tr>
<td>N Design or implement their own investigation</td>
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<td></td>
</tr>
<tr>
<td>O Design objects within constraints (egg-drop, toothpick bridges, etc.)</td>
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</tr>
<tr>
<td>P Work on extended science investigations of projects</td>
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</tr>
<tr>
<td>Q Work on open-ended problems</td>
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<tr>
<td>R Participate in field work</td>
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<td></td>
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<tr>
<td>S Record, represent, and/or analyze data</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>T Supply evidence to support claim or conclusion</td>
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<tr>
<td>U Write reflections in a notebook or journal</td>
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<tr>
<td>V Prepare written science reports</td>
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<td></td>
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</tr>
<tr>
<td>W Use mathematics as a tool in</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>problem-solving</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>Use calculators</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>Use computers as a tool (data analysis, spreadsheets)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td>Work on portfolios</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Watch audiovisual presentations (films, CD-ROMs, etc.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Other:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comments:
Appendix J  Classroom Observation Protocol

Teacher: ______________________________________________________

Observation Dates:_______________________________________________

School: _______________________________________________________

District: _______________

Teacher Gender: _______Male _______Female

Science Class Observed:___________________________________________

Grade Level(s): _______________ Class Period _________________________

Students: Number of Males _____ Number of Females _______

Total # students_____

Purpose of the Lesson:

According to the teacher, the purpose of this lesson was:
**Instructions:** for the next four sections, please mark the number of times you saw the following indicators. If the indicator does not apply to the lesson, mark N/A.

1. **Design**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Not at All</th>
<th>To a great extent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>The instructional materials supported the instructional approach.</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>The pace of the lesson was appropriate for the developmental levels/needs of the students.</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>The pace of the lesson was appropriate for the number and types of activities.</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Students were given time to discuss topics and concepts and help each other understand them.</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>Students were encouraged to generate ideas, questions, conjectures, and/or propositions over the material.</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>The activities and tasks were appropriate for the focus of the lesson.</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>The teacher’s questioning strategies enhanced the development of student conceptual understanding/problem solving.</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>The teacher’s questioning strategies emphasized higher order questions.</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>The teacher’s questioning strategies identified student misconceptions.</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>The teacher’s classroom management style enhanced the lesson quality.</td>
<td>2</td>
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<tr>
<td>11</td>
<td>1</td>
<td>The teacher moved around to different students answering questions and acting as a resource person to enhance student investigations.</td>
<td>2</td>
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<tr>
<td>12</td>
<td>1</td>
<td>The teacher appeared confident in his/her ability to teach science.</td>
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<tr>
<td>13</td>
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2. Implementation

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<th>Rating 4</th>
<th>Rating 5</th>
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<tr>
<td>1</td>
<td>The instructional materials supported the instructional approach</td>
<td></td>
<td></td>
<td></td>
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<td>2</td>
<td>The pace of the lesson was appropriate for the developmental levels/needs of the students.</td>
<td></td>
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<td>3</td>
<td>The pace of the lesson was appropriate for the number and types of activities.</td>
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<td>4</td>
<td>Students were given time to discuss topics and concepts and help each other understand them.</td>
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<td>5</td>
<td>Students were encouraged to generate ideas, questions, conjectures, and/or propositions over the material.</td>
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<td>6</td>
<td>The activities and tasks were appropriate for the focus of the lesson.</td>
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<tr>
<td>7</td>
<td>The teacher’s questioning strategies enhanced the development of student conceptual understanding/problem solving.</td>
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<td>8</td>
<td>The teacher’s questioning strategies emphasized higher order questions.</td>
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<td>9</td>
<td>The teacher’s questioning strategies identified student misconceptions.</td>
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Notes:
3. Science Content Knowledge

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<th>To a great extent</th>
<th>N / A</th>
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</thead>
<tbody>
<tr>
<td>1 The science content was significant and worthwhile.</td>
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<td></td>
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</tr>
<tr>
<td>2 The science content was appropriate for the developmental levels of the students in this class.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>3 The content was aligned with district standards.</td>
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<tr>
<td>4 Students were intellectually engaged with important ideas relevant to the focus of the lesson.</td>
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<tr>
<td>5 Teacher-provided content information was accurate.</td>
<td></td>
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<tr>
<td>6 Teacher-provided content and responses to student questions was free of misconceptions.</td>
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<tr>
<td>7 The teacher displayed an understanding of science concepts.</td>
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<td></td>
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</tr>
<tr>
<td>8 Appropriate connections were made to other areas of science, to other disciplines, and/or to real-world contexts.</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>9 Science was portrayed as a dynamic body of knowledge continually subject to investigation, analysis, new evidence, and reinterpretation.</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>10 Elements of science abstraction (e.g., symbolic representation, theory building) were included when it was important to do so.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 The degree of &quot;sense-making&quot; of science content within this lesson was appropriate for the developmental levels/needs of the students and the purposes of the lesson.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 Teacher checked for understanding of complex concepts,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 Teacher noted and identified students’ misconceptions, and arranged for further discussion to clarify and correct student misconceptions</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>14 Other:</td>
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</table>

Notes:
4. Science Process Knowledge

<table>
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<th>To a great extent</th>
<th>N / A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students were:</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>presented with a problem, data, etc. to think about (alone or with others).</td>
<td></td>
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<tr>
<td>2</td>
<td>required to analyze data from scientific literature.</td>
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<tr>
<td>3</td>
<td>given an opportunity to learn and distinguish between qualitative and quantitative observations</td>
<td></td>
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<tr>
<td>4</td>
<td>required to ask a question they could investigate.</td>
<td></td>
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<tr>
<td>5</td>
<td>able to make predictions about what would happen before doing lab activities or experiments.</td>
<td></td>
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<tr>
<td>6</td>
<td>required to test hypothesis or questions in activities or experiments.</td>
<td></td>
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<tr>
<td>7</td>
<td>able to identify and control variables when doing lab activities or experiments.</td>
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<tr>
<td>8</td>
<td>able to design and set up their own experiments.</td>
<td></td>
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<tr>
<td>9</td>
<td>drawing inferences.</td>
<td></td>
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</tr>
<tr>
<td>10</td>
<td>required to fill in a data table when doing lab activities or experiments.</td>
<td></td>
<td></td>
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<tr>
<td>11</td>
<td>required to write down information from observations of their experiments in a notebook or journal.</td>
<td></td>
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<tr>
<td>12</td>
<td>required to construct a chart or data table.</td>
<td></td>
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<tr>
<td>13</td>
<td>required to create a graph and graph data generated from their experiments.</td>
<td></td>
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<tr>
<td>14</td>
<td>required to discuss the results and data form their experiments with each other.</td>
<td></td>
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<tr>
<td>15</td>
<td>required to discuss reasons for outcomes that were different than what they predicted.</td>
<td></td>
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<tr>
<td>16</td>
<td>encouraged to try their experiments more than once to check their results.</td>
<td></td>
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<tr>
<td>17</td>
<td>given the opportunity to critique, judge, evaluate other experiments or work.</td>
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<tr>
<td>18</td>
<td>able to take it “a step further” and design additional experiments to further their research.</td>
<td></td>
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</tr>
<tr>
<td>19</td>
<td>using balances, scales, or thermometers.</td>
<td></td>
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<tr>
<td>20</td>
<td>using magnifying lenses, microscopes, or dissecting scopes.</td>
<td></td>
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</tr>
<tr>
<td>21</td>
<td>using meter sticks, timers, or stopwatches.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Using graduated cylinders, beakers, flasks, etc. to</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Description</td>
<td></td>
<td></td>
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<tr>
<td>---</td>
<td>------------------------------------------------</td>
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</tr>
<tr>
<td>23</td>
<td>using live or preserved animals and plants.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>using computers with probes or science software.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Other:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
5. Rating of the Quality of the Lesson.
Select the capsule description that best characterizes the lesson you observed.

___ Level 1: Ineffective Instruction
There is little or no evidence of student thinking or engagement with important ideas of science. Instruction is highly unlikely to enhance students' understanding of the discipline or to develop their capacity to successfully “do” science. Lesson was characterized by either:

___ Passive “Learning” Instruction is pedantic and uninspiring. Students are passive recipients of information from the teacher or textbook; material is presented in a way that is inaccessible to many of the students.

___ Activity for Activity’s Sake Students are involved in hands-on activities or other individual or group work, but it appears to be activity for activity’s sake. Lesson lacks a clear sense of purpose and/or a clear link to conceptual development.

___ Level 2: Elements of Effective Instruction
Instruction contains some elements of effective practice, but there are serious problems in the design, implementation, content, and/or appropriateness for many students in the class. The content may lack importance and/or appropriateness; instruction may not successfully address the difficulties that many students are experiencing, etc. The lesson is very limited in that it’s not likely to enhance students’ understanding of the discipline or to develop their capacity to successfully “do” science.

___ Level 3: Beginning Stages of Effective Instruction
Instruction is purposeful and characterized by quite a few elements of effective practice. Students are, at times, engaged in meaningful work, but there are weaknesses, ranging from fairly minor to substantial, in the design, implementation, or content of instruction. For example, the teacher may short-circuit a planned exploration by telling students what they “should have found”; instruction may not adequately address the needs of a number of students; or the classroom culture may limit the accessibility or effectiveness of the lesson. Overall, the lesson is somewhat limited in its likelihood to enhance students’ understanding of the discipline or to develop their capacity to successfully “do” science.

___ Level 4: Accomplished, Effective Instruction
Instruction is purposeful and engaging for most students. Students actively participate in meaningful work (e.g., investigations, teacher presentations, discussions with each other or the teacher, reading). The lesson is well-designed and the teacher implements it well, but adaptation of content or pedagogy in response to student needs and interests is limited. Instruction is
quite likely to enhance most students' understanding of the discipline and to develop their capacity to successfully “do” science.

___ Level 5: Exemplary Instruction
Instruction is purposeful and all students are highly engaged most or all of the time in meaningful work (e.g., investigation, teacher presentations, discussions with each other or the teacher, reading). The lesson is well-designed and artfully implemented, with flexibility and responsiveness to students’ needs and interests. Instruction is highly likely to enhance most students’ understanding of the discipline and to develop their capacity to successfully “do” mathematics/science.
6. Possible questions for teacher interview after observing the lesson:

1. Describe the textbook you use for this class:

   Pros and Cons of using this text:

2. Does your district encourage teacher professional development? ______

   If so, explain:

3. Rate the extent to which the Biology 1 Summer Academy class influenced
   the selection of topics/instructional materials/pedagogy for this lesson.

   ____ Not at all   ____ Somewhat   ____ To a great extent   ____ Not Applicable

4. Do you feel that there is positive teacher collegiality within your
   school/district?_________

   Describe:
5. Did school/district scheduling policies, including class length/block scheduling influence the way you teach your science classes? ________

If yes, explain:

6. What percent of your instructional materials do you prepare yourself

1. Do you use/adapt commercially prepared materials? ________

2. Do you use district-mandated materials? ________

Comments:

The physical environment of the room includes:

- Size and “feel” of the room, including what’s on the walls;
- State of repair of classroom facilities;
- Appropriateness and flexibility of furniture;
- Availability of running water, electrical outlets, storage space; and
  - Availability of equipment and supplies (including calculators and computers).

a) Describe the physical environment of this classroom.

b) Did the physical environment constrain the design and/or implementation of this lesson? Yes _____ No _____

If yes, explain:
## Appendix K  School Demographic Data

<table>
<thead>
<tr>
<th>School</th>
<th>Level</th>
<th># Student</th>
<th>% Minority</th>
<th>% Attendance</th>
<th>School Perf</th>
<th>Read Score</th>
<th>Write Score</th>
<th>Math Score</th>
<th>Science Score</th>
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**Legend:**
- **School** (confidentiality bars school names, so schools are numbered)
- **Level:** 1 = elementary school, 2 = middle school, 3 = high school
- **Student Number** = number of students attending that school
- **% Minority** = the percentage of minority students attending that school
- **% Attendance** = percentage of students in school reported on a daily basis
- **School Perf** = school performance level measured by CSAP scores
- **Read Score** = average reading score for 5th grade
- **Write Score** = average writing score for 5th grade
- **Math Score** = average mathematics score for 5th grade
- **Science Score** = average science score for 5th grade
Appendix L  Biology 1 Multiple Choice Test

Cells, Human Systems and Heredity  SS# ___________________
Pretest  (last 4 digits only)

1. The statement “matter is composed of small particles called molecules which are in constant motion” is which of the following?
   a) a fact
   b) a theory
   c) hypothesis

2. Because it
   a) is a statement on which physical science experts agree
   b) predicts a causal relationship between variables
   c) provides an explanation for many natural phenomena

3. An experiment was done with four beakers of the same amount of different colored sand. They were all placed 50 cm away from a 100 watt bulb light source. The temperature of each sample was recorded every five minutes. Which is the independent variable in this experiment?
   a) the distance of the light from the sand
   b) the color of sand in the beakers
   c) the length of time under the light

4. Because the experimenter determines
   a) the colors of sand to test
   b) how often to measure the temperature
   c) the distance of the light from the sand

5. Three drops of red dye were dropped into each of two 500 ml beakers filled with water. Red dye temperature was 21°C, water temperature of beaker A was 37°C and beaker B was 5°C. What would you expect to see happen?
   a) the red dye will disperse in beaker A more quickly than in beaker B
   b) the red dye will disperse in both beakers at about the same rate
   c) the red dye will disperse in beaker B more quickly than in beaker A
6. Because

a) kinetic energy of cold water molecules will cause faster dye dispersion  
b) dye and water temperature don't affect kinetic energy of water molecules  
c) kinetic energy of warm water molecules will cause faster dye dispersion

7. The drawing below is that of a large cheek cell magnified 1000X. The diameter is 6 cm as measured with a ruler. Choose the answer that most accurately gives the actual size of the vacuole.

a) 6.00 μm  
b) 0.60 μm  
c) 0.06 μm

8. Because

a) 1 m = 100,000 μm  
b) 1 cm = 0.100 mm  
c) 1 μm = 0.001 mm

9. A starch solution was pipetted into the dialysis tubing bag which was then submerged in a glucose solution in a beaker. The next day, both the contents of the dialysis tubing bag and the beaker water were tested for the presence of sugar and starch. What would you expect to find?

a) the dialysis bag solution would be positive for starch and negative for sugar; the beaker water would be negative for starch and positive for sugar  
b) the dialysis bag solution would be positive for starch and sugar, the beaker water would be negative for starch and positive for sugar  
c) the dialysis bag solution would be positive for starch and negative for sugar, the beaker water would be positive for both starch and sugar

10. Because

a) starch would not move through the dialysis bag membrane, but sugar would  
b) starch would move through the dialysis bag membrane and so would sugar  
c) starch would move through the dialysis bag membrane, but sugar would not
11. Three test tubes with 3 ml sheep blood suspension were mixed with different saline solutions. The blood in tube A was mixed with 5 ml of 0% saline, Tube B was mixed with 5 ml of 0.85% physiological saline, and Tube C was mixed with 5 ml of 5% saline. What would you expect to see if you put a drop of the different suspensions on a glass slide and observed them under the microscope?
   a) tube A would show normal red blood cells
   b) tube B would show normal red blood cells
   c) tube C would show normal red blood cells

12. Because
   a) tube A would show no net gain in water movement in or out of the red blood cells
   b) tube B would show no net gain in water movement in or out of the red blood cells
   c) tube C would show no net gain of water movement in or out of the red blood cells

13. In the process of photosynthesis
   a) sugar is broken down to provide chemical energy
   b) solar energy is converted into chemical energy
   c) $\text{CO}_2$ reacts with water to make sugar for energy

14. Because the source of energy for photosynthesis is
   a) sugar
   b) carbon dioxide
   c) sunlight

15. Which of the following is **not** required for photosynthesis
   a) carbon dioxide
   b) oxygen
   c) water

16. Because
   a) water molecules are split to produce oxygen
   b) plants get their carbon from the soil
   c) glucose provides the hydrogen and oxygen for water
17. An experiment with yeasts exposed to different nutritional conditions was done to observe how the presence or absence of an energy source might affect respiration. Four gas-collecting test tubes were set up as follows:

1. yeast suspended in 10 ml water
2. yeast suspended in 10 ml of glucose solution
3. 10 ml water
4. 10 ml glucose solution

What would you expect to see after the tubes were incubated one hour at 37° C?

a) some gas produced in tubes 1 and 2; no gas in tube 3 and 4
b) a lot of gas produced in tubes 1 and 2; small amount of gas in tube 4

18. Because

a) yeast will respire only with an energy source like glucose
b) yeast will respire with or without glucose as long as there is light
c) glucose will break down in water and mimic respiration

19. A class of biology students was studying respiration. To discover what the final products of respiration in vertebrates were, they used glucose that was tagged with radioactive oxygen and fed it to mice. These animals were carefully watched. In which compound would you expect to find the radioactive oxygen atoms to show up?

a) water
b) carbon dioxide
c) oxygen

20. Because glucose is broken down into

a) carbon, hydrogen and oxygen
b) water and carbon dioxide
c) energy and water

21. There are three processes involving nucleic acids: replication, transcription, and translation. Which of these do not involve mRNA?

a) replication
b) transcription
c) translation
22. Because mRNA does not

a) involve the process of decoding a molecule to produce proteins
b) attach to DNA to link bases together into new DNA strands
c) produce a coded molecule from which to make proteins

23. If body cells of an animal have 20 pairs of chromosomes, how many chromosomes would the sperm cells of the male animal have?

a) 10 chromosomes
b) 20 chromosomes
c) 40 chromosomes

24. Because

a) all cells of an animal species have the same number of chromosomes
b) sperm cells are haploid, so they would have one of each chromosome
c) sperm cells are diploid, so they would have twice the number of chromosomes

25. In which of the following cell types would you find mitosis occurring?

a) division of a fertilized egg
b) spore formation in plants
c) gamete formation

26. Because

a) spore formation in plants is asexual because spores are identical
b) gamete formation is an asexual process in plants
c) a fertilized egg will differentiate into nonsexual somatic tissues

27. What is the end result of mitosis versus meiosis?

a) mitosis results in two cells that are identical, meiosis results in four cells each with half the genetic information of the parental cell
b) mitosis results in two identical cells, meiosis results in four identical cells, all cells will have half the genetic information of the parental cell
c) mitosis and meiosis both result in two identical daughter cells each with half the genetic information of the parental cell
28. This is important because

a) both somatic body cells and reproductive sex cells need all their genetic information to reproduce  
b) all tissue cells have half the genetic information so they can combine sexually to regenerate tissues  
c) somatic cells can reproduce on their own and sex cells must combine together for reproduction

29. You are given a culture of animal cells that are dividing actively. If you add a radioactive nitrogenous base (A, G, C, or T) to the culture, then which of these results would be the case after just one cell division?

a) only one of the daughter cells would be radioactive  
b) both of the daughter cells would be radioactive  
c) neither of the daughter cells would be radioactive

30. Because

a) the DNA would incorporate the radioactive base while replicating, so both daughter cells would be radioactive  
b) making a base radioactive changes its structure so it would not be incorporated into replicating DNA and neither daughter cell would be radioactive  
c) the DNA would incorporate the radioactive base into the replicated strand making one daughter cell radioactive

31. The DNA base sequence for one strand of a segment of double-stranded DNA is AGTGTGTCGTACCT. Which of the following is the sequence for the other strand of the same molecule of DNA?

a) TCACAGCATGGA  
b) UCACAGCAUGGU  
c) TCCATGCTGTGA

32. Because the other strand

a) consists of a base sequence in the reverse of the template strand  
b) contains the same base sequence only the base U in place of T  
c) contains the complementary bases of the template strand
33. You want to transcribe the DNA base sequence AGTGTGTCGTACCT. Which of the following would be the transcribed base sequence?

a) TCACAGCATGGA
b) UCACAGCAUGGA
c) AGUGUCGUACCU

34. Because the transcribed strand is the

a) complementary base sequence of the template strand
b) same base sequence as the DNA with U in place of T
c) complementary base sequence of DNA with U in place of T

35. DNA mixtures must be separated from each other for analysis. Which procedure is used for this task?

a) electrophoresis
b) DNA sequencing
c) Hybridization

36. Because DNA can be separated by

a) base sequence
b) molecular weight
c) bonding to probes

37. Protein functions are based on

a) their specific shape
b) the site of synthesis
c) their size

38. Which of the following statements is true concerning mutations? They necessarily involve a change in

a) the amino acid sequence of the protein
b) the resulting protein structure
c) DNA base sequence

39. The reason that children may look different from their parents is that

a) chromosomes are randomly assorted
b) there is blending of chromosomes
c) chromosomes adapt to their environments
40. The relationship between DNA, genes, and chromosomes is:

a) DNA contains genes which are composed of chromosomes
b) genes contain chromosomes which are composed of DNA

C) chromosomes contain genes which are composed of DNA
Appendix M Biology 1 Constructed Response Test

Cells, Human Systems and Heredity Name ____________________________

Write your answers out clearly and briefly. Include drawings where it says to.

41A. What are the characteristics that distinguish prokaryotes from eukaryotes? Discuss at least five distinguishing characteristics.

41B. What are the characteristics that separate plant cells and animal cells? Discuss at least three differences between plant cells and animal cells.
42. Using readily available materials, design an experiment for your class that involves testing the respiration rate of an organism against the ambient temperature of the classroom. Be sure to include a hypothesis, the independent and dependent variables, controls, exact steps in the procedure, etc. You should be able to use this experiment in your class, so design it around the level of students you teach.
43. Describe how photosynthesis occurs in two separate types of reactions.

44. DNA is referred to as a self-replicating molecule.

A. Explain (with drawings) how DNA can replicate itself.
B. Explain how DNA is transcribed (with drawings).

C. Explain how translation occurs (with drawings).
Appendix N  Multiple Choice Test Question Writing Guide

Content Guidelines
1. Every item should reflect specific content according to the test specifications.
2. Every item should reflect a specific cognitive process.
3. Every item should be based on something important to learn, avoid trivial content. Use content experts, etc.
4. Test concepts, principles, or procedures by embedding these in the question and using examples that are different in content those presented in the text (novelty). Ask student to paraphrase, give an example, do critical thinking/problem solving.
5. Avoid overly general or overly specific content. Overly specific items are too trivial, overly general are too vague.
6. Avoid opinion-based items. Test on well-known and publicly supported facts, concepts, principles, and procedures.
7. Avoid trick questions. Characteristics of trick questions:
   a) Deliberately misleading
   b) Overly trivial or specific content
   c) Discrimination among options was too fine
   d) Irrelevant window dressing
   e) More than one answer choice is correct
   f) Principles presented in ways students did not learn
   g) Very ambiguous items
8. Appropriate academic level, content not too easy or too difficult

Style/Format Concerns
9. Format items vertically instead of horizontally. It is much easier to read.
10. Edit items for clarity. Present ideas as clearly as possible.
11. Edit items for correct grammar, punctuation, capitalization, and spelling. Use acronyms carefully.
12. Simplify the vocabulary. Reading comprehension should not interfere with test performance. Vocabulary should be simple enough for the weakest student in the group.
13. Avoid verbosity so reading time is shortened. Test taking time will be shorter as well. Too many words affects clarity.
14. Proofread each item – work out problems. If you find three errors in the final copy, you have missed at least one.

Writing the Stem
15. Make directions clear, the focus of the question should be obvious.
16. Stem should be as brief as possible.
17. The main ideas should be in stem, not choices. No unfocused stem.
How to Avoid Various Clues to the Right Answers

18. Clang Associations – clang associations include phrases in the stem that are repeated in the options. This provides clues to the correct answer.

19. Ridiculous Options – may be for humor or by accident, but since the response is so implausible, no student would choose it (therefore, it is a nonfunctional distractor).

20. Formal Prompts – has to do with the way the distractors are listed. Several of the distractors are presented as a set, so there is an odd one – and students will often choose that one.

21. Specific Determiners – usually an extreme choice that uses the words absolutely, always, never, completely, totally, and forever. Usually a distractor with an extreme word in it is incorrect.

22. Faulty Grammar – incorrect grammar often gives a clue to the correct answer. Oftentimes, several choices will contain gerunds (ing words) and one will not. If the student reads the question carefully, they may see that the gerunds do not fit grammatically.
### Appendix O Test Question Matrix

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**Legend:** The question numbers are limited here to avoid printing two pages, but go to 40 for the Biology 1 MC test and 44 for the Biology 2 MC test.
Appendix P  Biology 2 Multiple Choice Test

Ecology, Biodiversity, and Adaptation  SS# ____________________
Pretest  (last 4 digits only)

1. Examine the phylogenetic trees below. Based on evidence from these trees, which of the following statements is true? (Baum et al., 2005).

a) a lizard is more closely related to a fish than to a human
b) a lizard is more closely related to a human than to a fish

c) a lizard is equally related to fish and humans

2. Because lizards

a) share a common ancestor that is the same age as the common ancestors of fish and humans
b) are on the same side of the tree as fish, so are more closely related to fish
c) lizards share a more recent common ancestor with humans, so they are more closely related to them.

3. The statement “fossils have been found that are clearly intermediate in appearance between dinosaurs and birds” is which of the following?

a) fact
b) theory
c) opinion

4. Because

a) it is a statement by an educated expert in the field
b) it explains a causal relationship between variables
c) it is something which can be observed and measured
5. Plate tectonics may be regarded as a
   a) fact and a theory
   b) fact, but not a theory
   c) theory, but not a fact

6. Because
   a) plate movements have been measured, but the cause(s) are a conceptual product of the human mind
   b) plate tectonics is only a theory, but the evidence for plate movements is substantial
   c) evidence for plate movements has raised theory to the level of fact

7. Whales have a detached set of pelvic bones in their skeletons. Since whales are sea creatures, they don’t use their pelvis. This type of structure is called a(n)
   a) homologous structure
   b) vestigial structure
   c) adaptative structure

8. Because
   a) the structure used to be functional in whales’ ancestors
   b) these bones evolved to help whales re-emerge on land
   c) these bones are derived from the same feature in whales’ ancestors

9. An experiment was conducted on salamanders to observe what happened to their eyesight when placed in the dark for extended periods of time. 100 salamanders were placed in separate containers which were then kept in the dark for several years. Then the salamanders were put together so they would mate randomly with each other. Which of the following is true about the offspring of these matings?
   a) most of the offspring should have less pigment and poorer eyesight than their parents
   b) almost all the offspring should have the same pigment and eyesight as their parents
   c) some of the offspring should have less pigment and poorer eyesight than their parents
10. Because
   a) the dark will cause a reduction in the amount of pigment produced and most salamanders will have reduced eyesight
   b) some genes will mutate so some of the offspring will carry genes for less pigment
   c) long periods of exposure to the dark will not alter the genes of the salamanders

11. Scientists have collected fossils from three different locations. It has been determined that at location “A”, 512 different species were collected and 256 of them were still living today. At location “B” there were 321 fossil species with 107 were still living. At location “C”, there were 215 fossil species with 43 still living. It can be inferred that the oldest of the three sites is location:
   a) A
   b) B
   c) C

12. Because
   a) only 1 in 5 of the fossil species at this location is still alive today
   b) the smallest total number of fossil species is found at this location
   c) the largest number of extinct fossil species is found at this location

13. Humans share over 98% of their unique DNA sequence with
   a) gorillas
   b) chimpanzees
   c) orangutans

14. Because humans
   a) evolved from this species
   b) share a most recent common ancestor with this species
   c) have the same number of chromosomes as this species

15. Darwin’s theory of common descent states that living and extinct species
   a) can be traced to a single ancestral type
   b) arose from separate, unrelated lineages
   c) arose via spontaneous generation
16. Because

a) life is very complex and could not have arisen by mutation and selection
b) species arose from many separate places on the earth
c) all species share features that can be explained by common ancestry

17. A population of insects is sprayed with an insecticide. Ninety five percent of the insects are killed. If the five percent of the insects that survive reprodu

a) all of the insects will be killed by the second spraying
b) ninety five percent of the insects will be killed by the second spraying
c) a much lower percentage of the insects will be killed by the second spraying

18. Because

a) insects that survived the first spraying were genetically resistant to the insecticide
b) the insecticide caused resistance to develop in the insects that survived the first spraying
c) the insecticide caused a mutation in the insects that survived the first spraying

19. The Biological Species Concept requires that members of the same species must all

a) have DNA that is 99.9% similar
b) be descended from the same individuals
c) be able to interbreed and produce viable, fertile offspring

20. Because

a) descendants should be of the same species as their parents
b) members of the same species can only breed with other species members
c) DNA similarities of members of a species determines if they are closely related

21. You are systemically investigating the trees in a park. Use the following taxonomic key as a tool to identify the tree represented by the tree branch and leaves below.
KEY: for Trees with Needlelike or Scale-like Leaves:
   a. Leaves long, needlelike;
      i. Needles in bundles or groups along twigs;
         1. Needles 2-5 in bunches on the branch, evergreen
            a. Needles in bunches of five, 2-4 inches long. . . . White Pine
         2. Needles many, more than 5, drop in autumn . . . . Larch
      ii Needles occurring singly;
         1. Needles blunt, flat; in flat sprays on twigs . . . . . . . . . . Balsam Fir
         2. Needles sharp; on all sides of twigs
            a. Needles, neither in opposing pairs nor in whorls of 4-5 . . . .
   b. Leaves very small and scale-like, hugging twigs:
      i. Leaves blunt; conifers . . . . . . . . . . . . . . . . . . . . . . White Cedar
      ii. Leaves sharp; a flowering tree . . . . . . . . . . . . . . . . . . . . . . Tamarisk

Scale |----- = 2 inch

Identify the tree or tree type in the picture using the key.

   a) Juniper
   b) White Pine
   c) Red Pine
22. Because

a) needles are 2-5 in a bunch  
b) needles are in whorls of 3-4  
c) needles are 1-2 inches long

23. Speciation of two sexually reproducing populations requires that

a) the two populations become geographically isolated from each other  
b) the two populations must have different physical traits from each other  
c) the two populations become reproductively isolated from each other

24. Because separate species

a) cannot continue to exchange genetic information  
b) need to be able to tell each other apart  
c) must live in different habitats

25. Average family size in the U.S. is currently at about 1.9 so the current population should be

a) increasing slowly  
b) stable  
c) declining slowly

26. Because

a) zero population growth requires an average family size of 2.0  
b) population growth reflects family size of the previous generation  
c) family size does not take divorce rates into account

27. For most ecosystems, the ultimate source of energy is in the form of

a) heat  
b) light  
c) chemicals

28. Because most living organisms need a

a) number of important nutrients, minerals and vitamins  
b) temperature warm enough for body systems to function  
c) source of energy to be converted to different uses
29. The spatial distribution of animals and plant species on a given continent is governed by
   a) biotic and abiotic factors
   b) biotic factors only
   c) abiotic factors only

30. Because
   a) potential distribution is dictated by where a species is able to live as a result of physical and chemical aspects of the environment
   b) potential distribution is always greater than the actual distribution as a result of physical and chemical aspects of the environment
   c) biotic factors govern numerical abundance, but not spatial distribution as a result of physical and chemical aspects of the environment

31. The upper limit in feeding “levels” or trophic structure of most ecosystems is
   a) 4 to 5
   b) 6 to 8
   c) 9 to 11

32. Because
   a) evolutionary time scales restrain the stepwise accumulation of trophic levels in the food chain
   b) species at higher levels of the food chain suffer extinction from buildup of toxic wastes
   c) inefficiencies of energy conversion limit the trophic structure of ecosystems

33. If water lilies on a pond double each day and if one plant multiplies to fully cover the pond in 30 days, on what day will the pond have 50% coverage?
   a) day 15
   b) day 24
   c) day 29

34. Because addition of new plants each day increases by a
   a) constant number
   b) constant fraction
   c) function of pond size
35. The major biomes of the contemporary world strongly reflect the influences of

a) climate
b) humans on the landscape
c) isolation and evolutionary diversification

36. Because

a) natural biomes are now dominated by invasive species
b) biomes vary considerably in species makeup
c) biomes reflect variation in vegetation structure

37. In the alpine ecosystem of the Colorado Front Range, which soil nutrient is likely to be at concentrations that serve as the primary limiting factor in plant productivity?

a) phosphorus
b) nitrogen
c) calcium

38. Because the other two are

a) common in the bedrock
b) deposited through wet and dry deposition
c) required in lesser amounts relative to availability

39. The single best approach to evaluate the water quality in a river like the Platte River is to monitor the

a) water chemistry in the river
b) populations of life forms in the river
c) pollution sources entering the river

40. Because

a) monitoring of pollution sources lets you know what is entering a pristine aquatic system
b) monitoring the water chemistry gives you very precise information on water condition
c) life forms in aquatic systems reflect water quality trends over time
41. Which of the following is a mechanism for evolution?

   a) natural selection  
   b) inheritance of acquired characteristics  
   c) sexual reproduction

42. Because

   a) genes can be modified by the environment  
   b) natural selection allows individuals with desirable genes to produce more offspring  
   c) chromosomes with stronger traits blend with higher success rates

43. Most animal populations in nature vary in ways that are best described as

   a) cyclical and predictable  
   b) irregular and unpredictable  
   c) stable and highly predictable

44. Because

   a) cycles are the rule for both physical and biological processes on Earth  
   b) stability is one important goal in the evolutionary process  
   c) the behavior of complex systems is driven in part by stochastic processes
Appendix Q Biology 2 Constructed Response Test

Ecology, Biodiversity, and Adaptation  Name _______________________

Short answer questions
Write your answers out clearly and briefly. Include drawings where it says to.

1. Explain why decomposers are necessary for life on earth.

2. Explain why two different species in an ecosystem can share the same habitat, but not the same niche.

3. A paleontologist prepared a display of Cambrian fossils and another of Cenozoic fossils. Student discussions in a classroom centered around a comparison of these two groups of fossils to living species. Which group of fossils would be more similar to living species and for what reasons?

4. The population of the United States is about 300,000,000 and is growing at the rate of 1.3% per year. How many years until the population reaches 12,000,000,000? Show your work.
5a. Use the drawing below to answer these two questions. Which group of reptiles gave rise to modern birds? Justify your choice.

5b. Would you expect the DNA of crocodilians to be more similar to the DNA of modern birds or the DNA of turtles? Explain your reasoning.
6. How do the jaws of carnivores and herbivores differ and how do these differences reflect adaptations to their respective diets?

7. Explain the steps in the process of how species form. Use diagrams or drawings if possible.

8. Discuss how natural selection is thought to have caused changes in the populations of peppered moths in England since the 1850s.
9. To the best of your knowledge, describe the likely “food chain” or trophic structure for a stretch of the Platte River above Chatfield Reservoir in Waterton Canyon (or a similar location of a river in similar climate). Spell out all the likely “steps” in the food chain.

10. Examine the data in this histogram and answer the questions that follow.

Relative Abundance of Aquatic Insects by Order

![Histogram](image)

These two bars represent two stream sites; one pristine; and one contaminated by heavy metals.

A. Which site has the higher diversity and why?
10B. Which site would you predict is contaminated by heavy metals? Defend your answer.

11. Review the figure and answer the questions below it.

A. The data above provide proof that lynx control hare numbers. True or false? Defend your answer.
B. Are the hare numbers cyclic in your view? Discuss your reasoning.

C. What other factors besides lynx numbers might affect either of these populations? Make a list
Appendix R  Misconceptions over Biology 1 topics

Cells, Human Systems and Heredity

Codes for the various categories of misconception topic:


1. Criteria such as number of legs, body covering, large size, land habitat, etc. are used to determine whether organisms are animals.  C
2. Classification is mutually exclusive rather than hierarchical (one organism can be classified as a bird and an animal).  C
3. Humans are not animals.  C
4. Plants get their food from the environment rather than manufacturing it internally and/or plants get their food from the soil via roots and store it in the leaves.  PR, C
5. Water, minerals and fertilizer are food for plants.  C
6. Respiration and photosynthesis are not energy transfer processes because plants convert energy directly from the sun into matter.  C, PR
7. Plants change water and carbon dioxide into sugar (instead of plants convert carbon dioxide from the air and hydrogen atoms from water into sugar.  Ce, PR
8. Plants give off only oxygen.  Ce, PR
9. Photosynthesis is a plant process and respiration is an animal process.  PR
10. Respiration means breathing and not energy release.  Ce, PR
11. Food is a requirement for growth rather than a source of matter for growth.  TFM
12. Animal, plant and nonliving environment matter are fundamentally different and not transformable into each other.  TFM
13. Dead organisms rot away and their material disappears.  TFM
14. Decay is gradual and inevitable without the need for decomposing agents.  TFM
15. Non-biological processes cause decay/breakdown.  TFM
16. Processes involve creating and destroying matter rather than transforming it from one substance into another.  TFM
17. Recycling happens through soil minerals, but does not incorporate water, oxygen, and carbon dioxide.  TFM

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18. Cells and molecules can be used interchangeably. Ce
19. Cells and molecules are the same size, except that cells are smaller than some large molecules like proteins and DNA. Ce
20. Living things contain cells (rather than make up cells), and non-living is dead. Ce, HS
21. Trouble conceptualizing microbes as agents of change. M
22. All microbes are “bad”. M
23. All diseases are caused by “germs”. M
24. When the shape of something changes, so does its mass. D
25. Mass is the most important factor determining whether an object will sink or float. D
26. A clay ball which will sink in water will displace more water than a clay boat made out of the ball. D
27. Objects that float on water will float on any liquid. D
28. Weight and density are the same thing. D
29. Air has no weight (mass), it is nothing. CM
30. Molecules melt when the substance does and they are the same color as the substance. PM
31. Gases are not matter because they are invisible. D
32. Helium and hot air are the same gas. D
33. Air and oxygen are the same gas. D
34. When something is burned, it is used up and nothing remains. D, EF, C
35. Substances contain particles instead of consisting of particles. Water has particles in it with water or air between the particles. PM
36. Particles are comparable in size to cells, dust specks, etc. and can be seen with an optical microscope. PM
37. Each molecule takes up an invariant amount of space. PM
38. Liquids expand as they are cooled. H
39. A thick liquid has a higher density than water. PM
40. Particles of the same substance in different states have different properties. (ice particles are cold and hard, water particles are large and soft, etc.) PM
41. Liquids have larger or smaller particles than solids. Same with gases. PM
42. When water evaporates, it splits up into atoms of oxygen and hydrogen. PM
43. The bubbles in a boiling liquid are bubbles of air (rather than water vapor). PM, ETC
44. Particles of solids have no motion. PM
45. Expansion of matter is due to expansion of particles rather than to increased particle spacing. PM
46. Energy is not stored in food. Food only gives you energy when you eat it. ETC
47. Energy is not conserved because it is a waste product; it gets used up. ETC
48. Liquids rise in a straw or open test tube because of suction. ETC
49. Heat rises and makes things rise when it does. H
50. Heat acts like a fluid – it accumulates in one spot until that spot is full and then it overflows into other areas. H
51. Heat is a substance, it is not energy. H
52. The temperature of an object depends on its size. H
53. Boiling is the maximum temperature a substance can reach. H
54. There is no difference between heat and temperature – they are used interchangeably. H
55. Some substances (like flour) can’t heat up. H
56. Metals get hot quickly because they attract heat. H
57. When water evaporates, it ceases to exist. W
58. The same exact molecules of water that existed when dinosaurs roamed the earth are still present. W
59. The oxygen we breathe does not come from plants. PR
60. Measurement is only linear. ME
61. The metric system is more accurate than other measurement systems. ME
62. A gene and an allele are different entities. G
63. As a zygote divides and differentiates that inheritance information segregates to new cells according to their future function. G
64. Every cell of an organism carries only the hereditary information it needs for the specific functions it carries out. G
65. A dominant trait is stronger and overpowers the recessive trait. G
66. Dominant and recessive traits are the norm (incomplete dominance is twice as prevalent as complete dominance.) G
67. A clone is actually the same person. G
68. A clone could be made to spare the life of a dying person. G
69. A clone is not a normal organism, it is creating life. G
70. Cloning is not a natural process. G
71. A clone will have the same feelings and emotions as its parent. G
72. Great people could be reborn by cloning. G
73. Human systems operate in isolation from each other. HS
74. Muscles are not found all over the body. HS
75. Blood leaves the vessels and enters parts of the body. HS
76. Blood vessels end in a dead end. The do not reconnect, so blood has to flow backward to get back to the heart. HS
77. The only gas we breathe out is carbon dioxide. PR
78. Plant leaves take in water. PR
79. Matter is created from the sun’s energy through photosynthesis. PR, ETC
80. Air travels to the body in vessels like blood. HS
81. Intestines are in the stomach. HS
82. Food turns energy into our bodies. HS
83. Food goes from the stomach into the blood stream. HS
84. Vitamins give us energy. HS
85. Cold weather and rain can cause a person to get a cold or flu. M
86. Viruses and bacteria are the same thing. M
88. All bacteria are harmful. M
89. Antibiotics can kill viruses. M
90. Antibodies are maintained in the body in high numbers in case they are needed. M
91. Most of the food we eat leaves the body through the intestines. HS
92. Only foods that are needed are absorbed in the intestine. Foods that we do not need stay in the intestine and are excreted from the body. HS
93. When we diet, we lose weight as energy or sweat. HS
94. Solids not used by the body either stay in the intestine or travel back to it and leave through the anus. HS
95. Fertilization happens in the vagina. G
96. The fetus does not need oxygen in the womb. HS
97. The fetus does not produce waste products in the womb. HS
98. Genes are carried only for the traits the organism has. G
99. Acquired changes can be passed on to offspring. G
100. Genetic inheritance involves averaging the genes from both parents so the child’s characteristics are somewhere in between those of the parents. G
101. The sex of a human embryo is not determined until some time after the cells start to divide.
Appendix S  Misconceptions over Biology 2 topics

Ecology, Biodiversity and Adaptation

Codes for the various categories of misconception topic:

CC=carrying capacity, E=ecosystem, LF=limiting factors, C=competition,
EF=energy flow, N=niche, S=succession, EA=ecological adaptation, FW=food webs, PPI=predator/prey interaction, SBA=structural and behavioral adaptations, TFM=transformation and flow of matter, NS=natural selection, GTC=geologic time change, EV=evolution, PR=photosynthesis/respiration

(www.binghampton.edu., Driver, Squires, Rushworth, and Wood-Robinson, 1994, Sweetland, web source)

1. Species exist in an ecological system because of their compatible needs and behaviors: they “get along.” CC, C, N
2. Populations exist in states of either constant growth or decline depending upon their position in a food chain. CC, FW, E, N
3. Some ecosystems have limitless resources and provide an opportunity for limitless growth of a population. CC, E, LF, C, S
4. The relative size of prey and predator populations have no bearing on the size of each other. CC, FW, PPI S, LF
5. Density-dependent factors are biotic, and density-independent factors are abiotic. LF, C, N, S
6. There are more herbivores because people keep and breed them. CC
7. Populations increase until the limits are reached, then they crash and go extinct. CC, C, S
8. Varying the population of an organism will only affect the others that are directly connected through a food chain. E
9. Populations are either in equilibrium or decreasing depending on their position in the web. E, CC, LF, C, S
10. Varying the population of an organism may not affect an ecosystem because some organisms are not important. E, N, S
11. Varying the population of an organism will affect all others organisms to the same degree. E, N, S, EA, C, LF
12. Organisms higher in a food web eat everything that is lower in the food web. E, EF, FW, PPI
13. The top of the food chain has the most energy because it accumulates up the food chain. E, EF, FW, TFM
14. Populations higher in a food web increase in number because they deplete those lower in the web. E, EF, FW, PPI
15. Animals’ energy comes from the sun. EF, TFM
16. Ecosystems are not an organized whole, but a collection of organisms. E
17. Communities change little over time. E, S, C
18. There are more herbivores because people keep and breed them. E, EF, FW
19. Decomposers release some energy that is cycled back to plants. E, EF, TFM
20. The number of producers is high to satisfy consumers. E, EF, PPI
21. Plants do not live in water. E, EF
22. Plants are dependent on people, not vice versa. E, EF, FW
23. Energy is not lost in trophic transfer. E, EF, TFM
24. An organism cannot change trophic levels. E, FW, EA
25. Humans provide food for other organisms. E, FW
26. All factors are limiting except the most abundant one. LF, E
27. The most limiting factor is the least abundant one. LF, E
28. The needs and roles of a species are general and typical of species. C, N
29. Traits are passed on by bigger, stronger organisms that replace the smaller, weaker ones. C, EA
30. Plants take in food from the outside environment, and/or plants get their food from the soil via roots. EF, FW
31. Carbon dioxide is a source of energy for plants. EF
32. Succession involves separate stages leading ultimately to a deterministic climax. S, E
33. The climax community is usually the final stage – long-lasting and self-perpetuating. S, E
34. Traits are developed by individuals in response to the needs of the individual. EA
35. Traits develop because they are part of a predetermined plan. EA
36. Traits are properties of populations. EA
37. Adaptation equals evolution. EA, E
38. Green plants are the only producers of carbohydrates in ecosystems. FW
39. Food webs are interpreted as simple food chains. FW
40. Carnivores are big or ferocious and herbivores are passive or smaller. FW, PPI
41. Carnivores have more energy or power that herbivores do. FW, PPI
42. Plants are weak and cannot defend themselves. PPI
43. In a food web, a change in one population will only affect another population if the two populations are directly related as predator and prey. FW, PPI
44. Organisms intentionally effect changes in body structure to exploit particular habitats. SBA
45. Organisms respond to a changed environment by seeking a more favorable environment. SBA, E, A
46. Organisms adapt deliberately. SBA
47. Environmental conditions are solely responsible got changes in traits. NS, EA, SBA
48. Organisms develop new traits through overuse or under use of certain body structures or abilities. NS, EA, SBA
49. A mutation modifies an individual’s own form during its life rather than only its germ cells and offspring. NS
50. Changing a population results from the gradual change of all individuals in the populations (rather than the survival of a few individuals that preferentially reproduce). NS. EA
51. Adaptations result from some overall purpose or design. NS
52. The Earth was always as it is now – any changes must have been sudden and comprehensive. GTC
53. Glaciers and mountains were single acts of creation - not formed over long periods of time. GTC
54. Dinosaurs and humans existed at the same time. GTC
55. Humans are responsible for the extinction of dinosaurs. GTC
56. Some human races have not evolved as much as others. EV
57. Evolutionary changes are driven by need. EV
52. Living objects can change to meet their survival needs. EV