THE EFFECTS OF USING METACOGNITIVE STRATEGIES ON STUDENT UNDERSTANDING OF EVOLUTIONARY CONCEPTS

by

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ABSTRACT

The purpose of this action research project was to observe the effects metacognitive strategies had on student learning, long-term memory, motivation, and teacher enthusiasm in a high school Biology classroom during a unit on Evolution. A three-week unit including the history of evolution, steps of natural selection, and evidence supporting the theory was used as the nontreatment unit and taught using regular teaching strategies. This was followed by a three-week treatment unit covering genetic variation, distribution, and speciation, and included metacognitive strategies like reflection journaling, QUAD notes, and peer justification. Data was collected using preunit and postunit assessments, student reflection journals, surveys, interviews, and teacher reflections. While the intervention seemed to have little or no effect on student understanding, student attitude, and teacher enthusiasm, it did improve student retention of concepts over time. It would seem that the use of metacognitive strategies led to a longer, more durable learning experience.

INTRODUCTION AND BACKGROUND

Many of my students consistently lack the desire to put forth any effort beyond simple recall of information. They are not problem solvers, but rather, surface-level learners. They want to memorize definitions but never really seem to understand the theories or applications behind what they've learned. They want the material handed to them, but when it is presented this way, they remember very little. Whenever I give an assignment, be it reading, completing a worksheet, doing a web-quest, or investigating something in the lab, they just hunt to find the answers without really caring to understand the information or its applications.

My biggest question, thus far in my teaching career, is: how can I get my students thinking more deeply about our class concepts? Research into this question introduced me to the concept of metacognition, which can be roughly defined as "thinking about thinking" (Livingston, 1997, p. 1). Flavell (1979) listed the importance of metacognition in learning: "…metacognition plays an important role in oral communication of information, oral persuasion, oral comprehension, reading comprehension, writing, language acquisition, attention, memory, problem solving, social cognition, and various types of control and self-instruction…" (p. 906). Knowing this, I now wonder, if my students start thinking about the way they learn, can they become more successful learners?

When I reflect on my own experiences as a high school student, I realize that I was similar to my current students in many ways. While I was always motivated to make good grades, I was content with memorizing information and regurgitating it on a test. I never needed to push beyond this most basic form of learning. Needless to say, my first

year in college was a disaster. When professors wanted something more than simple recall, I struggled. It wasn't until my junior year of college that I learned how to think beyond memorization. I learned strategies that fit my own unique learning needs, for example, pausing during reading to consider what I just read, or rewriting textbook definitions using my own terms. My college grades quickly improved and I now recognize that that was when I fully developed a sense of metacognition.

I want to help my students become better performers. I want them to be energetic and active learners. I want them to go to college and, because someone took the time to help them develop their learning skills, feel that it is not too hard to learn. By teaching metacognitive skills, I believe I can help my students be more successful not only in science, but in all areas of their lives.

This action research on metacognition was done with a group of tenth-grade Biology students in the Bliss School District of Bliss, Idaho. Bliss is a small town located in a rural area of south, central Idaho. According to the U.S. Census Bureau, the population is 318.

Students attend school four days a week, Monday through Thursday. The school day is divided into five, 75-minute class periods, and students attend all classes every day. The community of Bliss is poverty-ridden; approximately 91% of our 130 K-12 students participate in the Free and Reduced Lunch program (L. Pulse, personal communication, November 3, 2012). Many of my students live in single-parent homes and do not get the attention and support they need to be strong learners. Few go on to college, and the jobs available in the community are extremely limited. These circumstances, coupled with the typical challenges of being an adolescent, put my

students at risk for making unhealthy life choices. Flavell (1979) inferred that having a strong metacognitive ability could not only allow for better learning in the classroom but also could be a protective factor against negative peer influence outside the classroom.

The aim of my study was not to research the impacts of metacognition on life-choices (although that would make a very interesting project indeed), but to determine the effect it had on my students as learners in an academic setting. My focus question was: What are the effects of using metacognitive strategies on students' understanding of evolutionary concepts? I also investigated three sub-questions: what are the effects of using metacognitive strategies on students' long-term memory of evolutionary concepts; what are the effects of using metacognitive strategies on students' attitudes and motivation to learn; and what are the effects of using metacognitive strategies on the teacher's motivation and enthusiasm for teaching?

CONCEPTUAL FRAMEWORK

Current literature shows that metacognition has positive effects on understanding, student motivation to learn, student long-term retention, and teacher enthusiasm for teaching in the classroom. The investigations cited in the following paragraphs were chosen because of their relevance to this action research project. Connections between metacognition and success in learning will be demonstrated.

Metacognitive development is necessary for all students to thrive as learners, but perhaps the job of promoting this development falls more heavily on teachers of high-poverty students than those who work with students of a higher socioeconomic status (SES). One study especially relevant to my teaching situation supported the idea of promoting metacognitive strategies with low SES students (Olivares-Cuhat, 2011).

"Children in high poverty urban schools may be caught in a cycle that prevents them from developing the very learning styles that would enable them to become more effective learners" (p. 7). If a child can become a more effective learner, he or she will be more successful in the classroom. This education can allow the student to rise above his or her current life circumstances.

The observation that my students are surface-level learners is consistent with those made by Berry, Mulhall, Gunstone, and Loughran (1999). In a study that focused on the usefulness of laboratory work in high school science classrooms, Berry et al. found that students often strived for task completion rather than understanding. The authors suggest that if a teacher's main objective is to increase knowledge, he or she should make sure students know the objectives and purpose of the investigation before starting the task. Blank's (2000) review of literature supports this pedagogical recommendation. She cited several studies which stated that in order for a student to gain a conceptual understanding of a topic, it is essential that he or she first be able to identify how and why something is known. Being able to articulate the objectives and purpose of a given activity is an example of a metacognitive strategy, and a student who truly understands a concept will have no problem making these types of connections (Georghiades, 2000).

Metacognition and student understanding of course content go hand-in-hand. According to Haider and Naqabi (2008), "expert science students regularly stop to evaluate their understanding" (p. 216). Students who are not proficient in metacognitive strategies are less successful in solving problems and thus have a weaker understanding. An increased metacognitive ability aids in the development of a deeper understanding of course content (Davidowitz & Rollnick, 2003). In one study, high school chemistry

students who employed metacognitive strategies while solving stoichiometry problems were more successful than those who tried to plug numbers into an equation without really understanding why they were using it (Haider and Naqabi,). Davidowitz and Rollnick concluded that "metacognition is a necessary prerequisite for deep approaches" (p. 47). In other words, metacognition is essential in working past surface-level learning towards critical thinking and higher level problem solving.

Metacognition also seems to aid in the long-term memory of concepts. Blank (2000) compared two models of instruction. One of these, status checks, required students in a seventh grade science class to reflect on what they knew about an ecological concept prior to instruction and then justify how they knew those things. They would then reflect again, postinstruction, and identify how and why their initial beliefs changed. At the conclusion of the project, it was determined that students in the treatment group demonstrated a greater long-term memory of concepts when they scored higher on a delayed postunit test.

These conclusions are consistent with those made by Georghiades (2000). He observed that elementary-aged children who received metacognitive instruction (concept mapping, reflections, peer discussions, etc.) during a unit on electricity were more successful at remembering the content over a longer-term. This higher retention is most likely due to the fact that students were made to think about the content on a deeper level than they normally would have.

Students in a classroom that employed metacognition also had higher rates of engagement (Georghiades, 2000). Blank's study (2000) showed that seventh grade science classrooms in which metacognitive strategies were used had higher levels of

student participation than their non-metacognitive counterparts. A three year cross curricular study in a Norwegian school found that ninth grade students thought metacognitive strategies to be time-consuming but useful, and some of these students said that they used these strategies at home when preparing for a test (Postholm, 2011).

Data show that using metacognitive strategies in a classroom can also have a positive effect on teacher enthusiasm. Robins, Villagomez, Docter, Christopher, Ortiz, and Passmore (2009) observed that their high school chemistry students had difficulties understanding gas laws. After determining students did not struggle with solving algebraic problems, but rather with the conceptual applications, teachers took a metacognitive approach to enhance student understanding. Their study concluded that teachers "came away with a better awareness of and appreciation for their [students'] educational needs which, in turn, has informed our [the teachers'] practice" (Robins et al., p. 40).

Student reflection was the metacognitive teaching strategy that appealed to me the most while reviewing the literature. Blank (2000) referred to student reflections as status checks. While doing these, students responded to prompts such as: how do you know; what makes you think so; why do you think that will happen and why; and, what is the purpose of this lesson? Georghiades's (2000) strategies were similar. Through reflective discussions and diaries, he would ask students to reflect on what they knew about a topic both prior to and after a lesson (and how and why their views may have changed), encouraged students to explain to each other how they went about solving a problem, asked students to explain the purpose of a lesson and how that information might be

useful, and required students to identify three things they learned that day along with any points that remained unclear.

The literature indicates that metacognition plays a strong factor in learning. Teachers can foster the development of student metacognition by using reflection strategies like status checks (Blank, 2000). When students take time to reflect on and think about what they are thinking, reading, or doing, student understanding, long-term memory, engagement, and teacher enthusiasm all improve.

METHODOLOGY

The purpose of this investigation was to observe the effects of metacognitive strategies on students' understanding and long-term memory of evolutionary concepts, students' attitudes and motivation to learn, and teacher's enthusiasm for teaching. The action research project was carried out over a six week period beginning in January and ending in February, 2013.

Participants

Bliss High School serves 30 students in grades nine through twelve. Because of the low number of students in each class, there is only one section of each subject offered every year. I chose the sophomore Biology students for this project because I am very familiar with them (I have been their science teacher every year since they were in the seventh grade). This group has always been low in its motivation and ability, and it is my hope that by using metacognitive strategies I can help these students become more successful learners.

Biology is a two-trimester, core class required for graduation. There are eight students enrolled, and it is evenly split by gender. Three students are Hispanic and come

from non-English speaking homes. Most of the students in this class are economically disadvantaged, with all but one participating in the Free and Reduced Lunch Program (L. Pulse, personal communication, November 3, 2012). The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained.

Intervention

This study was divided into two, three-week units designed to introduce basic principles of evolution. To determine the effects metacognitive strategies had on learning and motivation, one nontreatment unit and one treatment unit were implemented. The nontreatment unit emphasized the development of the theory, the process of natural selection, and supportive evidence. The treatment unit focused on sources of genetic variation, types of distribution, and isolation. Specific objectives for each unit can be found in Table 1. Reading assignments, discussions, demonstrations, formative assessments, vocabulary sheets, worksheets, and student activities were all incorporated into both units.

Before beginning the treatment unit, I introduced students to the idea of metacognition and explained my purpose in adding metacognitive strategies such as not directly answering questions, reflective journals, QUAD notes, and peer justification. The first strategy I used was to avoid giving students direct answers to questions. For example, if a student asked a question about something, I would resist providing an immediate and direct answer and instead ask him/her what he/she thought and what made them think that way. If his/her thinking was incorrect, I talked through the steps used to reach an appropriate conclusion

Table 1
Unit Content Objectives

Nontreatment Unit Objectives
1. Trace the historical development of the Theory of Evolution 2. Outline the steps of Natural Selection 3. List types of evidence used to support the Theory of Evolution
Treatment Unit Objectives
1. Explain the sources of genetic variation 2. Compare and contrast the three ways natural selection can affect the distribution of phenotypes 3. Describe various types of isolation that lead to speciation

The second strategy I used was daily reflective journals. In these, students would reflect upon what they thought they knew about a given topic prior to instruction (see Table 2). At the completion of the lesson, they would reflect again, using the same prompt, and then compare their responses to see if any of their ideas had changed (before, I thought….now, I know…). Students were then asked to describe how they learned best or what caused them difficulty during the lesson. I also required students to reflect on why they thought a lesson activity was important (identify the purpose of the activity). Each student was issued a spiral notebook in which to record their reflections, and the notebooks were not allowed to leave the classroom. Students were required to complete the reflections every day that there was a lesson or learning activity.

The third metacognitive strategy used in this unit was QUAD notes. Before beginning a reading assignment, students were instructed to divide a blank piece of paper into quadrants. While reading, students would identify things they already knew in the first quadrant. In the second quadrant, students listed things they found interesting. The third quadrant was for information the student learned while reading, and the fourth was reserved for questions or points of confusion. Reading assignments were given once a week, and QUAD notes were only assigned during the treatment unit.

Table 2
Example Reflection Prompts

Prelesson Prompts
1. From where do all the variations in a population come?
2. How can Natural Selection affect how common traits are in a population?
3. How can new species be formed?
Postlesson Prompts
1. Questions from above (specific for the lesson) plus:
2. Prior to the lessons I thought…Now I know…
3. Strategies that helped me understand were…
4. Strategies that didn't help me understand were…

The final strategy used in the treatment unit required students to justify their responses to questions from worksheets and activities to a partner. For example, partners would explain to each other why they answered questions the way they did. This exercise pushed students to really think about why they knew (or how they came to know) certain things. A comparison of the nontreatment and treatment unit plans is shown in Table 3.

If metacognitive strategies are incorporated during the treatment unit, learning should increase because the content was taken to a deeper level. When students reflected on how their ideas had changed after a lesson, they were identifying misconceptions. By identifying the parts of a lesson that best helped them to understand the material, they were evaluating their own unique learning preferences. QUAD notes required students to pay close attention to what they were reading so that they could identify information they found interesting or confusing. Having to justify an answer to peers required students to not only think about what they knew, but how they knew it and why. Instead of regurgitating random details, students had to push themselves to think about what they had learned.

Table 3
Research Plan

Nontreatment Unit	Assigned Readings, Student Activities, Demonstrations, Discussions, Formative Assessments, Vocabulary Sheets, Worksheets
Treatment Unit	*Included the above methods PLUS:* Not directly answering student questions Reflective Journals (status checks): Content prompts (both prior to and after instruction) Identify how and why your thoughts changed Identify learning strategies that worked best Identify learning strategies that didn't work Identify the purpose of a learning activity prior to starting it QUAD notes Peer Justification

Data Collection

Data were gathered for each question according to the triangulation matrix in Table 4. Pretreatment and posttreatment surveys (Appendix A), preunit and postunit, and pretreatment and posttreatment student interviews (Appendix B), teacher and student reflections (see Appendix C for teacher reflection form), formative assessments such as one-sentence summaries and muddiest points (Angelo & Cross, 1993), and pretests and posttests with delayed questions (see Appendix D) provided data for each project question. Comparing multiple sources of data for each question gave a more accurate account of the relationship between the treatment and each project question than could have been gained by using a single source of data.

Table 4
Data Triangulation Matrix

Focus Question	Data Source 1	Data Source 2	Data Source 3
Primary Question:			
1. Student Understanding of Concepts	Preunit and Postunit Assessments (tests, quizzes, formative assessments)	Student Reflection Journals (content prompts)	Preunit and Postunit Student Interview Questions
Sub-Questions:			
2. Students' long-term memory of Concepts	Delayed Unit Test Questions	Delayed Formative Assessment Questions	Delayed Student Interview Questions
3. Students' attitudes and motivation to learn	Pretreatment and Posttreatment Student Survey Questions	Pretreatment and Posttreatment Student Interview Questions	Teacher's Reflection Form
4. Teacher's motivation and enthusiasm for teaching	Teacher's Reflection Form	Pretreatment and Posttreatment Student Survey Questions	Pretreatment and Posttreatment Student Interviews Questions

Comparing preunit to postunit data allowed me to determine growth of understanding over a unit. For example, an increase in the mean score on a unit posttest, when compared to the pretest, indicated improvement in understanding in that particular unit. By comparing data across units I was able to determine the effectiveness of the treatment. For example, a greater growth in understanding in the treatment unit would have indicated that the intervention was successful. The delayed unit assessments were given nine days after the postunit assessment to determine long-term memory, and those scores were compared to the original posttest scores. Delayed formative assessment questions were randomly given throughout the weeks following the unit posttest. All

pretests and posttests can be found in Appendix D and were created using test bank software that accompanied the textbook (Miller & Levine, 2008).

The survey (Appendix A) consisted of a questionnaire in which the students were given prompts to respond to. Each student was surveyed twice, both prior to and after concluding the action research.

I did not choose to interview every student. Instead, I chose six: two high, two medium, and two low-achieving students. To determine a student's classification, I considered his class grade. Students with an A or B were grouped as high, students with a C were grouped as medium, and students with a D or F were grouped as low. When choosing these students, I sought out those who I felt would respond to my questions openly and honestly. These six students remained consistent throughout the project. Appendix B lists the interview questions.

Student reflection journals and formative assessments were assessed for understanding of content. When evaluating reflections and formative assessments, I used a simple grading scale of one, two, or three points. Responses which showed a lack of understanding received a one. Replies that were fairly accurate and/or complete received a two. A score of three was given to answers that were both complete and accurate. Reflection prompts (see Table 2) asked questions specific to the lesson's objective. Formative assessment prompts were designed to evaluate the student's broad understanding of the material. Examples of formative assessments include: write a one-sentence summary of what you learned today; list three ideas you learned during today's lesson and any points that remain unclear; identify the most important idea from this lesson and explain why you think it is important; thinking about what we learned today,

write a question that could be on a test and then provide the correct answer. Formative assessments were given daily throughout the nontreatment unit and on days in which there were no reflection journals during the treatment unit.

Timeline

This action research project began immediately after returning from Christmas Break and lasted six weeks. Each unit (one nontreatment and one treatment) lasted three weeks, for a total of twelve, 75- minute class periods. Table 5 provides a summarized timeline of the data collection tools. A more detailed schedule that includes daily objectives can be found in Appendix E.

Table 5
Timeline

Date	Data Collection Tool
Day 1 (Start Nontreatment Unit)	1. Nontreatment Unit Pretest 2. Student Interviews: a. Pretreatment Student Interviews b. Nontreatment Preunit Student Interviews 3. Pretreatment Student Surveys
Days 2-12	1. Teacher Observation Form 2. Formative Assessment
Day 13 (End Nontreatment Unit)	1. Nontreatment Unit Posttest 2. Nontreatment Postunit Student Interviews 3. Teacher Observation Form
Day 14 (Start Treatment Unit)	1. Treatment Unit Pretest 2. Treatment Preunit Student Interviews 3. Student Reflection Journal
Day 15	1. Teacher Observation Form 2. Reading Checks 3. Formative Assessment
Day 16-17	1. Student Reflection Journal 2. Teacher Observation Form
Day 18	1. Teacher Observation Form 2. Reading Checks 3. Formative Assessment
Day 19	1. Nontreatment Unit Delayed Test Questions 2. Nontreatment Unit Delayed Student Interview Questions 3. Student Reflection Journal 4. Teacher Observation Form
Day 20	1. Student Reflection Journal 2. Teacher Observation Form
Day 21-22	1. Teacher Observation Form 2. Reading Checks 3. Formative Assessment
Day 23	1. Student Reflection Journal 2. Teacher Observation Form
Day 24	1. Teacher Observation Form 2. Formative Assessment
Day 25 (End Treatment Unit)	1. Treatment Unit Posttest 2. Student Interviews: a. Treatment Postunit Student Interviews b. Posttreatment Student Interviews 3. Posttreatment Student Surveys 4. Teacher Observation Form
9 days after treatment unit posttest	1. Treatment Unit Delayed Test Questions 2. Treatment Unit Delayed Student Interview Questions

DATA AND ANALYSIS

The use of metacognitive strategies during instruction had minor, if any, effects on conceptual learning, student attitude, and teacher enthusiasm. It did however seem to improve the students' long-term memory. Posttest gain scores were slightly higher in the nontreatment unit, and differences in student interview scores were minor. Delayed test scores showed a gain in student long-term memory of concepts. Teacher reflections and student interviews showed a slight decline in student attitude, while survey data indicated an improvement. With respect to teacher enthusiasm, student interviews and surveys showed a decline, while teacher reflections showed a slight increase.

Conceptual Understanding

Metacognitive strategies did not seem to improve student understanding. Only half of the students had a higher gain score on the treatment unit posttest than on the nontreatment unit posttest. When scoring student responses to interview questions, I saw no major differences between the nontreatment and treatment units.

After instruction, students improved their nontreatment and treatment unit pretest scores by an average of 35% and 44%, respectively. Table 6 compares the average test scores of three nontreatment units (two occurred before the action research project) and one treatment unit. In order to more accurately compare the two units, I calculated an average gain score ((posttest-pretest)/(100-pretest)) for each unit. The average gain score in the treatment unit was 3.5% lower than in the nontreatment unit. Only four of the eight students had higher gain scores after the intervention. Table 7 compares gain scores for the nontreatment and treatment unit tests.

Table 6
Comparison of Three Unit Tests Without Treatment And One Unit Test With Treatment

Unit Test (no treatment)	**Unit Test (no treatment)**	**Nontreatment Unit Posttest**	**Treatment Unit Posttest**
69.9%	59.6%	78%	68%

Table 7
Nontreatment and Treatment Unit Pretest, Posttest, and Gain Scores

	Pretest	**Posttest**	**Gain Score**
Nontreatment	43%	78%	62.5%
Treatment	24%	68%	59%

Interview questions (see Appendix B) were assessed on a scale of one to three (where one indicated a poor understanding and three indicated a complete understanding). Questions were designed to evaluate low, middle, and higher level understanding. Table 8 compares pre and postunit scores for the nontreatment and treatment units. Students were able to improve their responses to all questions after instruction, but the differences do not indicate that the metacognitive strategies used in the treatment unit improved understanding any more than regular teaching strategies.

Table 8
Comparison of Nontreatment and Treatment Unit Interview Scores (Using A 1-2-3 Scale)

	Low Cognitive Question	Middle Cognitive Question	High Cognitive Question
Nontreatment Preunit	1.0	1.0	1.7
Nontreatment Postunit	2.2	1.7	2.2
Treatment Preunit	1.7	1.0	1.5
Treatment Postunit	2.0	1.5	2.2

Students were able to demonstrate learning after instruction in both units. When asked to describe how polar bears must adapt to the increasing global temperatures to avoid extinction (nontreatment unit high-level cognitive question), student responses in the preunit interviews were: “Swim to another place or eat while they swim,” “Grow gills so they could survive in the water,” and, “mate before swimming or move to a different place.” Out of the six students interviewed, only one demonstrated a strong understanding of the material prior to the unit. She said that “…if they all just die, they wouldn’t have time to evolve. They could evolve if they had thousands of years, but for now they’re just in trouble.”

The postunit responses, while better, were still not completely on target. The students who gave the above comments said in the postunit interview that “they could lose hair, eat fish while on their way to the next chunk of ice, swim faster, and lose weight as they swim,” “if there’s no more ice they have to either learn to live in another environment or evolve gills,” and, “they can either change their physical traits, or change their habitat.” Responses such as these were problematic because they suggest that students believe that organisms choose to evolve.

Though not reflected in the numerical data, probably due to the averaging of student scores, some students were able to articulate their responses in the treatment unit interviews much more clearly than in the nontreatment unit. I also saw a much better use of conceptual vocabulary terms.

When given a picture of directional selection, students were asked to come up with a scenario that could explain what the diagram showed (middle-level treatment unit question). One student, in his preunit interview, said that the picture showed “the

distribution of traits in a species before and after natural selection." At the end of the unit, he was able to give the example of "beak size growing because drought caused no little seeds." Another student responded that the picture showed a "change in how long it took," in the preunit interview (though I'm not sure what was meant by "it"), and, "a group of frogs eating easy, then the food gets higher up [off of the ground] so they [the frogs] have to grow longer necks." In other words, this student was describing a situation in which a group of frogs needed to adapt to higher-growing vegetation.

When asked to summarize how isolation leads to speciation (low-level treatment unit question), one student's response changed from, "to more isolated the more species becomes the same," in the preunit interview to, "once the population splits, the genetic pools can change, causing reproductive isolation," in the postunit interview.

In comparing prelesson to postlesson reflections and formative assessments throughout the treatment unit, it was evident that some students were able to improve their conceptual understanding while others were not. When asked, "from where do new species come?", one student who did gain a better understanding wrote that "new species can come from mutations and gene shuffling," in his prelesson reflection, and in his postlesson reflection attributed the formation of new species to "geographic, behavioral, and temporal isolation". When asked to compare the two reflections, he wrote: "prior to the lesson I thought that speciation happened by mutations and gene shuffling. Now I know that's not right. That stuff gives us different phenotypes."

Another student who demonstrated a better understanding wrote in a prelesson reflection that "…eventually after one species changes over time, the new organisms are so much different from the original that it is considered a new species." Her postlesson

response to the same question was that new species form "by geographic isolation. Eventually, if the two populations change enough, it may form a new species."

One of the students who did not demonstrate a better understanding wrote in his prelesson reflection that "new species come from when there is a genetic change in the DNA; kind of like a donkey and a horse, when they breed the genetics change and form what we call a mule." After instruction, he wrote, "when two different species mate and can produce offspring causing alleles to change within the new species causing a new species kind of like horse + donkey = mule: new species." When asked to compare the prelesson and postlesson responses, he wrote, "I thought pretty much the exact thing I have now."

Long-Term Memory of Concepts

Metacognitive strategies seemed to have a positive impact on student long-term memory of concepts. Test scores show improvement between the nontreatment posttest and delayed test and the treatment unit posttest and delayed test. The class lost an average of 11.4% in the nontreatment unit but gained 6.4% in the treatment unit. All but one student (88%) improved their long-term memory of concepts after the metacognitive strategies were used. These results can be seen in Table 9. It should be noted here that, when analyzing the posttests, I chose to consider only questions that were directly related to the questions on the delayed test.

Table 9
Nontreatment and Treatment Posttest Versus Delayed Test Scores

	Posttest	**Delayed Test**
Nontreatment	81.1% (SD= 14.7)	69.8% (SD = 13.2)
Treatment	71.5% (SD = 14.8))	77.9% (SD= 20.1)

While test data show improvement, the students' opinions about their long-term memory did not change much. When asked how much information they typically remember from one unit to the next, most students reported "some". For the pretreatment unit, one student claimed she remembered "only a little bit", five said "some", and two said "most". After the treatment unit, one said a little bit (this was the same person as in the pretreatment survey), six said some, and only one claimed to remember most of the information.

Of the eight students, only one changed her response after the treatment. Her opinion of her ability to remember information long-term declined from "most" to "some". On the pretreatment survey, this student said, "I forget some of the small details about things." After the treatment, she wrote, "I forget things pretty easily."

The other seven students (88%) did not change their opinions after the intervention. The student who reported remembering only a little bit in both surveys commented, "I focus on what I'm learning" in the pretreatment survey, and, "It's hard to remember something from a long time ago" in the posttreatment survey. The student who claimed to remember most things in both surveys said, "I can remember most things" in the pretreatment survey, and, "I remember a lot" in the post-treatment survey.

Student Attitudes

The results of using metacognitive strategies on student attitudes were inconclusive. According to the teacher reflections, student attitude and motivation declined on average by .3 points during the treatment unit. Students' attitudes were much more positive on days when they were engaged in hands-on activities than when they were working out of the book. Reading and comprehension are a problem with several

members of this class, and since the treatment unit required students to work out of the book more often than the nontreatment unit, it is not surprising that their attitudes declined.

Pretreatment and posttreatment student interviews also showed a decline in attitude. Before the treatment, when asked, "Do you look forward to coming to class?", five students (83%) said yes and one student (17%) said sometimes. However, two of the students who said they looked forward to going to class admitted that it was because lunch followed the class period. One student told me, "Science is not my thing. I enjoy the projects, but not reading. It's hard to understand." Another said, "Yeah. It's the only class we actually learn in. We learn something new every day."

After the treatment, four students (67%) said they looked forward to class and two (33%) said they sometimes looked forward to it. One of the higher achieving students said, "…it's not boring like the rest. It has that sort of fun feeling when you walk in the room." Another student commented, "I learn most in Biology and something new is taught every day." When asked what they didn't enjoy, several students commented, "Tests." Another said that she hated, "anything that has to do with math."

Students seemed to appreciate the value of the reflection journals. When asked about their usefulness, one student said, "It helped me after I re-answered the same question" (she was referring to times when they had to compare a prelesson and postlesson reflection). Another said, "They made me think about the material and ask myself questions." This comment articulates the very thing I was hoping students would gain from the treatment- the ability to internalize information and recognize points that caused confusion.

Pretreatment and posttreatment surveys showed a small improvement in student attitude. When asked to evaluate if their peers are excited to learn Biology, prior to the treatment, seven students (88%) said somewhat and one (12%) said not at all. The student who said "not at all" offered the comment, "None of them enjoy class. We would all rather be sleeping." After the treatment, only two students changed their response: six (75%) now said "somewhat" and two (25%) said, "very". The student who made the comment about her peers not enjoying class changed her answer from "not at all" to "somewhat". Her rationale was that, "some don't want to learn at all." The other student improved from "somewhat" on the pretreatment survey to "very" on the posttreatment survey. This student's comment before starting the research was, "Just depends on what we are learning and the difficulty of it." After the research, she said, "This is the class I've seen them try the hardest in so it must interest them."

Similar results were seen when students were surveyed about their own excitement to learn in class. Before the treatment, seven (88%) said somewhat, and one (12%) said very. After the treatment, those numbers improved to six (75%) somewhats and two (25%) verys. Only one student changed his answer. On the pretreatment survey, he reflected, "Biology isn't my favorite class, but it also has its ups like its downs." After the treatment, he commented, "I'm learning a lot of new things I've never known about!"

The metacognitive strategy that the students seemed to most enjoy was the peer justification. This is a very outspoken and social group, so they really seemed to benefit from working together. In one particular activity, I divided the class into two groups (one with four boys and the other with four girls) and had them work through a lesson describing mechanisms of evolutionary change. In their groups, they were to read the

information and answer a series of questions. During this time, I walked around and listened to their discussions. Both groups had disagreements, and when they figured out that I wasn't going to give away any answers, started defending themselves by going back through the packet and pointing out to their group members where they found the information. During this time, one student smiled really big and said, "I really like this!" Another student wrote in her reflection journal, "Doing activities in groups help me learn more. I think it's because everyone contributes to it, we all have our own version of the right answer. It also makes you think about your own answers and how to make your answers better."

Something I asked students to do in the treatment unit was to examine their attitudes about their learning preferences. After teaching an objective in the treatment unit, I listed all the relevant learning activities we did and then had students reflect on which ones helped them to learn best, and why, and which ones didn't help them to learn, and why. It was interesting how much their attitudes varied.

For example, one student claimed that the vocab sheets (a strategy used in both units) helped her learn best. She said, "The vocab sheets help me because they give me the opportunity to look back very quickly and see what I wrote and my way to remember it." Another student commented on the vocab sheets by saying, "The vocab sheets didn't really help with the section because I don't really know what the definition means when I write them down."

QUAD notes was another strategy that was met with mixed attitudes. When asked to identify which learning activities helped the student to better understand the material, about half the class identified the QUAD notes. One student wrote, "The

QUAD notes help me because they make me go a lot deeper into the section by making me put down what I learned and what was interesting to me." Another wrote, "QUAD notes helped me because I get to write down my thoughts and then I also remember it because I'm writing it down." One student even expressed the desire to use them in other classes. "I want to make a QUAD note for my English class, because I learn a lot off of them. I can write down what's interesting, confusing, and what I know."

Other students didn't feel the QUAD notes helped them learn. "I feel like I'm just reading and writing stuff down, but not really learning anything," wrote one student. Another wrote, "I feel like it takes long, and while I think of what I know, learned, and have questions about, I forget what I have just read."

Several students indicated a struggle with reading the sections in the text. "Reading in the books is a little difficult because they use too big of words and it's very hard to understand," wrote one student. Another wrote, "The reading doesn't help me at all because the things are made to sound way more complicated and hard to understand."

After reading comments like these, I decided to try a summarizing activity. In the supplemental materials that came with my textbook package, I have a book of one-page section summaries. For our last section in the treatment unit, I gave each student a copy of the summary and asked them to further summarize it. We started by reading through it, one paragraph at a time, and highlighting the key terms and phrases. I then had each student summarize every paragraph in a sentence of ten words or less.

Students were responsive to this activity. All but two reported in their reflection journals that the summaries helped them understand the material better. One student said, "The summaries help the most, because I have to summarize the big scientific words

into my own little understanding words. They help me on what's being said and what's happening." One student who claimed it didn't help wrote, "Section summaries really didn't help me that much. I really don't know why."

The last question in the posttreatment interview was, "What have you learned about yourself and your own learning throughout the last six weeks?" Several students were able to identify specific learning strategies that they could use to be better learners. "It's a lot easier if we explain everything we learned and do postlesson reflections," said one student. Another said, "I learned that I need to re-read things I don't understand." Another student commented, "I learn through activities; reading in books doesn't really help me."

Teacher Motivation

The use of metacognitive strategies during instruction produced extremely small differences in the level of teacher motivation and therefore constituted no overall change. The teacher reflection forms, which allowed me to self-evaluate my enthusiasm and motivation on a scale of one through five (one being least motivated and five being most), had only a .2 average increase between the nontreatment and treatment units (3.8 and 4.0, respectively).

Pretreatment and posttreatment surveys and interviews also showed only slight changes in the level of teacher enthusiasm. However, the students' perspectives were different from my own. On a scale of one to three (where one means least excited and three means most), the average score on the surveys was 3.0 in the pretreatment and 2.9 in the posttreatment. The student who gave a score of two justified her response by commenting, "knowing how our class gets off subject, I'm sure that's why. Other than

that, pretty good." This student must have been trying to relate the class' frequent off-task behavior to my enthusiasm of teaching them.

Before treatment, five out of the six (83%) students interviewed said that the teacher always looked like she was having fun while teaching. When I asked why they said always, one responded by saying, "its how you express yourself, like your face expressions." Another said, "All the time. You always seem really into it. You're upbeat and vibrant, and give us other ways to learn it. You're really involved; you don't just give us work and then walk away."

After the treatment, four students changed their answers. One student who first rated my enthusiasm as a three in the pretreatment interview gave a five in the posttreatment interview. His pretreatment comment was, "Sometimes, when you're not yelling at everyone." After the treatment, this student said, "I think you have fun in the class and are laid back and take our jokes well, which makes class funner and more interesting." The other three students' evaluations of my enthusiasm went down, from a score of five in the pretreatment interview to four in the posttreatment. However, this decline was not supported by their comments. One of these students said in the pretreatment interview, "You explain it [the subject material] a lot better than other teachers." In the posttreatment interview, where he gave a four, he said, "You always seem excited."

These results accurately reflect how I felt about the treatment: it did not really impact my overall level of motivation. For the most part, I enjoyed teaching both units. The students were more engaged in this subject matter (Evolution) than any other topic we'd covered throughout the year (probably because the units were presented as broad,

conceptual topics rather than being filled with lots of detailed information), and I enjoyed the discussions and level of participation that occurred.

One metacognitive strategy I felt worked well was avoiding giving students direct answers to questions. About halfway through the treatment unit, one student (a lower-level learner) asked the question, "Where do all the genes come from?" Instead of directly answering his question, I told him to think back to the very first cell that ever existed and all that had to have changed between that time and the present for things to be the way they are now. I then asked him to predict what might happen if the ozone layer continues to shrink. After talking through the possibilities, he finally decided that darker skinned people would be better adapted and white (lighter) people would be selected against. I asked him what would happen to the frequency over time, and he told me that we would eventually have more dark skinned people and fewer light skinned people. He then commented, "So, we're never going to stop changing?" This was a big revelation for him, and it was fun to watch.

After a bit more discussion, I was finally able to correct a misconception that he had carried throughout the entire unit thus far- that we (organisms) don't choose to change. I explained that, as a white person, I cannot "will" my body to make darker skin. I don't know if this student ever really got his initial question answered (where do all the genes come from?), but I felt that this experience was invaluable in his understanding of the major principle of evolution and never would have happened if I had just answered his first question.

There were moments during both units when I got frustrated with the class. One day during the nontreatment unit, I noted on a reflection form that I was frustrated

because “only two kids participated in the discussion. Just half of them have the assignment finished.” The students were working through a webquest that day and I was aggravated by the amount of chatting going on. The task required students to read through a lot of information and pick out the important and relevant details. This group is not strong in their ability to read and interpret and, because of their struggles, was easily distracted and off task.

A similar event took place during the treatment unit while the students were working on QUAD notes. As I mentioned, they are not strong readers and not intrinsically motivated to try and understand things that confuse them. One student commented, “This is so dumb” (an indication that he was frustrated or bored). The group was also extra chatty that day and needed constant reminding to get back on task. In both of these examples, the students’ negative attitudes about their work directly impacted my own enthusiasm and motivation for teaching.

INTERPRETATION AND CONCLUSION

While the intervention seemed to have little or no effect on student understanding, student attitude, and teacher enthusiasm, it did seem to improve student retention of concepts over time. However, due to the large standard deviation in the test scores, the data is not statistically significant. Regardless, the higher scores on the delayed treatment posttest could have been a result of students having a better understanding of the material after all, even though the immediate test scores showed no significant gains. Instead of cramming directly before a test and forgetting everything immediately after, students may have understood the concepts better after the intervention strategies were used.

Reflection journals required students to examine and then reexamine their ideas about a given concept. They had to articulate their thoughts in their own words, instead of copying verbatim from their textbook or notes to answer questions on a worksheet. In doing QUAD notes, students had to identify concepts within the reading that did not make sense to them as well as recognize the information they already knew. By doing these types of activities, students' understanding went beyond that of rote memorization. Information became more relevant and meaningful, allowing them to retain the concepts for a longer period of time. It would seem that the use of metacognitive strategies led to a longer, more durable learning experience.

Gains in the delayed test scores during the treatment unit were surprising and are probably due to a combination of the students having a better grasp on the material and the differences in format between the posttest and delayed test. The posttest (see Appendix D) consisted of 58 multiple choice, short answer, and applications-type questions. The delayed test only had three open response questions. Students may have felt more comfortable with the delayed test because it was shorter, not worth a large portion of their grade, and more open-ended than the questions on the unit posttest.

Unfortunately, both my teaching position and the project requirements created unavoidable limitations for this action research. Limiting factors such as time constraints and a small class size made it nearly impossible to accurately determine the full effects of the intervention. This study lasted just six weeks and only consisted of one nontreatment and one treatment unit. There were only eight students participating, and the units consisted of different content, making it very difficult to compare nontreatment and treatment unit data with any degree of certainty.

While I tried to keep both units as conceptual as possible, the content within the treatment unit was inherently more difficult. The nontreatment unit was more introductory in nature and the objectives were easier to grasp (see Table 1). Treatment unit objectives were broader and required students to apply information to given situations, a higher-order (and thus more difficult) task.

It would be interesting to perform this action research again but on a bigger scale. In the future, I could do a long-term project lasting over the course of several school years. I could do this a few different ways. One option could be to teach a full year of Biology using the metacognitive strategies described in this project, and then teach another full year without them. Another option would be to teach an entire year using metacognitive strategies with all my classes (each class is a different subject), and then compare those data with a year's worth of nontreatment data from each class. Or, I could extend it even further by teaching two (or more) consecutive years using the intervention and then doing a comparison. Any of these options would be possible because I am the only science teacher in our district and teach the same groups of kids for four consecutive years. These results would be much more significant because the time and content factors would be removed.

Reading comprehension is a huge concern I have with many of my students. The Common Core Standards emphasize the importance of this skill, and I worry that many students will have difficulties passing these state assessment tests. I would like to investigate more metacognitive interventions that specifically target this issue and then promote their use my classes.

VALUE

I gained valuable insight about my teaching practices while doing this action research. The level of interest among the students and the higher-than-average unit posttest scores surprised me. I think the reason students were more interested and performed better in both the nontreatment and treatment units when compared with past units is because the quantity of information they were responsible for knowing was smaller. Typically, I give unit tests over four to five chapters' worth of information about every six weeks. In this project however, each unit was a single chapter, and we spent three weeks on each unit. Also, this material was a lot more conceptual and less detailed than my other units.

It is my belief that both the longer time frame and the decrease in required content knowledge led students to be more successful. These feelings of success could be a reason for the higher level of interest. Therefore, I plan to reconstruct my curriculum for future classes by breaking the units down into smaller sections and cutting the required content of each unit down to the core concepts.

Another insight I had while conducting this research is the necessity for a variety of learning activities. As mentioned in the Student Attitudes subsection of the Data and Analysis, different students respond differently to different types of activities. While some students claim they learn from reading, many felt it was a waste of time. Several students felt group tasks benefited them the most, while others valued independent work. Because my students are so diverse in their learning preferences, I need to diversify my teaching strategies. If I can cut the required amount of content in my curriculum, more

time can be spent doing multiple types of learning activities that reinforce the key concepts and meet the various needs of my students.

I have a newly found respect for educational research. Going into this, I had no idea the amount of work and planning a project like this required. Looking back, there are so many things I could have done differently that may have impacted the results of this study.

One of these involves the student interview process. There is so much valuable information to be gained from these interviews that students should be given maximum time to fully develop and deliver their responses to the questions. My interview sessions always felt too rushed, and I think that put a lot of pressure on my students and probably impacted the quality of their responses. Next time I will do a better job scheduling out times for these interviews. Depending on what is being evaluated, it might help to give the questions out prior to the interviews to allow students even more time to prepare. However, I wouldn't want to do this if, for example, I was assessing long-term memory because students would look up the answers before coming in.

Something else that can be improved is the quality of reflection prompts. Not all students grasped the purpose of doing the pre and postlesson reflections. This strategy could be enhanced by following a Think-Pair-Share model; after students write their initial reflections, they discuss them with a partner and then as a class. This would be repeated after the postlesson reflection, and I could facilitate the discussions over how their knowledge changed after instruction.

When going through the data, I was surprised at how few formative assessments I had. Formative assessments are so important because they allow the teacher to know,

early on, where students are confused. Had I done more frequent assessments I might have been able to identify what was causing my students problems and could have then addressed these issues. This may have improved the conceptual understanding and long-term memory outcomes of the project.

Teaching is not a new profession, but a constantly evolving one. As our students' needs change, so must our practices. By engaging in and evaluating educational research, I can be more aware of best practices and adjust my own strategies to better face the challenges within my own classroom.

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APPENDICES

APPENDIX A

STUDENT SURVEY QUESTIONS

"Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at anytime. Your participation or non-participation will not affect your grade or class standing."

Survey questions were designed to evaluate student and teacher motivation. Questions were given both prior to and after completing the action research.

1. How much do you normally understand in this class? Circle your choice:

1- nothing	2- a little bit	3- some	4- most	5- everything

Why did you choose that number?

2. What motivates you to learn in this class (parents, grades, love of the subject, etc)? Explain.

3. How often do you study outside of class? Circle your choice:

1- never	2- just before a test or quiz	3- once a week	4- a couple times a week	5- every day

Explain how you normally study.

4. How much do you typically remember from one unit to another?

1- nothing	2- a little bit	3- some	4- most	5- everything

Explain why you chose that answer.

5. How excited do you think your peers are to learn in this class? Circle one.

1- not at all	2- somewhat	3- very

Explain why you answered the way you did:

6. How excited are you to learn in this class? Circle one.

1- not at all	2- somewhat	3- very

Explain why you answered the way you did:

7. How excited does Mrs. Robbins seem to be about teaching this class? Circle one:

1- not at all	2- somewhat	3- very

Explain why you answered the way you did:

APPENDIX B

STUDENT INTERVIEW QUESTIONS

"Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at anytime. Your participation or non-participation will not affect your grade or class standing."

Student interview questions were designed to evaluate: student understanding of the content, long term retention of the subject matter, motivation to learn, and teacher enthusiasm to teach. Each interview was digitally recorded on an audio capture device.

Question set one addressed understanding of current unit material. Students were interviewed both before and after each unit. High, middle, and low cognitive questions were asked to each student, and responses were assessed using the 1-2-3 scale (1= poor understanding, 2= partial understanding, 3= complete understanding).

Unit One:
Low: In a single sentence, try to summarize the theory of evolution.
Middle: Why is evolution considered a scientific theory?
High: With increasing global temperatures, icebergs and glaciers (home to polar bears) are melting. Polar bears must now swim long distances between chunks of ice, and many are drowning. How might polar bears adapt so that their species don't go extinct?

Unit Two:
Low: Try to summarize how isolation leads to speciation.
Middle: Show student a diagram of directional selection. Ask: Can you give a scenario of what this diagram is showing?
High: Someone suggested that shuffling a deck of cards before dealing out a hand is a good analogy for the effect sexual reproduction has on the frequency and combination of alleles in a population. Do you think this is a good analogy? Why or why not?

Question set two addressed long-term retention of concepts. The questions were delivered two weeks after completion of the unit.

Unit One: Unit One Interview Question Set, given two weeks after the Unit One posttest

Unit Two: Unit Two Interview Question Set, given two weeks after the Unit Two posttest

Question set three addressed student motivation and was given prior to starting and after completing the action research:

Pretreatment: Do you look forward to coming to class? Explain. What do you think we'll be learning about in the next six weeks? Are there any parts you're excited to learn? Anything you're not looking forward to? What do you think will be the most important concept we cover?

Posttreatment: Do you look forward to coming to class? Explain. What, specifically did you like about this unit? Why? Were there any parts you didn't like? Why? What do you think was the most important concept we learned? How come? How is this information useful beyond this class? What were your thoughts on the reflection journals? Do you feel that they helped you to understand the material? Did you enjoy reflecting on the prompts? Why or why not? What have you learned about yourself and your own learning throughout the last six weeks?

Question set four addressed teacher enthusiasm and was given both prior to starting and after completing the action research:

How often do I look like I'm having a lot of fun teaching you guys? How often do I seem bored? Explain.

Question five was left open ended and was consistent from unit to unit:

Is there anything else you'd like to say about what we've been doing in class?

APPENDIX C

TEACHER REFLECTION FORM

Teacher DAILY Reflection Form

Date: _____

Nontreatment Unit Treatment Unit (circle one)

Content Objective:

_____

_____

Learning Activities:

_____

_____

Rate on a scale of 1-5 (1 being very low and 5 being very high), my perception of:

1. My Enthusiasm for teaching: _____
Comments:

2. My Motivation for teaching: _____
Comments:

3. My preparation for teaching: _____

4. Student Motivation to learn: _____
Comments:

6. Students' Attitude (1= poor, 5=great): _____
Comments:

7. Describe any "Ah-ha" or "Uh-oh" moments:

APPENDIX D

PRETESTS AND POSTTESTS WITH DELAYED QUESTIONS

NOTE: The unit pretests were the same as the unit posttests. Delayed unit questions were given nine days following the unit posttest.

Unit 1 (Nontreatment) Test — Chapter 15

Name: _____

Multiple Choice
Identify the choice that best completes the statement or answers the question.

____ 1. Darwin noticed that many organisms seemed well suited to
a. being preserved as fossils.
b. providing humans with food.
c. surviving in the environment they inhabited.
d. swimming from South America to the Galapagos Islands.

____ 2. On the Galápagos Islands, Charles Darwin observed
a. completely unrelated species on each of the islands.
b. species exactly like those found in South America.
c. somewhat similar species, with traits that suited their particular environments.
d. species completely unrelated to those found in South America.

____ 3. The species of finches that Charles Darwin found on the Galápagos Islands displayed different structural adaptations. One of the adaptations that Darwin noted was the
a. similarities of the birds' embryos.
b. birds' different-shaped beaks.
c. length of the birds' necks.
d. number of eggs in each bird's nest.

____ 4. Based on the adaptations Charles Darwin observed in finches and tortoises in the Galápagos, he wondered
a. if species living on different islands had once been members of the same species.
b. if finches and tortoises had originated from the same ancestral species.
c. if all birds on the different islands were finches.
d. why all tortoises on the different islands were identical.

____ 5. Darwin began to formulate his concept of evolution by natural selection after
a. experimentation with animals.
b. observations of many species and their geographical location.
c. reading the writings of Wallace.
d. agreeing with Lamarck about the driving force behind evolution.

____ 6. In the 1800s, Charles Lyell emphasized that
a. the human population will outgrow the available food supply.
b. all populations evolve through natural selection.
c. Earth is a few thousand years old.
d. past geological events must be explained in terms of processes observable today.

____ 7. James Hutton's and Charles Lyell's work was important to Darwin because these scientists
   a. explained volcanoes and earthquakes.
   b. explained all geologic events on Earth.
   c. suggested that Earth was old enough for evolution to have occurred.
   d. refuted the work of Lamarck, which was based on misunderstandings.

____ 8. Which is a major concept included in Lamarck's theory of evolution?
   a. Change is the result of survival of the fittest.
   b. Body structure can change according to the actions of the organism.
   c. Population size decreases the rate of evolution.
   d. Artificial selection is the basis for evolution.

____ 9. Lamarck's theory of evolution includes the concept that new organs in a species appear as a result of
   a. continual increases in population size.
   b. the actions of organisms as they use or fail to use body structures.
   c. an unchanging local environment.
   d. the natural variations already present within the population of organisms.

____ 10. In an experiment, suppose that the wings of fruit flies were clipped short for fifty generations. The fifty-first generation emerged with normal-length wings. This observation would tend to disprove the idea that evolution is based on
   a. inheritance of natural variations.
   b. inheritance of acquired characteristics.
   c. natural selection.
   d. survival of the fittest.

____ 11. Darwin realized that the economist Malthus's theory of population control
   a. applied only to humans.
   b. could be generalized to any population of organisms.
   c. could be generalized only when populations lived in crowded conditions.
   d. explained why the number of deaths exceeded that of births.

____ 12. In 1859, Charles Darwin published his revolutionary scientific ideas in a work titled
   a. *Principles of Geology.*
   b. *Essay on the Principle of Population.*
   c. *Evolution in Malaysia.*
   d. *On the Origin of Species.*

____ 13. Darwin was prompted to publish his theory of evolution by
   a. an essay by Wallace on evolution.
   b. the publication of Lamarck's theory of evolution.
   c. the vice governor of the Galápagos Islands.
   d. the work of Hutton and Lyell.

____ 14. When Charles Darwin returned from the voyage of the *Beagle*, he
a. immediately published his ideas about evolution.
b. realized his ideas about evolution were wrong.
c. wrote about his ideas but waited many years to publish them.
d. copied the evolutionary theory of Wallace.

____ 15. Why might Darwin have hesitated to publish his concept of evolution by natural selection?
a. He realized it was not supported by his data.
b. He felt it was too similar to Lamarck's to be considered original.
c. He was disturbed by his findings, which challenged fundamental scientific beliefs.
d. He realized that his idea was contradicted by the work of Hutton and Lyell.

____ 16. Charles Darwin's observation that finches of different species on the Galápagos Islands have many similar physical characteristics supports the hypothesis that these finches
a. have the ability to interbreed.
b. acquired traits through use and disuse.
c. all eat the same type of food.
d. descended from a common ancestor.

____ 17. According to Darwin's theory of natural selection, individuals who survive are the ones best adapted for their environment. Their survival is due to the
a. possession of adaptations developed through use.
b. possession of inherited adaptations that maximize fitness.
c. lack of competition within the species.
d. choices made by plant and animal breeders.

____ 18. When a farmer breeds only his or her best livestock, the process involved is
a. natural selection.
b. artificial selection.
c. artificial variation.
d. survival of the fittest.

____ 19. When lions prey on a herd of antelopes, some antelopes are killed and some escape. Which part of Darwin's concept of natural selection might be used to describe this situation?
a. acquired characteristics
b. reproductive isolation
c. survival of the fittest
d. descent with modification

____ 20. Which statement about the members of a population that live long enough to reproduce is consistent with the theory of natural selection?
a. They transmit characteristics acquired by use and disuse to their offspring.
b. They tend to produce fewer offspring than others in the population.
c. They are the ones that are best adapted to survive in their environment.
d. They will perpetuate unfavorable changes in the species.

____ 21. Charles Darwin called the ability of an organism to survive and reproduce in its specific environment
a. diversity.
b. fitness.
c. adaptation.
d. evolution.

____ 22. According to Darwin's theory of natural selection, the individuals that tend to survive are those that have
a. characteristics their parents acquired by use and disuse.
b. characteristics that plant and animal breeders value.
c. the greatest number of offspring.
d. variations best suited to the environment.

____ 23. Which of the following phrases best describes the results of natural selection?
a. the natural variation found in all populations
b. unrelated species living in different locations
c. changes in the inherited characteristics of a population over time
d. the struggle for existence undergone by all living things

____ 24. An adaptation is an inherited characteristic that can be
a. physical or behavioral.
b. physical or geographical.
c. acquired during the organism's lifetime.
d. the result of artificial selection.

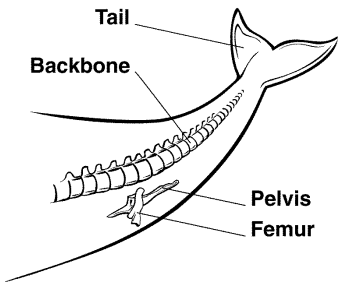


Figure 15–1

____ 25. In humans, the pelvis and femur, or thigh bone, are involved in walking. In whales, the pelvis and femur shown in Figure 15–1 are
a. examples of fossils.
b. vestigial structures.
c. acquired traits.
d. examples of natural variation.

____ 26. Modern sea star larvae resemble some primitive vertebrate larvae. This similarity may suggest that primitive vertebrates
a. share a common ancestor with sea stars.
b. evolved from sea stars.
c. evolved before sea stars.
d. belong to the same species as sea stars.

____ 27. Darwin's concept of evolution was NOT influenced by
a. the work of Charles Lyell.
b. knowledge about the structure of DNA.
c. his collection of specimens.
d. his trip on the H.M.S. *Beagle*.

____ 28. People of Charles Darwin's time understood that fossils
a. were preserved remains of ancient organisms.
b. were available for every organism that ever lived.
c. were unrelated to living species.
d. were evidence for the evolution of life on Earth.

____ 29. The number and location of bones of many fossil vertebrates are similar to those in living vertebrates. Most biologists would probably explain this fact on the basis of
a. the needs of the organisms.
b. a common ancestor.
c. the struggle for existence.
d. the inheritance of acquired traits.

____ 30. Charles Darwin viewed the fossil record as
a. evidence that Earth was thousands of years old.
b. a detailed record of evolution.
c. interesting but unrelated to the evolution of modern species.
d. evidence that traits are acquired through use or disuse.

____ 31. The hypothesis that species change over time by natural selection was proposed by
a. James Hutton.
b. Jean-Baptiste Lamarck.
c. Thomas Malthus.
d. Charles Darwin.

____ 32. Charles Darwin's theory of evolution explains all of the following EXCEPT
a. how species become extinct.
b. how inherited traits are passed from parent to offspring.
c. how species change over time.
d. how evolution takes place in the natural world.

____ 33. Darwin's theory of evolution suggests that
a. species change over time.
b. extinct species are not related to living species.
c. different species can interbreed.
d. animals that look alike are the most closely related.

____ 34. Darwin's theory of evolution is based on the idea(s) of
a. heritable variation and natural selection.
b. use and disuse.
c. a tendency toward perfect, unchanging species.
d. the transmission of acquired characteristics.

____ 35. Which concept is NOT included in the modern theory of evolution?
a. descent with modification
b. natural selection
c. transmission of acquired characteristics
d. competition among the members of a population

____ 36. Which phrase best defines evolution by natural selection?
a. an adaptation of a species to its environment
b. a sudden replacement of one population by another
c. changes in a species as it becomes more perfect
d. a process of change in species over time

Short Answer (answer on a separate sheet of paper, please)

37. In what way did the voyage of the *Beagle* provide Charles Darwin with an ideal opportunity for collecting and analyzing data?

38. State a general observation that Charles Darwin made about organisms and their environments.

39. What did Charles Darwin learn about the land tortoises of the various Galápagos Islands?

40. What did observations of the tortoises of the Galápagos lead Charles Darwin to hypothesize about these animals' ancestry?

41. What did Charles Darwin discover about the Galápagos birds that he thought were different kinds of wrens, warblers, and blackbirds?

42. Were Darwin's hypotheses about natural selection and evolution similar to the ideas of most other scientists of his time? Explain.

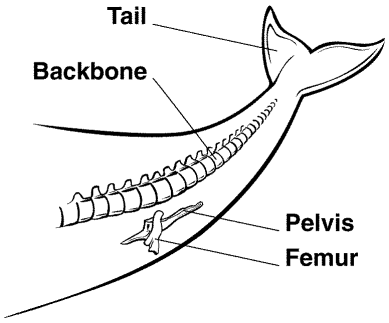


Figure 15–1

43. How could structures like the whale pelvis and femur shown in Figure 15–1 contribute to the theory of evolution?

44. Summarize Charles Darwin's contribution to science.

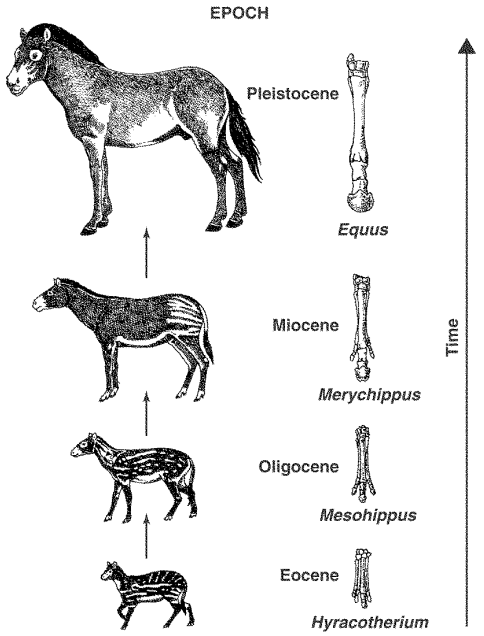


Figure 15–2

45. **Interpreting Graphics** According to Figure 15–2, how did overall body size of the horse change during its evolution?

46. **Observing** In Figure 15–2, how does the size of the head change as the horse evolves?

47. **Inferring** Scientists have never seen the ancient horses shown in Figure 15–2. What do you think was the main type of evidence scientists used to prepare these diagrams?

48. **Inferring** Does Figure 15–2 show that all species get much larger as they evolve?

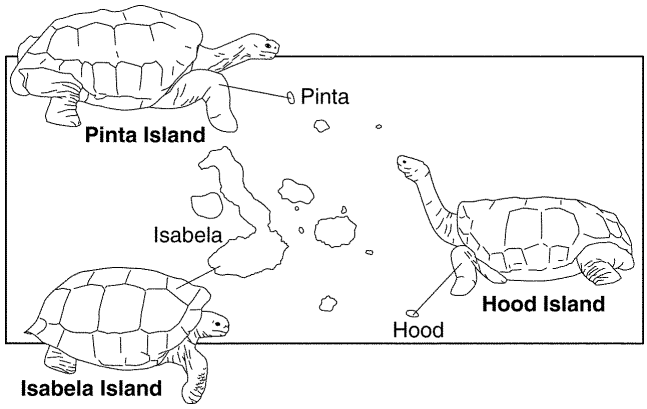


Figure 15–3

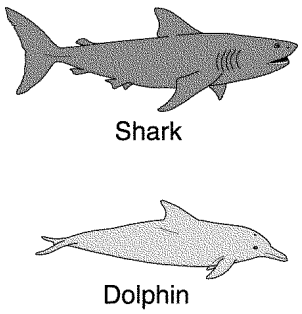
49. **Interpreting Graphics** What differences are apparent in the bodies of the three tortoise species shown in Figure 15–3?

50. **Interpreting Graphics** Which of the tortoises shown in Figure 15–3 has the longest neck?

51. **Applying Concepts** Can you tell from Figure 15–3 how closely the three tortoise species resemble the ancestral species? Why or why not?

52. **Inferring** Vegetation on Hood Island is sparse and sometimes hard to reach. How might the vegetation have affected the evolution of the Hood Island tortoise shown in Figure 15–3?

53. **Forming Hypotheses** Considering the body structure of the tortoises shown in Figure 15–3, which tortoises—a population from Pinta Island or a population from Isabela Island—might survive more successfully on Hood Island? Why?



Comparison of Two Vertebrates		
Characteristics	**Shark**	**Dolphin**
Habitat	Ocean	Ocean
Type of Vertebrate	Fish	Mammal
Composition of Skeleton	Cartilage	Bone
Type of Teeth	Large numbers of sharp teeth	Large numbers of sharp teeth
Respiration	Breathes in water	Breathes in air

Figure 15–4

54. **Applying Concepts** Charles Darwin would say that sharks like the one in Figure 15-4 exhibit fitness. Explain what that means, and discuss two specific adaptations as part of your explanation.

55. **Comparing and Contrasting** Sharks and dolphins, which belong to different vertebrate groups, are not closely related. How can Darwin's ideas about evolution help explain such a similar appearance?

56. **Predicting** Suppose a dolphin population becomes trapped in a harbor that is growing smaller and more shallow because of climate changes. Is it likely that the dolphins would evolve into a land-dwelling species in a few thousand years? Explain your answer.

Unit 1 Delayed Questions (given 9 days after posttest)

1. Explain how the finches and tortoises that Charles Darwin observed on the Galapagos Islands influenced his thinking.

2. What sources of evidence did Charles Darwin consider when he presented his concept of evolution by natural selection?

3. What might happen if a well-adapted population experienced sudden major changes in its environment?

Unit 2 (Treatment Unit) Test Chapter 16

Name: _____

Multiple Choice
Identify the choice that best completes the statement or answers the question.

____ 1. Which of the following statements describe what all members of a population share?
a. They are temporally isolated from each other.
b. They are geographically isolated from each other.
c. They are members of the same species.
d. They have identical genes.

____ 2. All the genes of all members of a particular population make up the population's
a. relative frequency.
b. phenotype.
c. genotype.
d. gene pool.

____ 3. Which statement below about gene pools is typically true?
a. They often contain some traits with two or more alleles.
b. They contain only dominant alleles.
c. They belong to two or more interbreeding species.
d. The relative frequencies of the alleles never change.

____ 4. Interbreeding among members of a population results in
a. different types of alleles in the gene pool.
b. changes in the relative frequencies of alleles in the gene pool.
c. no changes in the relative frequencies of alleles in the gene pool.
d. an absence of genetic variation in the population.

____ 5. In a population, the sum of the relative frequencies of all alleles for a particular trait is
a. equal to 100 percent.
b. equal to the number of alleles for the trait.
c. constantly changing.
d. dependent on the number of alleles.

____ 6. A change in a sequence of DNA is called a
a. recombination.
b. polygenic trait.
c. single-gene trait.
d. mutation.

____ 7. The two main sources of genetic variation are
a. genotypes and phenotypes.
b. gene shuffling and mutations.
c. single-gene traits and polygenic traits.
d. directional selection and disruptive selection.

____ 8. In organisms that reproduce sexually, inheritable variation is due mostly to
a. mutations during gamete formation.
b. polygenic traits.
c. gene shuffling during gamete formation.
d. the effects of radiation.

____ 9. Gene shuffling includes the independent movement of chromosomes during meoisis as well as
a. mutations from radiation.
b. changes in the frequencies of alleles.
c. crossing-over.
d. mutations from chemicals.

____ 10. In a particular population, sexual reproduction can produce
a. mutations.
b. many different phenotypes.
c. new allele frequencies.
d. meiosis.

____ 11. The gene shuffling that occurs as part of sexual reproduction
a. changes the gene pool's allele frequencies.
b. does not change the gene pool's allele frequencies.
c. keeps the phenotypes consistent.
d. is caused by radiation or chemicals.

____ 12. Natural selection acts directly on
a. alleles.
b. genes.
c. individual organisms.
d. mutations.

____ 13. Which of the following is NOT a way in which natural selection affects the distribution of phenotypes?
a. directional selection
b. stabilizing selection
c. disruptive selection
d. chance events

____ 14. When individuals at only one end of a bell curve of phenotype frequencies have high fitness, the result is
a. directional selection.
b. stabilizing selection.
c. disruptive selection.
d. genetic drift.

____ 15. When individuals with an average form of a trait have the highest fitness, the result is
a. not predictable.
b. disruptive selection.
c. directional selection.
d. stabilizing selection.

____ 16. In a population of finches in which one group of birds has a short, parrotlike beak and another group has a long, narrow beak, what process has probably occurred?
a. directional selection
b. disruptive selection
c. stabilizing selection
d. genetic drift

____ 17. If a mutation introduces a new skin color in a lizard population, which factor might determine whether the frequency of the new allele will increase?
a. how many other alleles are present
b. whether the mutation makes some lizards more fit for their environment than other lizards
c. how many phenotypes the population has
d. whether the mutation was caused by nature or by human intervention

____ 18. In genetic drift, allele frequencies change because of
a. mutations.
b. chance.
c. natural selection.
d. genetic equilibrium.

____ 19. Which of the following events do biologists consider a random change?
a. directional selection
b. speciation
c. disruptive selection
d. genetic drift

____ 20. Genetic drift tends to occur in populations that
a. are very large.
b. are small.
c. are formed from new species.
d. have unchanging allele frequencies.

____ 21. The type of genetic drift that follows the colonization of a new habitat by a small group of individuals is called
a. the Hardy-Weinberg principle.
b. the founder effect.
c. directional selection.
d. stabilizing selection.

____ 22. One similarity between natural selection and genetic drift is that both events
a. are based completely on chance.
b. begin with one or more mutations.
c. involve a change in a population's allele frequencies.
d. take place only in very small groups.

____ 23. The situation in which allele frequencies of a population remain constant is called
a. evolution.
b. genetic drift.
c. genetic equilibrium.
d. natural selection.

____ 24. One of the conditions required to maintain genetic equilibrium is
a. natural selection.
b. mutations.
c. nonrandom mating.
d. no movement into or out of the population.

____ 25. The genetic equilibrium of a population can be disturbed by each of the following EXCEPT
a. nonrandom mating.
b. movement into and out of the population.
c. a large population size.
d. mutations.

____ 26. The allele frequencies of a population are more likely to remain unchanged if
a. the population size is reduced.
b. frequent movement into and out of the population occurs.
c. all mating is random.
d. the mutation rate increases.

____ 27. According to the Hardy-Weinberg principle, genetic equilibrium would be more likely in a population of mice if
a. the population size rapidly decreases.
b. mutation rates within the population rise.
c. no natural selection takes place.
d. there is frequent movement into and out of the population.

____ 28. Which factor would most likely disrupt genetic equilibrium in a large population?
a. the production of large numbers of offspring
b. mating that is not random
c. the absence of movement into and out of the population
d. the absence of mutations

____ 29. The separation of populations by barriers such as rivers, mountains, or bodies of water is called
a. temporal isolation.
b. geographic isolation.
c. behavioral isolation.
d. genetic equilibrium.

____ 30. A factor that is necessary for the formation of a new species is
a. reproduction at different times.
b. geographic barriers.
c. different mating behaviors.
d. reproductive isolation.

____ 31. What situation might develop in a population having some plants whose flowers open at midday and other plants whose flowers open late in the day?
a. behavioral isolation
b. geographic isolation
c. temporal isolation
d. genetic drift

____ 32. The geographic isolation of two populations of a species tends to increase differences between their gene pools because it
a. prevents interbreeding between the populations.
b. prevents interbreeding within each population.
c. causes temporal isolation of the two populations.
d. increases differences in courtship behavior.

____ 33. Although they often live in the same habitat, the American toad breeds earlier in the spring than the Fowler's toad does. What can be inferred from this information?
a. The two species do not interbreed because of geographic isolation.
b. The two species do not interbreed because of temporal isolation.
c. The two species interbreed throughout the spring season.
d. The American toad will cause the extinction of the Fowler's toad.

____ 34. Which is the first step that occurred in the speciation of the Galápagos finches?
a. establishing genetic equilibrium
b. behavioral isolation
c. ecological competition
d. arrival of the founding population

____ 35. The Galápagos finch species are an excellent example of
a. speciation.
b. genetic equilibrium.
c. stabilizing selection.
d. selection on single-gene traits.

Short Answer (use a seperate sheet of paper, please)

36. Explain how you could calculate the relative frequency of an allele in a gene pool.
37. What are the two main sources of genetic variation? Which of them is more common?
38. What does a bell-shaped curve showing the phenotypes for human height indicate about the relative number of very short and very tall people?
39. Is an allele for a trait that has no effect on a species' fitness affected by natural selection? Explain.
40. Why might genetic drift occur if a small number of individuals colonize a new habitat?
41. List the five conditions necessary to maintain genetic equilibrium in a population.
42. Which population, one of nearly identical organisms or one of phenotypically varied organisms, would be more likely to remain in genetic equilibrium?
43. Why might a geographic barrier such as a large river cause the formation of a new species of small rodents but not a new species of birds?
44. What are three mechanisms for reproductive isolation? Which mechanism isolates two populations of similar frogs with different mating calls?
45. What are the major steps that were likely involved in the speciation of the Galápagos finches?

Other

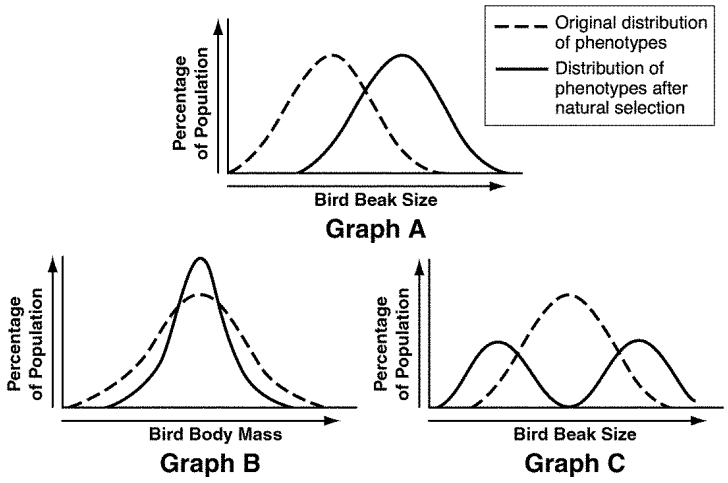


Figure 16–1

46. **Interpreting Graphics** According to Graph A in Figure 16–1, what has occurred?
47. **Interpreting Graphics** According to Graph B in Figure 16–1, what has occurred?
48. **Interpreting Graphics** According to Graph C in Figure 16–1, what has occurred?
49. **Inferring** Which of the three graphs shown in Figure 16–1 might show a population of birds with members that specialize in different types of food? Explain.
50. **Inferring** What factors or conditions might have led to the change shown in Graph A of Figure 16–1?

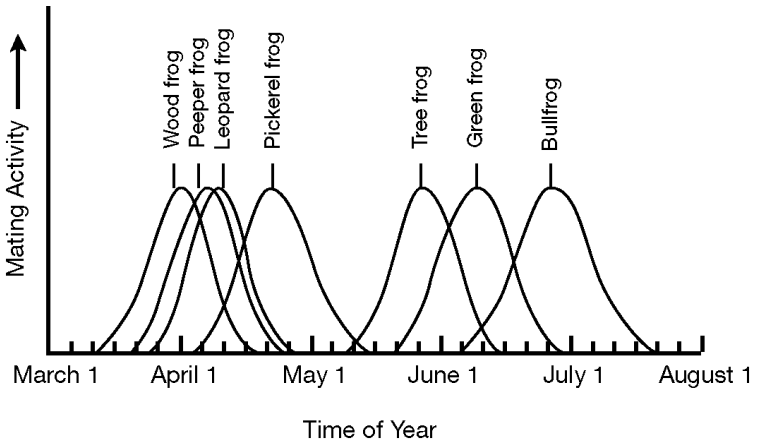


Figure 16–2

51. **Interpreting Graphics** Describe the information about frog species that is shown in Figure 16–2.

52. **Inferring** Based on Figure 16–2, what mechanism appears to keep bullfrogs reproductively isolated? Would that mechanism necessarily be the only isolating mechanism? Explain.

53. **Inferring** Peeper frogs and leopard frogs do not interbreed even when they share a habitat. Use the information in Figure 16–2 to determine what mechanism probably keeps the two species reproductively isolated.

54. **Predicting** Frog mating does not occur in cold weather. Assume that the mating times shown in Figure 16–2 are for frogs in the northern part of the United States. How might these curves change for frogs in the southern part of the United States? Explain.

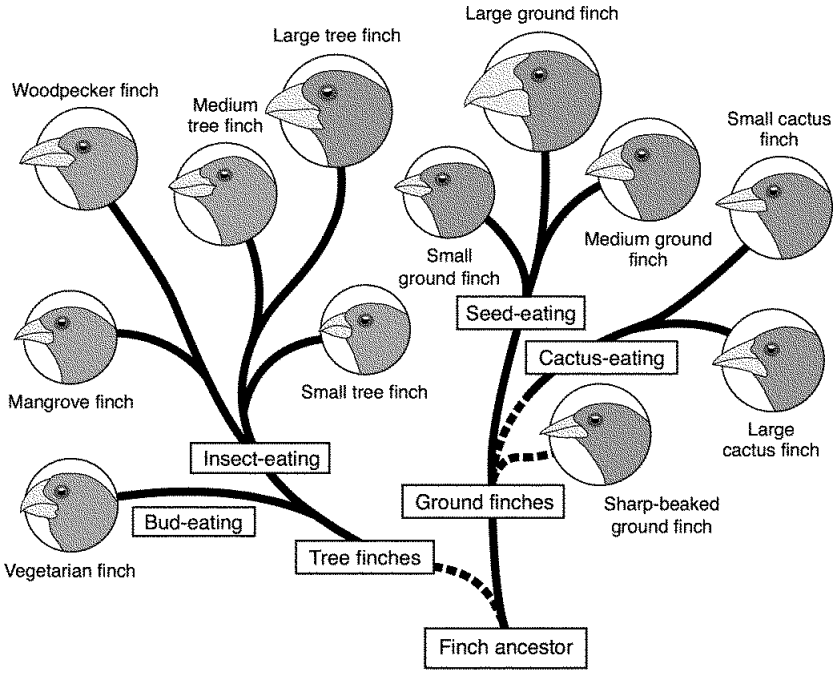


Figure 16–3

55. **Applying Concepts** Explain what speciation means using examples from Figure 16–3.

56. **Designing Experiments** Suppose that researchers suspected that two groups shown in Figure 16–3 were actually a single species. How might the researchers test that hypothesis?

57. **Formulating Hypotheses** Examine Figure 16–3 and observe the large ground finch and medium ground finch. Assume that the diagram shows the average type of beak for each group. If these species were formed from a single type of natural selection, which type is it most likely to be? Explain.

58. **Interpreting Graphics** Competition for resources plays a key role in natural selection. Describe one way that competition for food might have influenced the evolution of the large tree finch.

Unit 2 Delayed Questions (given 9 days after posttest)

1. Explain how shuffling a deck of playing cards can be a good model for the effect of sexual reproduction on the relative frequency of alleles in a population and the possible combinations of alleles.

2. How are directional selection and disruptive selection similar? How are they different?

3. Assume that a geographic barrier that results in two very different ecosystems splits a single population. What would likely happen to the two separate populations? Would this process occur more quickly, less quickly, or at the same rate as it would if the two populations lived in similar ecosystems?

APPENDIX E

DETAILED TIMELINE

Date	Learning Activities	Data Collection Tool
Wednesday, 1-2-12	Begin Nontreatment Unit Objective: Trace the historical Development of the Theory of Evolution	1. Nontreatment Unit Pretest 2. Student Interviews: a. Pretreatment Student Interviews b. Nontreatment Preunit Student Interviews 3. Pretreatment Student Surveys
Thursday, 1-3-12	Objective: Trace the historical Development of the Theory of Evolution	1. Teacher Observation Form 2. Formative Assessment
Friday, 1-4-12		1. Teacher Observation Form 2. Formative Assessment
Monday, 1-7-12	Objective: Trace the historical Development of the Theory of Evolution	1. Teacher Observation Form 2. Formative Assessment
Tuesday, 1-8-12	Objective: Outline the steps of Natural Selection	1. Teacher Observation Form 2. Formative Assessment
Wednesday, 1-9-12	Objective: Outline the steps of Natural Selection	1. Teacher Observation Form 2. Formative Assessment
Thursday, 1-10-12	Objective: Outline the steps of Natural Selection	1. Teacher Observation Form 2. Formative Assessment
Monday, 1-14-12	Objective: List the types of evidence used to support the Theory of Evolution	1. Teacher Observation Form 2. Formative Assessment
Tuesday, 1-15-12	Objective: List the types of evidence used to support the Theory of Evolution	1. Teacher Observation Form 2. Formative Assessment
Wednesday, 1-16-13	Objective: List the types of evidence used to support the Theory of Evolution	1. Teacher Observation Form 2. Formative Assessment
Thursday, 1-17-12	Objective: List the types of evidence used to support the Theory of Evolution	1. Teacher Observation Form 2. Formative Assessment
Monday, 1-21-12	Unit Review	1. Teacher Observation Form
Tuesday, 1-22-12	**TEST DAY**	1. Nontreatment Unit Posttest 2. Nontreatment Postunit Student Interviews 3. Teacher Observation Form
Wednesday, 1-23-12	Begin Treatment Unit Explain metacognition Identify purpose of reflection journals and reading checks. Objective: Explain the sources of genetic variation	1. Treatment Unit Pretest 2. Treatment Preunit Student Interviews 3. Student Reflection Journal: a. From where do all the variations in a population come?
Thursday, 1-24-12	Objective: Explain the sources of genetic variation	1. Teacher Observation Form 2. Formative Assessment

	Reading Assignment and QUAD notes	
Monday, 1-28-12	Objective: Explain the sources of genetic variation	1. Student Reflection Journal: a. From where do all the variations in a population come? b. Prior to the lessons, I thought….Now I know… c. Strategies that helped me understand were… d. Strategies that didn't help me understand were… 2. Teacher Observation Form
Tuesday, 1-29-12	Objective: C&C the 3 ways natural selection can affect the distribution of phenotypes	1. Student Reflection Journal: a. How can Natural Selection affect how common traits are in a population? 2. Teacher Observation Form
Wednesday, 1-30-12	Objective: C&C the 3 ways natural selection can affect the distribution of phenotypes Reading Assignment and QUAD notes	1. Teacher Observation Form 2. Formative Assessment
Thursday, 1-31-12	Objective: C&C the 3 ways natural selection can affect the distribution of phenotypes	1. Nontreatment Unit Delayed Test Questions 2. Nontreatment Unit Delayed Student Interview Questions 3. Student Reflection Journal a. How can Natural Selection affect how common traits are in a population? b. Prior to the lessons, I thought….Now I know… c. Strategies that helped me understand were… d. Strategies that didn't help me understand were… 4. Teacher Observation Form
Monday, 2-4-12	Objective: Describe various types of isolation that lead to speciation	1. Student Reflection Journal: a. How can new species be formed? 2. Teacher Observation Form
Tuesday, 2-5-12	Objective: Describe various types of isolation that lead to speciation Reading Assignment and QUAD notes	1. Teacher Observation Form 2. Formative Assessment

Wednesday, 2-6-12	Objective: Describe various types of isolation that lead to speciation	1. Teacher Observation Form 2. Formative Assessment
Thursday, 2-7-12	Objective: Describe various types of isolation that lead to speciation	1. Student Reflection Journal: e. How can a new species be formed? f. Prior to the lessons, I thought….Now I know… g. Strategies that helped me understand were… h. Strategies that didn't help me understand were… 2. Teacher Observation Form
Monday, 2-11-12	Unit Review	1. Teacher Observation Form 2. Formative Assessment
Tuesday, 2-12-12	**TEST DAY**	1. Treatment Unit Posttest 2. Student Interviews: a. Treatment Postunit Student Interviews b. Posttreatment Student Interviews 3. Posttreatment Student Surveys 4. Teacher Observation Form
Tuesday, February 21, 2012 (last day of term).	Present and discuss action research data gained this far (all questions minus long-term retention)	1. Treatment Unit Delayed Test Questions 2. Treatment Unit Delayed Student Interview Questions