THE EFFECT OF IMPLEMENTING A PROBLEM-BASED LEARNING MODEL ON STUDENT ATTITUDE AND PERFORMANCE IN HIGH SCHOOL FRESHMAN BIOLOGY

by

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STATEMENT OF PERMISSION TO USE

In presenting this professional paper in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the MSSE Program shall make it available to borrowers under rules of the program.

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ABSTRACT

The focus of this project was to examine the effects of a student-centered Problem-Based Learning (PBL) model on student learning, attitude and performance in a freshman biology course. The project was implemented over a seven week period. The first treatment phase asked students to use the PBL process to actively engage the first two weeks of the ecology unit content. Students gathered data on a local invasive species, buckthorn, and then developed a PBL artifact, in the form of a scientific paper. The second phase consisted of three weeks of non-treatment instruction that adhered closely to traditional passive learning instructional and learning practices. The third and final phase again asked students to use the PBL process to actively engage the two week evolution unit constructed around a PBL case study, "The Galapagos," developed by Herreid & Schiller (1999). Through the analysis of data collected, I was able to determine that students enjoyed their increased role in the course and the parallels of PBL to the true nature of science made possible through the PBL active learning process. Students were able to show marked improvement on non-traditional assessments without negatively impacting performance on traditional assessments. All in all, students responded positively on the Likert surveys that they would like to continue learning concepts via PBL.

INTRODUCTION AND BACKGROUND

The science education landscape has been dominated by a traditional teacher-centered instruction style. This means that the vast majority of students learning science are being taught in classroom environments that contradict the widely accepted student-centered recommendations found in research and literature (Chandler & Leonard, 2003). American science students need opportunities to develop a capacity to engage in deeper, more formal thought if they are to meet the demands of the true nature of science as well as the ever-changing world around them (Manitoba Dept. of Education and Training, 1991; Allen & Duch, 1996; Chandler & Leonard, 2003; Abu Sbeih, Barakat, Boujettif, & Jalil, 2009).

I feel strongly that my students need opportunities to actively engage science in its true nature, meaning, utilizing inquiry approaches, if they are to be prepared for dynamic careers in science. Unfortunately, my curriculum employs teacher-centered practices that do not always facilitate such learning. As a result, I think that my current biology curriculum is not cultivating student interest in the sciences as much as it could be, nor is it properly preparing my students for problem solving challenges that await in the dynamic world. However, if my students were granted additional opportunities to take a more active role in the learning process, such as through the implementation of a Problem-Based Learning (PBL) model, then my curriculum would become more meaningful to my students.

The study was conducted in my two biology classes at the freshman campus of New Trier Township High School, Northfield, Illinois. New Trier Township is comprised of approximately 56,000 residents from seven affluent northern Chicago suburbs. The median household income in the township is approximately $143,000 and nearly 79% of the residents hold Bachelor's degrees (city-data.com, 2008). Due to the district's large size the high school is divided into two campuses. The Northfield campus, where I teach and this study was conducted, has 1100 students, all freshmen. In order to meet the diverse academic needs of 4200 high school students, the district uses a leveling system to teach students at either the college preparatory, accelerated, honors, or AP level (New Trier High School Profile 2011-2012). According to the Chicago Tribune, the New Trier student body demographics are: 84.1% white, 8.5 % Asian, 3.6% Hispanic, Multiracial/ethic 2.8%, .8% African American, and .2% Native American. Last year over 98% of the students graduated with 95% of those graduates going on to two or four-year colleges. The district is arguably one of the finest high schools in not only Illinois, but also the country. In general, the students are driven to succeed in school and they get ample support from their parents/guardians.

The need to shift away from teacher-centered instructional practices toward a curriculum that is based on student-centered, active learning principles in my classroom has provided focus for my study. This research project looked at the effect of implementing a Problem-Based Learning model on the academic performance of high school freshman biology students. Other questions that were investigated were:

- Will biology instruction that utilizes PBL principles result in improved student attitude toward engaging in science?
- Will biology instruction that incorporates PBL principles result in improved student content knowledge and subsequent assessment performance?

- How will the shifts in instructional practices, to a PBL process, impact teacher attitude?

CONCEPTUAL FRAMEWORK

The traditional teacher-centered instructional model that is common in science classrooms around the world emphasizes students learning science content passively through media such as lecture and "cookbook" laboratory activities (Michael & Modell, 1993; Bowen, Box, Myers, Pollard, & Taraban, 2007). Moreover, this passive learning model only asks students to engage in simple low-level cognitive thought, in the forms of basic factual recall (Allen & Duch, 1996; Chandler & Leonard, 2003; Abu Sbeih, Barakat, Boujettif, & Jalil, 2009). Interestingly, despite the ubiquitous nature of the teacher-centered instructional model in many science classrooms, there is little literature that supports its effectiveness (Chandler & Leonard, 2003).

The flaws of using a passive learning model were recognized during the 1950s by the education reformer John Dewey. Since then, there has been a constant call for a sweeping paradigm shift away from the passive learning model toward a model that incorporates more active learning principles (Gunel, 2008; Abu Sbeih et al., 2009). This call can be found in research literature, the National Science Education Standards, and from scientific organizations such as American Association for the Advancement of Sciences (AAAS) and the National Research Council (NRC) (Krajcik, Marx, Schneider, & Soloway, 2002; Chandler & Leonard, 2003; Abu Sbeih et al., 2009). Research has shown that science classrooms that embrace active learning techniques are truer to the nature of science while also allowing for improved student content knowledge and overall attitude toward science (Allen & Duch, 1996; Chandler & Leonard, 2003; Abu Sbeih et al., 2009).

The Call for an Active Learning Instructional Model

When science educators accept and incorporate active learning principles into their curriculum there are measureable positive gains in terms of science content knowledge and overall attitude toward engaging in science (Michael & Modell, 1993; Allen & Duch, 1996; Chandler & Leonard, 2003; Krajcik et al., 2002; Bowen et al., 2007; Abu Sbeih et al., 2009). However, despite this knowledge, researchers and scientific organizations, such as the AAAS and the NRC, have not seen active learning integrated into the vast majority of science classrooms (Abu Sbeih et al., 2009). Many science teachers still rely on the traditional and less effective teacher-centered model (Michael & Modell, 1993; Allen & Duch, 1996; Chandler & Leonard, 2003).

Bowen et al. (2007) demonstrated how the use of an active learning model that employed inquiry-based laboratory experiences was more effective than traditional textbook lab materials when teaching high school biology. The researchers discovered a 5.32% advantage on the content test for those students that had conducted the active learning lab as compared to those students that learned the concepts via traditional methods. When the researchers administered open-ended questionnaires following both traditional and active learning labs, students were found to have more to say and were also more positive following the inquiry-based, active learning lab.

Chandler & Leonard (2003) expressed how the “traditional classroom,” characterized by teacher-centered instruction, fails our students in three major ways: (1)

how science education is counter to the way students naturally learn because learning is "done to them" as opposed to "something they do" (p. 485); (2) how there is significant amount of literature explaining the benefits of active learning, yet minimal literature expressing the benefits of the traditional model (p. 486); (3) students can be successful in most science classrooms using simple low-level thought (p. 486). In other words, the traditional passive learning American science classroom does not align with academic research or with the way our students actually learn. Conversely, the active learning model places students as the focus of the classroom as they are asked to construct "…their own mental models from the information they are receiving" (Michael & Modell, 1993, p. 2). Other researchers support the claims that the teacher-centered classroom is a broken model. Michael & Modell (1993) argue that the teacher's role needs to shift from being a disseminator of facts or a lecturer to that of a guide. In a student-centered classroom the teacher supports student learning of concepts through the use of assessment. The assessment is applied on a regular basis and the data can then be used to make appropriate adjustments that will enable students to "close the gap" to the level of understanding that is required (Michael and Modell, 1993; Goodnough, 2006; Gunel, 2008).

Benefits of Using Problem-Based Science to Achieve Active Learning

Research has shown how the problem-based science (PBS) curricular model can be an effective medium for shifting the dominant instructional paradigm in the American science classroom toward a student-centered model. Utilizing a PBS model would not only align a classroom with long established recommendations in research literature and from scientific organizations, such as the AAAS and NRC, but it would also create a learning environment that is student-centered and true to active learning principles (Krajcik et al., 2002). Barrows (Goodnough, 2006) developed the problem-based learning (PBL) model, for use in the medical school curriculum at McMaster University, Ontario, Canada. Barrows wanted a curriculum that would help students develop a deeper understanding of the content by actively applying the concepts in class (Goodnough, 2006, p. 303).

By employing Barrow's PBL principles, the Goodnough study (2006) showed how PBL enabled heuristic learning to take place. This means that the active learning process allowed students to discover or learn something for themselves. In addition, the problem-based science model was shown to be more consistent with the way students actually learn. All in all, this study demonstrated how the problem-based science-learning model allowed for the development of not only a personal, but also a meaningful understanding of concepts.

The Abu Sbeih et al. (2009) research study demonstrated how a shift in the instructional practices of Saudi Arabian primary school science classrooms toward a student-centered instructional model created an environment that allowed students to exhibit several improvements, including: attitude toward science content, self-efficacy skills, and academic achievement especially on higher-level thinking tasks. By the end of the study, over 70% of the students preferred the student-centered model with a reduced teacher role. The student-centered model forced students to access their working memory more often than in the traditional learning model. As a result, students were observed engaging in more mature and higher-level thinking exercises. In another study that implemented PBL learning principles, students were found to be more "active, participating, and questioning throughout the class" (Allen & Duch, 1996, p. 50).

Krajcik et al. (2002) reported in their study how students educated using project-based science (PBS) outscored the national sample on the National Assessment of Educational Progress (NAEP) on nearly half of the items (p. 419). The researchers found many similarities in data, particularly for performance on NAEP for similar groups (white and middle class students who were not eligible for free lunch). These findings led the researchers to believe that project-based science is as effective, if not more, than traditional teaching models when it comes to performance on the national assessments of science knowledge. In summary, empirical data suggests that PBS, which is a student-centered, inquiry-based learning model, "…promotes success in science" (p. 420).

Enacting Problem-Based Learning/Science

While the positive benefits of PBS are well documented, there is a steep learning curve for educators when they attempt to shift the dominant instructional paradigm toward a student-centered, active learning environment. Although it might be easier for the teacher to simply lecture on course concepts, science educators can no longer afford to negatively impact our students by instructing science content in a passive manner (Gunel, 2008, p.217). In fact there are two critical components recognized by the large-scale Gunel (2008) study when it comes to enacting PBS, educators need to gauge the prior knowledge of students early and often and exhibit strong questioning skills. Both of these ideas helped veteran science educators in Iowa; shift their dominant instructional method toward active learning after years of instructing via teacher-centered methods.

While the Gunel (2008) study described necessary adjustments required by the educators themselves, the Blumenfield et al. (1991) study describe two major components of PBL that the students must complete to operate successful PBS projects. According to Blumenfield et al. (1991) the project requires a broad question and an opportunity for students to engage in activities where they gather artifacts and resources to include in their final product (371). The study found that during the PBL process as students “seek resolution to problems; they acquire an understanding of key principles and concepts” (372). Allen & Duch (1996), in introductory science courses for non-majors at the University of Delaware, found that briefly introducing relevant topics up front help with student curiosity and interest to fuel the design of the PBL projects (p. 44). Thus, the PBL model afforded students an opportunity to practice the true nature of science. Overall, when the PBL model was used, students were found to be “active, participating, and questioning throughout the class” (Allen & Duch, 1996, p. 50).

While there is substantial literature that calls for and demonstrates the effectiveness of PBS, the actual process for enacting PBS can be a daunting task for science educators. For example, the Toolin (2004) study of New York City Department of Education science teachers found that novice teachers “…were more concerned with daily routine of lesson planning, classroom management, and standardized test preparation” (p. 186-187). This focus on trying to simply “stay afloat” did not allow for experimentation with active learning principles. On the other hand, teachers with five-plus years’ experience or those who had recently completed an extensive education preparation program were found to be more willing to experiment with their teaching and try employing an active learning model, such as PBS.

PBS is not without its shortcomings, for example, students can become easily frustrated with the new active learning process because PBS calls on students to conduct science in a manner that is truer to the nature of science (Blumenfield et al., 1991; Allen & Duch, 1996; Toolin, 2004). Thus, while the PBS model does align the instructional paradigm with a more realistic application of science, such changes in learning are sure to be unfamiliar and intimidating for many students. As a result, the teacher can struggle to keep students motivated and focused throughout the PBS process (Blumenfield et al., 1991). Nevertheless, the students must learn to hone and employ various aspects of the true nature of science, such as creativity, curiosity, perseverance, and problem solving skills. In other words, the PBS model calls on students to engage in deeper, more formal thought, which is a good shift. In spite of these shortcomings, and in the best interest of our students, science educators must look past the limited weaknesses associated with PBS. This is due to the fact that the positive benefits, such as helping our students develop skills that will enable them to become lifelong learners, greatly outweigh the negatives. Table 1 describes common characteristics of the PBL process.

Table 1
Characteristics of PBL

Blumenfield et al. (1991)	The project requires the students to develop: 1. a broad question and 2. an opportunity for students to engage in activities where they gather artifacts and resources to include in their final product (371).
Allen & Duch (1996)	1. Introduce relevant topics up front helped fuel student curiosity and helped them discover a topic of interest for their PBL project.
Gunel (2008)	Adjustments made by the teacher: 1. Educators need to gauge the prior knowledge of students early and often in the process. 2. Educators need strong questioning skills.

In conclusion, as science educators we can no longer afford, in the best interest of our students, to instruct students using a teacher-centered, passive learning model. This archaic model does little to tap into student interest in the topic and creativity to solve problems. Therefore the model is failing to prepare our students for the dynamic world that awaits beyond our classroom (Michael & Modell, 1993; Allen & Duch, 1996; Chandler & Leonard, 2003; Bowen et al., 2007). Consequently, our science curriculum needs to align with the substantial amount of literature as well as national science organization recommendations that have, for years, been calling for a shift toward active learning. This well documented research describes the many positive student gains associated with the active learning, such as improved academic performance, attitude toward science, and overall more positive behavior (Krajcik et al., 2002; Bowen et al., 2007; Abu Sbeih et al., 2009). Enacting a PBL curriculum that aligns with research literature, the National Science Standards, and scientific organizations recommendation from the AAAS and the NRC, will allow our students to engage science in its true nature while also more properly preparing students for the problem-solving challenges that are imminent during and after high school (Blumenfield et al., 1991; Manitoba Department of Education and Training (1991); Allen & Duch, 1996; Toolin, 2004).

METHODOLOGY

The methodology for this project was focused on implementing a shift from the traditional passive learning model toward a student-centered, active Problem-Based Learning (PBL) paradigm. As mentioned in the Introduction, the participants for this study were two freshman biology classes I taught, with both sections at the accelerated level, which equates to an honors level at most high schools. The New Trier school day is divided into nine, forty-minute class periods. Students taking science meet in a classroom three days per week for 40 minutes and then have a double period laboratory experience the other two days per week. The combined student population of the two freshman biology sections was 47 students. Periods 1 and 2 had eleven boys and eleven girls while periods 3 and 4 had six boys and twenty girls. 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. Table 2 provides some basic demographics for the two classes.

Table 2
Demographics by Class

Class Period	# of Students	Male	Female	Caucasian	Asian-American	African-American	Latino	IEP/504 Plans
1 and 2	21	10	11	19	2	0	1	1
3 and 4	26	6	20	23	2	1	0	2

Intervention

The PBL treatment was implemented over a seven week period from mid-to-late November, 2012 through mid-January, 2013. The topics covered in the class during the intervention were Ecology, Classification, and Evolution.

The project was divided into five segments consisting of a pre-treatment phase, two treatment periods, a non-treatment period, and finally a post-treatment phase. The pre-treatment utilized a student survey (Likert scale) to gauge initial impressions of science class and instructional practices. The first treatment phase used the PBL process to actively engage the students in the first two weeks of the ecology unit's content. The students gathered data on a local invasive species, buckthorn, and then developed a PBL artifact, in the form of a scientific paper. The PBL active learning activities were developed with reference to resources from the Buck's Institute for Education (BIE) and Barron and Darling-Hammond's chapter "How Can We Teach For Meaningful Learning" in Powerful Learning: What We Know About Teaching for Understanding (Barron & Darling-Hammond, 2008a).

The second phase consisted of three weeks of non-treatment instruction that adhered closely to traditional passive learning practices. The non-treatment phase included the final seven days of the ecology unit and all eight days of the classification unit. In addition to the non-treatment period of the action research, my three sections of "nine-level" biology from the 2011-2012 school year provided a potential baseline for contrast. The 2011-2012 Ecology, Classification, and Evolution unit summative assessments were archived along with my grade book so they could be compared with the performance of this year's classes. The three 2011-2012 sections were appropriate for comparing academic performance by students because the majority of last year's ecology, classification, and evolution instructional methods were dominated by typical teacher-centered practices, such as passive lecture and textbook generated labs. In addition to the 2011-2012 summative assessments, I also gave a non-treatment unit test for the classification unit during the project. This would allow for comparison of student performance between the two 2012-2013 classes (see Appendix H). It is important to note that I did try to incorporate the writing of a scientific paper artifact in my 2011-2012 ecological curriculum. Unfortunately, the artifact seemed disconnected from the passive learning instructional practices and the overall process proved negative for both the students and me.

The third phase again used the PBL process to actively engage students during the two week evolution unit. The student-centered, active learning evolution unit was constructed around a PBL case study from *National Center for Case Study Teaching in Science* database, titled, "The Galapagos," a PBL lesson, (see Appendix A) developed by Herreid & Schiller (1999). The PBL case study challenged students to find resolution to real-world problems facing the Galapagos Islands as two factions, government and fisherman, fight over the islands' natural resources (Herreid & Schiller, 1999). The final post-treatment phase allowed for a second Likert scale-based student survey to gauge impressions of the PBL process and the science class in general. Table 3 summarizes the research plan.

Table 3
Research Plan

Pre-Treatment Phase	Pre-treatment Likert scale student survey
Treatment Phase - Part I	Students used PBL principles to actively engage the first two weeks of the ecology unit. The following "problems"/questions and accompanying activities were employed during the PBL treatment: • Buckthorn random sampling field lab on lab days (85 minute class periods). "What is the estimated population size of the invasive buckthorn in the Watersmeet Prairie Grove?" • "Daily tasks" were employed on non-lab days (40 minute class periods): o Random sampling activity using the classified section in newspaper; "What is an invasive species?"; "Pop Growth Activity – what are the effects of reintroducing wolves on populations in the Greater Yellowstone Ecosystem"; "In what ways do species interact?"; "Why is the world green?"
Non-Treatment – Phase I	Three weeks of non-treatment instruction adhered to traditional passive learning instructional and learning practices. The non-treatment phase consisted of fifteen days or the final seven days of ecology unit and the eight day classification unit
Treatment Phase – Part II	Student actively engaged the two week evolution unit constructed around the three part PBL case study, "The Galapagos," from the *National Center for Case Study Teaching in Science.*
Post-Treatment Phase	Endpoint Likert scale student survey Endpoint formal student interviews

Following the Blumenfield et al. (1991) recommendation, the first treatment phase during the ecology unit PBL was centered on a broad question, "what is the estimated population size of the invasive buckthorn tree in the Watersmeet Prairie Grove?" Also, I added a sub-question "what can the invasion of buckthorn in Illinois prairies, such as Watersmeet Prairie Grove, teach us about ecological principles?" to serve as an important reminder that students could learn many ecological concepts as they examine a real problem facing our local forest preserves (Barron & Darling-Hammond, 2008b). Using these two questions as a launching point, the students conducted a student-centered random sampling field lab in Watersmeet Prairie of the

Forest Preserve of Cook County on the invasive buckthorn shrub. The students were divided into small groups of three to four students to develop data collection techniques, collect field data, problem solve, learn ecological concepts, and develop an authentic scientific paper (Barron & Darling-Hammond, 2008b).

Additional questions about ecological concepts were raised through two 80-plus minute field data collection experiences as well as during class time on non-lab days when students analyzed their data, asked questions, and peer reviewed sections of their scientific papers. Formative assessments were also employed throughout the treatment period to gauge student progress with the novel PBL process. The student supplemental questions generated by the formative assessment not only kept the learning process student-centered, but also gave students concepts to research and discuss when they were not in the field gathering data.

The students worked in small groups (3-4 students) and utilized student-centered class discussions, as opposed to teacher-centered lecturing, to cover ecological concepts such as population growth, species interaction, and energy flow. As a safeguard to make sure students covered these and other important ecological concepts, I wrote several big picture questions and developed daily accompanying activities, which enabled me to guide student-centered conversation and collaboration if the fieldwork did not generate questions. For example, asking students, “In what ways do species interact?” allowed students to ponder concepts such as niche, symbiosis, and trophic levels. There was also the accompanying species interaction activity that helped students engage the concept and practice symbiotic examples. Another sample question was, “Why is the world green?” This question enabled students to research and discuss food webs, ecological pyramids, and trophic levels. I devised these supplemental questions to guide students with research, discussion, and learning about important ecological concepts. In addition, these questions enabled student learning to remain active instead of allowing the curriculum to shift back toward teacher-centered passive learning, such as lecture. Thus, the field experience and, if necessary, the supplemental questions were the catalyst for raising ecology concepts that needed to be researched and understood as they developed their final scientific paper, and prepared for the summative assessments (mid-unit quiz and post-unit test).

During the non-treatment phase (part three) of the action research project, concepts were taught using a traditional passive learning model. Students learned the final seven days of the ecology unit and the full two-week classification unit using teacher-centered instruction methods including lectures, one-day "cookbook" science laboratory experiences, and nightly homework assignments. In addition, one round of formative assessment was employed toward the end of the non-treatment phase to anonymously gauge student perception of the traditional model. The following questions were used: Are any taxonomy unit concepts confusing you? What are your feelings about learning the ecology energy flow and taxonomy notes using the traditional model (lecture, lab, and nightly separable homework assignments)? Does this style work for you? Why or why not?

Finally, during the third phase students were again asked to use the PBL process to actively engage a major portion of the two week evolution unit. To accommodate the PBL shift, the design of the unit used recommendations from, "The Galapagos" PBL case study. Students worked in small groups (4-5) and utilized student-centered group work and class discussion to cover evolution concepts including: natural selection, adaptations, genetic drift, and biodiversity. The PBL case study served as a catalyst for discussing the evolution concepts in a student-centered manner. During this second treatment phase, per Herreid & Schiller's (1999) recommendations, evolution topics were initially discussed in class and reviewed prior to the start of the PBL case study. The rationale for such a sequence was to assure students have an appropriate understanding of the evolution concepts before engaging in Part I of the "The Galapagos" case study. In addition, the PBL study required a 75-minute time commitment over a four day period to thoroughly complete all three parts. However, due to the fact that New Trier High School has 40-minute class periods three days per week and two 80-minute lab days, the PBL was conducted over an entire week.

The first two parts of the case study asked students to address questions raised by reading the overview of Part I and II. After both Parts, each group reported their research findings for questions raised in each part. Using their new knowledge, the student group of 4-5 students role-played as one of the interest groups to try and reach agreement over the confrontations highlighted in Part III of the case study. In other words, the PBL case study raised a real-world complex issue involving the Galapagos Islands that the students were attempting to seek resolution. Table 4 summarizes the treatment and data collection schedule for the project.

Table 4
Treatment & Data Collection Schedule

Length of Unit	Unit Topic	Instruction Type	Data Collected
Two weeks	Ecology (1st half of unit)	Problem-Based Learning	Teacher Observations; Teacher Journaling; Formative assessment during PBL; Summative assessment at end of treatment cycle; Midpoint formal student interviews at end of two and half weeks.
Three weeks	Ecology (2nd half of unit) and Classification unit	Traditional instructional model	Teacher Observations; Teacher Journaling; Summative assessment at end of non-treatment cycle.
Two weeks	Evolution	Problem-Based Learning	Teacher Observations; Teacher Journaling; Formative assessment during PBL; Summative assessment at end of the treatment cycle.

Data Collection

Qualitative data collection techniques were employed using the following components: formative assessments, summative assessments (Appendices G, H, and I), creation of the PBL artifact, Likert scale student surveys (pre-treatment and endpoint of the project), individual student interviews (conducted at the midpoint and endpoint of the project), teacher observations, and twice weekly teacher journaling. The quantitative data collection was in the form of formative and summative assessments. Formative assessments were used at least twice weekly during the treatment as it was a crucial step of the PBL process. The formative assessment allowed the teacher-research to gauge student perceptions about the instructional practices and processes in each phase. Thus, using formative assessment allowed the teacher researcher to gauge student understanding of concepts and perceptions of the PBL or traditional learning process as well as bring questions or concerns to the surface. The summative assessments, on the other hand, were in the form of mid-unit ecology quiz, post-unit tests in ecology, classification, and evolution units, as well as the scientific paper (PBL artifact). Data was compared and contrasted to the performance of the 2011-2012 students. This comparison analysis would allow the teacher researcher to gauge how students performed when taught via traditional passive learning methods versus the active learning, student-centered PBL process.

Additionally, qualitative data collection was comprised of the student survey, student interviews, teacher observations, and teacher journaling. Likert-scale-based student surveys administered through Google Forms (Appendices B and C) were developed to gauge student perceptions about learning via the traditional, passive learning model as well as the treatment PBL process. Some of the survey questions had follow-up open-ended prompts, which provided an opportunity for more detailed explanation of a student's Likert scale choice. Formal individual student interviews (Appendices D and E) were conducted at the mid-point and at the end-point of the project using a random stratified selection process. Of the eleven selected students, the high-, moderate-, and low-level performance groups were represented by four, three, and four students, respectively. The formal student interviews aimed to gauge student attitude toward engaging in science and the impact of the PBL process versus the traditional instructional methods on their learning. In addition, the teacher researcher conducted instructor field observations throughout the project. Also, I wrote twice weekly journaling (appendix F), generally following the fieldwork experiences to gauge my perceptions of the PBL process not only on student performance and interest levels, but also the effects of the PBL process on my teaching. Table 5 summarizes the data collection strategies.

Table 5
Triangulation Matrix

Focus Questions	Data Source 1	Data Source 2	Data Source 3
Primary Question: 1. What effect does employing a Problem-Based Learning model have on the performance of high school freshman biology students?	Student survey (pre- & post-project)	Instructor field observations & twice weekly reflection journal	Student interviews (midpoint and end point of project)
Secondary Questions: 1. Will biology instruction that incorporates PBL principles result in improved student content knowledge and subsequent assessment performance?	Student survey (pre- & post-project)	PBL artifact, formative assessment, and unit assessments	Student interviews (midpoint and end point of project)
2. Will biology instruction that utilizes PBL principles result in improved student attitude toward engaging in science?	Student survey (pre- & post-project)	Instructor field observations & twice weekly reflection journal	Student interviews (midpoint and end point of project)
3. How did the shift in instructional practices to a PBL process impact the teacher?	Student survey (pre- & post-project)	Instructor field observations & twice weekly reflection journal	Student interviews (midpoint and end point of project)

DATA AND ANALYSIS

In an effort to gain insight about my focus and secondary questions, data was collected on the PBL treatment using both qualitative and quantitative methods. The data set was analyzed and the following themes were identified.

Students enjoyed the experiential learning environment created by the PBL model.

My first claim concerned how students recognized ways the PBL process led to more concrete learning. This salient learning was made possible by the increased role students had in class operations. Essentially, PBL enabled students to discover concepts through experiential learning rather than through passive teacher-directed learning. The students were able to recall concepts more readily when learned through the PBL process than when concepts were passively learned through reading in a text or via lecture.

The formal student interviews provided the clearest illustration for how students felt about the PBL process. Question 3 on the formal student interviews asked students "Which learning method, traditional (*i.e.* textbook reading, lectures, and one-day labs) or PBL, enabled you to understand concepts better?" Seven out of 11 students commented that they felt the PBL approach engaged them in active learning and lead to better understanding. For example, a male student from second period responded similarly to this question on both the mid-point and end-point formal student interview. His comment on the mid-point interview was, "[PBL] does help me understand the topics…I don't mind lectures…but feel that I am more directly involved with the PBL style." While his response on the end-point formal interview was, "PBL [because I] still have memories of the experience instead of reading out of a book or listening to a traditional lecture." Both of these quotes illustrated how the experiential learning woven into the PBL process resulted in this student feeling that he had more concrete learning of course concepts than compared to learning via the traditional passive learning model. Similar sentiment toward the memorable experiential PBL process was echoed by a majority of the students, 64% of the interview participants, during the end-point formal interviews.

In addition, the students provided interesting insight on their follow-up responses to Question 2 on the end-point Likert scale student-survey question. This particular question asked students if they "…enjoyed learning new science concepts through the Problem-Based Learning (PBL) model." One student explained how the "new concepts learned via the PBL model are a new, more hands-on method of learning and allow one to really grasp onto their learning and take it into their own hands to further understand biology concepts." Likewise, another student recognized how the PBL process, "…was more interesting than just taking notes and having a test. When the test did come on the big concepts I felt more prepared because I learned the concepts through real world experiences which makes it easier to understand." A third student commented how the PBL process, "…was a very interesting way TO learn and I had never learned in that style before, so it made it even more interesting to engage in." All in all Question 2 had a Likert scale average of 3.78 with a standard deviation of 0.65 (n=47), which means neutral but close-to-agree on the scale. Another way of stating this information was the fact that thirty students, or 64% of participates, responded that they "strongly agree" or "agree" to enjoy learning science concepts via the PBL process. On the other hand, only two students or 4% of participates, responded that they "disagree" with the question about enjoying learning science concepts via the PBL process. Similarly, Question 5 had a Likert scale average of 3.97 with a standard deviation of 0.71 (n=47), which meant the students “agreed” on average to “…enjoy the hands-on Problem-Based Learning (PBL) model experience.” Seventy-Eight percent of participates commented on the Likert student survey that they “strongly agree” or “agree” to Question 5 while only one student “disagreed” with Question 5.

The anonymously collected formative assessment data allowed the teacher-research to gauge student perceptions of the PBL process during the action research treatments. This fresh, in the moment, data collection provided a unique perspective of the PBL process. For instance, during the first treatment phase, students were asked whether or not they felt they had an increased role in the class since the PBL began. One student, in first period, responded:

> I feel like I have a larger role in the class structure because I am more independent now and doing things on my own. You are also talking less, which makes me even more independent and brings a larger role towards me.

Another student late in the data collection process made the following comment, “I like and learn from the traditional model, but I like the PBL a little better it’s more hands-on and I think I get more out of it.” In both cases, the students’ comment illustrated how the students thought the PBL provided a better medium for learning because it increased student involvement in the learning process. Without question the use of formative assessment proved a very beneficial tool and enabled the teacher-research to get a nice snapshot of how students perceived and were progressing using the novel PBL process. The formative assessment was great for bringing questions and/or concerns about the content or PBL process to the surface. As I went through the comments and reviewed the questions raised by the anonymous formative assessment, students would begin to realize others shared their concerns. This allowed other students to feel more comfortable to speak up with additional great questions. With the formative assessment providing another medium for student voice in the PBL paradigm, I was able to take their opinion into account as I made adjustments that would hopefully translate into more meaningful process for both the students and teacher-researcher alike.

Students appreciated how the PBL process aligns closer to the true nature of science.

My second claim is how students recognized the PBL process aligns closer to the way science is actually conducted by scientists. In other words, the PBL process was more tangible for the students because their learning closely mimicked the way science is actually conducted and scientific knowledge is gathered. At the same time, the PBL process was in stark contrast to the way many students had learned science hitherto because science instruction is often passive, teacher-directed.

The formal student interviews, once again, provided some of the best data. For example, Question 9 on the end-point student interview asked students, “Which learning method, PBL or traditional, do you feel more closely aligns with the way science is conducted in the real world?” Eight out of 11 students interviewed felt that the PBL model aligned more closely with the true nature of science. For instance, a female student from period three answered, “I would say PBL is more realistically how scientists work…they do more, you know to gather data, doing excursions to gather data…to do scientific work you do more of the PBL style of things.” Likewise, a female student from period one commented, “Probably PBL because scientists go out and do their research and experience it first-hand." In both of these examples it is clear that these students were aware of how PBL provided a better representation of the nature of science.

The free response follow-up questions on the Likert student survey also provided strong indication of students appreciating the PBL process as a truer representation for the nature of science. For instance, an anonymous student's answer for the follow-up to Question 2 demonstrated how the PBL process made the learning process more real, "It was very interesting to learn new concepts in 'real life' for example with the Galapagos islands we had to put together an agreement and for the Buckthorn we went out in the prairie." Similarly, students recognized how learning through real-world examples, such as through the PBL "lecture day" activities employed during the first treatment phase, made course concepts easier to understand. This was illustrated in a student's answer for the follow-up free-response to Question 10 on the end-point student survey, "it makes more sense to me to see the concept through the real world than just being told the information directly." Once again student comments reinforced how student learning of new concepts was much more concrete when their knowledge was gained through student-centered real-world experiences of the PBL model.

The Likert scale student survey provided a nice overview of student perceptions for how science learned through PBL correlated with the true nature of science. For example, when asked whether "the Problem-Based Learning (PBL) process is analogous to the research process used by professional scientists" students responded with a mean score of 3.06 (neutral) with a standard deviation of .571 on the pre-survey. However, the average score on the post survey for the same question increased to 3.55 (neutral, but edging closer to "agree") with a standard deviation of .652, representing a significant change (t[92] = 3.88, p = .0002). Furthermore, when students were asked whether or not "science concepts can be learned thoroughly by trying to solve real problems," students overwhelmingly responded in agreement with the question. Forty-one out of 47 students or 87% of the study participates, "strongly agreed" or "agreed" with the question. Only six students were "neutral" and no students selected "disagree" or "strongly disagree" in response to the question. All things considered, the PBL process appears to be effective for affording students an opportunity to learn science concepts using tangible problems that are also true to the nature of science.

Students commented how they would like to continue learning concepts using PBL.

Students recorded that they would like to learn concepts for other units during this school year using PBL learning principles. For example, the students were asked on the end-point formal interview about their impression of the PBL process and whether or not they would like to engage in the process again. Nine out of 11 students responded on the formal student interview that they would like to continue learning concepts via the PBL approach. For example, a female student in period three who has struggled with course concepts this year commented, "Yeah…because I think it not only helps understand with real examples it was fun and like you get to work with other people to help understand it." This student liked learning concepts using PBL principles because of the support she could get from her group members. A high achieving female student, also from period three, commented that she would like to use the PBL process again "because it was a fun experience." However, this student also went on to say, "You have to have a little bit of both [traditional and PBL]…I think you need notes and stuff to understand the raw material to use for tests…the PBL makes it more real…not just notes." Remarkably, this young lady recognized how coupling the traditional and PBL models together could prove to be a very effective paradigm. In other words, the traditional model could function well when it came to learning foundational knowledge and then the PBL process could be used to learn big picture concepts in a tangible manner.

Like the formal student interview questions the Likert student survey also provided insight into student perception of learning concepts through the PBL process. Overall, the students' claims supported the fact that they enjoyed engaging in PBL methods. For example, Question 10, on the end-point student survey asked students if "the Problem-Based Learning model 'lecture' day activities (such as the wolf or species interaction activities) are better than a traditional lecture day?" While the Likert scale average for Question 10 was 3.7 (neutral but close to agree on the scale), with a standard deviation of .75 might not suggest that the students enjoyed the PBL process. The student responses for the follow-up prompt to Question 10 demonstrated just how much they enjoyed the active learning principles associated with PBL. For example, an anonymous student commented:

> I think it's a lot more fun and helpful to learn through PBL and hands-on activities than regular lecture days. I understand that we have to keep on a schedule with curriculum, but sometimes the notes on lecture days are hard to write and I feel like I'm not absorbing anything and am just writing down words.

A second student described his feelings about the PBL process, when he stated, "The normal, regular lecture day can be kind of boring and repetitive on how we learn the subject. I feel that the PBL lecture day is more interesting and interactive." Similarly, a third student explained how “all PBL activities we have done so far allow for more hands-on learning that allow me to work at a comfortable pace and intake information and concepts more effectively.” All in all, it is clear how the Likert scale average might not always represent the whole story as this was the case for Question 10. The student comments illustrated how much they enjoyed the PBL process, notably the “lecture day” activities, for learning new concepts. Moreover, when asked if they “…would like to continue learning biology concepts using a Problem-Based Learning (PBL) model in the future?” Twenty-eight out of 47 participates, or 59.5% responded either “strongly agree” (8 students) or “agree” (20 students) on the Likert Scale survey. Fourteen out of the 47 participants, or 30% responded “neutral” to the question and only five out of the 47 participates, or 10.5% responded either “disagree” (4 students) or “strongly disagree” (1 student).

My observations in the teacher-research journal further supported the fact that the students enjoyed the PBL process and wanted to continue learning concepts using active learning principles at the foundation of PBL moving forward. In particular, the second round of formative assessment indicated an overall positive sentiment for using the PBL process to learn Ecology concepts. The students seemed to enjoy going outside and learning about invasive species during the buckthorn field lab. They also appreciated their greater role in class operations. One student captured the general student state of mind, when they stated, “I think it’s been a lot more fun doing labs and going out into the prairie. I think you have been talking less than before. I would much rather do labs than be talked to the whole period.” A second student responded, “…we are starting to do more interactive things. I learn better when I can interact with what I’m learning.”

The impact of the PBL approach on traditional and non-traditional assessment efficacy.

The PBL approach was able to improve student performance on non-traditional assessments, specifically the PBL artifact, without negatively impacting student performance on traditional assessments. For the Ecology quiz during treatment phase part I, the change from 2011/2012 to 2012/2013 school years was not shown to be significantly different, $t(120) = .761$, $p = 0.448$. Similarly, the Evolution treatment test during treatment phase part II also did not show change that was considered significantly different, $t(120) = .638$, $p = .5245$. Likewise, the change for the non-treatment classification test data also did not show significant difference either, $t(120) = .041$, $p = .967$. Even though none of this data reflects statistically significant improvement on the traditional assessments by the 2012/2013 students learning concepts through PBL, it does reflect that the 2012/2013 students achieved average scores on the traditional assessments that matched their 2011/2012 counterparts. Therefore, this data signifies how the PBL treatment did not negatively impact student performance eon the traditional assessments.

In spite of the fact that students did not perform statistically different on the traditional assessments, when you compare the two school years, the 2012/2013 scientific papers, or PBL artifacts, were of noticeably higher quality. Obviously the traditional summative assessments were designed to measure skills learned in a traditional teaching approach. Yet, the 2012/2013 students performed equally well on the traditional assessments while producing far better scientific papers. Despite using the same grading rubric in 2011/2012 and 2012/2013, which took into account the quality of writing, formatting of the paper, and graphs, the final drafts of the 2012/2013 buckthorn papers were of much higher quality and more closely resembled true scientific papers. On the other hand, the 2011/2012 final products were far less polished writing pieces. The improved quality of 2012/2013 may have resulted from the healthier group dynamics observed throughout the treatment phase. Students were much more diligent in completing their fair share of the writing during 2012/2013. Accordingly, there were less instances of students "letting down" their group during the PBL treatment. Furthermore, the statistical difference for student performance in 2011/2012 compared against 2012/2013 on the scientific paper artifact was shown to be extremely different, $t(120) = 6.41$, $p = .0001$. This improvement on the non-traditional assessment was also evident in my teacher journal that described improved work output by the students during the creation of the scientific paper, "…all things considered, I feel that the writing of the final paper has been less of an issue this year compared to last. The students appear to have taken more ownership of the scientific paper/artifact this year." The overall higher quality of the buckthorn scientific paper was probably attributable to the fact that group members took ownership over their share of the writing and the creation of the final group product.

Students valued the coupling of PBL and traditional methods before assessments.

The first four claims illustrated how the vast majority of students enjoyed learning science content through the more tangible PBL process. However, students also recognized the benefits and accessibility of concepts learned through the traditional instructional model. Students found the traditional model effective for disseminating foundational information on a topic. With that being said, students also commented that learning exclusively via traditional methods, such as being lectured or "talked at" for a full class period, was boring. Interestingly, two questions (number 14 and 15) on the end-point student survey asked students whether the traditional model (Question 14) or the PBL model (Question 15) prepared the students well for assessments had identical averages of 3.69 with standard deviation of .813 and .861, respectively, on the five-point Likert scale. This average was further supported by the responses on the follow-up question to survey Questions 14 and 15 that allowed students to explain their preferred process—traditional or PBL— in preparing them better for assessments. The free response comments fell into one of the following three categories: 19 students, or 40% of the study participants, made comments favoring the traditional model, 13 students, or 28% of the study participants, mentioned a combination of PBL and traditional being the most effective, and finally 15 students, or 32% of the study participants, preferred learning through the PBL model. A student's response for why they preferred the traditional model stuck out from the group:

> Traditional helps me better because I can memorize things better and in more detail for short term things that I need to remember just up until a test, when they are in my notes, I can remember the lecture and what is said easier than PBL which is more long term for me.

Unfortunately, this student's preference for learning concepts through the traditional model appears to have been for short-sided gains of performing well on the traditional summative assessments instead of assimilating the content into long term knowledge. While this rationale for preferring the traditional model makes sense, it was a frustrating realization for the teacher-researcher. Another student response on the follow-up question conveys the recognized value of learning concepts using a combination of both the traditional and PBL models, "The PBL process and a combination of the traditional process helps me learn best. But the PBL helps me learn better.” This response illustrates how an instructional approach that uses a combination of the two instructional models was appropriate and effective for this particular student. However, the student also felt that his/her comprehension of the concepts was more robust when learned via the PBL model.

During the end-point formal interview a high-achieving female student, in third period, summarized her sentiment about the ability of the traditional and PBL models to prepare her for assessments, when she stated, “Traditional is better for learning concepts, general concepts…getting general ideas in your brain. But PBL was better for going into great depth.” Likewise, a second high achieving female student in third period expressed how both the traditional and PBL learning models are effective for her and therefore have their place during instruction, when she stated, “I think it depends on the type of subject we are learning. If we are learning with definition or basic stuff the traditional model is better. With PBL if it is a more complex subject it’s better.” In both quotes the students made it quite clear that both instructional styles probably have their place in the science classroom. The traditional model is helpful for learning the foundational knowledge that allows the PBL process to be effective for committing more complex ideas to memory. In other words, PBL is better for these two female students for learning more complex content. Again, the experiential learning, which forms the core of the PBL process, appears to enable students to remember the more challenging concepts because they correlate those concepts with their personal experience.

<u>The teacher-researcher's difficulty adjusting to the student-centered PBL class structure.</u>

My final claim is how I had a difficult adjustment to the student-centered PBL paradigm. While the previous analysis claims illustrated how the students enjoyed an experiential learning model and freedom afforded to them by the PBL process, they also, struggled to adjust to that same freedom. Despite my efforts, such as through the development of "daily learning tasks" activities, the students periodically had a difficult time staying on task. This was notably the case on non-lab days when we met in a regular classroom (as opposed to a science lab or being outside in the local prairie). During the second treatment phase, despite having learning "tasks" associated with the "Galapagos" PBL lesson, some of the students still struggled to stay on task the entire class period. The common student response to why they were not working was, "well, I finished my questions/part...." Hearing this from the students was frustrating because the learning tasks had worked so well during the ecology unit PBL; they were unfortunately not helping students stay on task and work collaboratively in their small groups during the second treatment. My frustration with the PBL process was captured in an early teacher-research journal entry:

> My initial assessment of the PBL process is that the students enjoy having the more active role. However, the students easily get off task when they are working on addressing the big picture questions. Despite my attempts to keep moving and help students as well as give students "tasks" on non-lab days to keep them busy they still seem to be slipping off task. I wish there was an additional teacher/guide that could help answer questions and keep students on task.

Part of my frustration might have been attributed to not feeling as if I had enough time or the ability to give each group of students the required amount of support they appeared to need while they worked on their PBL artifact or "daily learning tasks" activities. The PBL activities often raised complex questions, which in turn required additional support, redirection or long responses and this tied me to one group. Therefore, I was unable to keep moving to other groups. In other words, I was unable to serve my guide/coach role effectively. Basically, being the lone adult in the room and trying to support all of the students in a new learning paradigm may have been a factor for why students would slip off task.

While the PBL process definitely resulted in deeper learning for the students it also required more time to cover topics. This resulted in feeling rushed at times as I tried to complete, especially, my treatment units in the allotted time outlined in my Treatment & Data Collection Schedule (Table 4). In order to "catch-up" to my established PBL research plan or where I had been in past years, I regretfully resorted to traditional methods to such an extent that I made the following comment in my journal during the second treatment phase, "Even last year, my curriculum did not have as much teacher-centered practices as I have resorted to this week." I was ashamed to write this comment in my teacher-research journal as I was supposed to be integrating active learning principles into my curriculum, not lecturing to "catch-up." Even though I could reference the Barron & Darling-Hammond's (2008b) article on PBL instruction, which discussed how lecturing can be appropriate for disseminating vital foundational content information quickly and easily during a PBL based curriculum, I unfortunately found myself, as a novice to the PBL process, relying too heavily on lecturing during the PBL treatment units. While I stated above that my sense of being behind may have been partly to blame for my slipping back into instructing via traditional methods, another culprit may have had to do with my own comfort level with the traditional teacher-centered style, or the fact I was teaching a freshman introductory Biology course. In freshman biology, many of the topics we were covering were new to my students and therefore required distributing critical foundational knowledge before the students would be prepared for the PBL work on the larger concepts. Also, as stated above, when I would fall behind, lecture was an effective way to “catch-up” quickly to a point in the unit where I felt I needed to be. All in all, the PBL process was both intriguing and frustrating. It was intriguing because it brought the teacher-researchers instructional practice into the 21st century as it integrated progressive learning application into my often too passive teaching style. But, the process was equally frustrating as it was not only novel for the students and teacher-research alike, but at times difficult trying to stay on track.

The various data collection media used in this study provided valuable insight into the effects of integrating the active principles of the PBL paradigm. For example, data highlighted how students enjoyed their increased role in the course made possible through the PBL active learning process. Data also suggested this sentiment may have had to do with the parallels of the PBL process to the true nature of science. In addition, the students responded positively on both the mid-point and end-point Likert student surveys when asked if they would like to continue learning concepts via PBL.

INTERPRETATION AND CONCLUSION

This action research project was designed to see what ways a curriculum based on PBL principles would impact student attitude toward engaging in science, understanding course concepts, and subsequent assessment performance in a high school freshman Biology survey course.

The subjective qualitative formal interviews (both mid- and end-point) as well as the five-point Likert student surveys (both pre- and post-treatment) exhibited student awareness of the ability of PBL as an effective model for learning and recalling more complex or “big picture” concepts. This may very well have had to do with the fact that the students were assimilating their learning of concepts with an experience. This hands-on learning made the process more memorable, which in turn allowed for easier recall of concepts than when learning was through passive teacher-centered means, such as a lecture.

Because students recognized the benefits of learning concepts through PBL principles, about 70% of study participants commented (on the student-survey follow-up question for Question 14 and 15), that they would like to learn science concepts using exclusively the PBL model or some combination of PBL and the traditional model. The remaining 30% of the study participants wanted to learn exclusively through the traditional methods. Other qualitative data revealed that numerous students felt that the traditional learning methods were valuable, especially for learning basic foundational knowledge and preparing them for traditional summative assessments.

Despite the fact that the PBL process did not result in statistically significant improvement for student performance on traditional summative assessment, it did not negatively impact student performance during 2012/2013 study either. This lack of improvement may have had to do with the fact that these traditional assessments test skills that align more closely with the traditional instructional model as opposed to the progressive active learning principles of PBL. Albeit, it should be noted that the 2012/2013 PBL study participants were in fact able to match past student performance on traditional summative assessments. Conversely, on non-traditional assessments, such as the buckthorn scientific paper (functioning as the PBL artifact), were found to have statistically significant gains in performance when comparing the 2012/2013 students with their 2011/2012 counterparts. Such non-traditional assessment instruments align more closely with active learning principles which are at the heart of PBL.

The PBL model demonstrated some beneficial qualities recognized by both students and the teacher-researcher. Though, based on some of the data, as well as my observations and reflections of the PBL process, I am not necessarily sold on concentrating a freshman high school science curriculum solely on PBL principles as being the most effective model. This is due to the fact that the PBL model was developed for use in medical schools where students already encompass a significant amount of foundational content knowledge. High school students, especially freshman students in a survey course, might not have the appropriate foundational knowledge to effectively execute a PBL lesson from the beginning of a unit. This makes using some traditional model practices compulsory to quickly and efficiently disseminate foundational knowledge that ensures students are prepared for the PBL or other active learning work. In other words, I think moderation of both techniques, traditional and active, is a key component to any curriculum.

In order to more effectively integrate PBL practices into my curriculum next year, I would like to utilize the active learning PBL approach towards the end of the units. This change will give me more time to prepare students for the active learning PBL. By granting students the appropriate background knowledge upfront, they should be able to get more out of the experiential learning at the heart of PBL and in due course develop a more concrete understanding of science concepts, especially the more challenging “big picture” ideas. During the early stages of the unit, small “real world” problems/“lecture day” activities would be employed as a means of integrating active learning principles early and often into the unit. The rationale for this is two-fold. First it keeps student-centered problem-based learning in play early in the unit, even though it is being used concurrently with traditional practices, and secondly it will allow students to practice active learning techniques and become increasingly more independent in anticipation of the main PBL. Both of these practices should enable the main PBL to run more smoothly.

My struggles as a novice with implementing an active learning curriculum was a recurring theme throughout the research project as I, all too often, reverted back to traditional practices. This occurred when I needed to quickly cover topics before an upcoming traditional assessment, or if I fell behind on my plan because the student-centered learning process took slightly longer than anticipated. To more effectively use the PBL active learning approach I need to cut back the amount of material in each unit. This is tricky because I have a comfort level with not only the traditional teaching style but also my biology curriculum. Nevertheless, the PBL approach not only enabled students participating in the study to achieve a stronger understanding of the unit concepts, but also allowed them to match traditional assessment performance of past groups of students. Furthermore, the PBL treatment students were able to excel on non-traditional assessments. As a result, I need to find the "enduring understandings," or concepts that are most critical, in each unit and then tailor my PBL curriculum around those topics. PBL or other active learning practices need to be incorporated because a curriculum based solely on traditional teaching practices will often result in surface-level understanding for short term gains such as performing well on traditional assessments. However, the data suggests that true long-term knowledge of biology concepts becomes possible when students use a combination of some traditional but mostly PBL practices to address "real-world" problems.

VALUE

This project was an eye-opening experience into the art of educational research because it enabled me to examine how implementation of student-centered, active learning Problem-Based Learning (PBL) impacted both student learning and my own pedagogy.

This project allowed me to realize how the use of data, especially qualitative in nature, provided an exceptional basis for informing not only this project, but also my curricular ethos moving forward. Unfortunately, during my early years of teaching, the use of data was not something I had fully incorporated into my decision making process. In addition, whenever I did use data in the past, I often relied too heavily on quantitative techniques to provide information about how students were progressing. However, after conducting this research project, I realize now that I was missing a critical component by not gathering qualitative data particularly student voice, for example in the form of formal student interviews, which should be used to inform my pedagogy. Also, if my goal is to make my classroom more student-centered then qualitative data collection, and the candid information that it provides, needs to be an essential component of my teaching moving forward.

Another implication of this project was the fact that many students became aware of the limitations of the traditional learning model, especially for learning complex concepts. In short, the passive learning model does little more than to achieve low-level cognition. This type of learning, *e.g.* rote memorization, does not help students truly understand concepts and subsequently recall those ideas long term. In fact, student preferences for learning through the traditional model were often for short-sided gains such as performance on a summative traditional assessment that have little application in the real-world. On the other hand, many students recognized how the active learning, student-centered PBL functioned much more effectively in terms of its ability to provide a medium for learning course concepts concretely, especially the more challenging ideas.

A similar implication realized during this project was the fact that a majority of students recognized how they could thoroughly learn biology concepts, particularly the more challenging ideas, using real-world problems. The experiential learning that occurs during PBL lessons made learning concepts more memorable and easier to recall. In order to support this more concrete way of learning concepts, I will need to develop additional “lecture day” active learning activities. These activities will be used to replace traditional passive learning lectures while also providing real-world problems that students investigate to learn unit concepts and practice student-centered learning skills to help insure that students remain on task when they have more freedom in the student-centered learning environment. In other words, these activities provide an ideal system for allowing students to actively learn concepts and do so concretely while also improving applicable problem-solving skills.

This project and the implications identified were meaningful for me as an educator because the focus was self-directed professional development that was unique to my classroom. However, I must admit, this process was also quite challenging because it forced both the students and me out of our comfort zones. Even though the qualitative student data toward PBL was mostly positive, there still remains room for improvement in terms of my ability to integrate opportunities for and facilitation of PBL, or other active learning, lessons into my curriculum. I need to abandon my comfort with teacher-centered curricular principles, which are also pervasive in the science education landscape, in favor of implementing additional units using PBL or similar student-centered, active learning methods. However, in order to achieve this goal, my curriculum needs to be pared down to the most important ideas in each unit. In other words, my introductory high school biology course needs to contain less breath and more depth of the most critical concepts. This leads me to wonder if the Next Generation Science Standards (NGSS), which are supposed to be adopted later this year by the Illinois State Board of Education and 25 other states, will assist science educators in reducing the amount of content breadth and help make PBL or other active learning more feasible or hinder that goal?

Coupled with this shift toward depth of content is the need to change the way students are assessed in my classroom. Low-level cognitive traditional summative assessments are archaic and thus need to make way for non-traditional assessment opportunities, such as writing a scientific paper or engaging in case studies, that align with progressive active learning ideals. These non-traditional assessments will support the experiential learning at the heart of PBL by allowing students to develop and demonstrate their concrete understanding of critical science concepts during the creation and subsequent submission of their PBL artifacts. Consequently, I am curious to identify other or better types of non-traditional assessments that could support the active learning process. In addition, will the adoption of NGSS, and the subsequent standardized assessments that will certainly accompany these new standards, undermine the necessary shift toward non-traditional assessments?

Despite my struggles to shift away from the traditional model and integrate student-centered, active learning principles in my classroom, I eagerly wait to try PBL or other active learning opportunities again next year. I chose PBL as the focus of this project based on the potential gains for student learning of course concepts as well as student attitude towards engaging in science. Even though the action research and PBL process was a challenging undertaking, I am glad that the supportive MSSE program pushed me to try such a progressive teaching approach. In addition, using action research to look at my course curriculum and pedagogy through an analytical lens is vital for my continued growth as a science educator. Consequently, I look forward to utilizing the action research process as a professional development tool again in the near future.

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APPENDICES

APPENDIX A

“THE GALAPAGOS” PROBLEM-BASED LEARNING CASE STUDY

NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

The Galapagos

by
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Part I – In The Beginning

Kate stood on the edge of the *caldera* and peered down into the shadows. She could barely make out the movement a thousand feet below. But there, she was sure, was the tortoise she had named Alfredo, slowly making his way among the lava rocks toward the water pool. All 500 pounds of him. Kate marveled at the volcanoes around her. Before she had started this journey, she had read about the Galapagos and their volcanic origins. But she hadn't expected to be so emotionally moved by the islands themselves, by their stark scenery. A young graduate student, she was about to embark on a four-year study of the biology of the longest living animals. Alfredo had been around long before Darwin had arrived in the islands—and here he was, still ambling among the lava.

The origins of the Galapagos were similar to the origins of the Hawaiian Islands, but the Galapagos clearly were younger, more stark and barren. Kate had read that the Galapagos were a chain of islands, some of which no longer broke the surface of the water. How were these islands formed, she wondered. Was it from a hot spot at the bottom of the ocean bubbling up magma at periodic intervals? Somewhere in the sea nearby in the Galapagos Rift there were hydrothermal vents belching sulphurous gases. Some biologists believed that these vents were the sites of the origin of life.

It had been a long-time dream of Kate's to visit the Galapagos Islands, and they hadn't disappointed her. Made up of 13 large islands and dozens of smaller ones, the Galapagos straddle the Equator in the eastern Pacific Ocean, some 600 miles off the coast of mainland Ecuador. Large, jagged outcroppings of lava alternated with small sandy beaches along the shorelines. Isolated patches of mangroves along the shore gave way to cactus in the arid lowlands of the islands, then lush cloud forests in the moist upper regions, and finally tree ferns and scrubby grasses in the otherwise barren uplands.

But it was the astonishing array of animals that took Kate's breath away. Like every other visitor to the islands, from the first Europeans to set foot on these shores to Darwin some 300 years later in 1835, she was struck by the strangeness and tameness of the fauna. On shore, scores of sea lions lazily sunned themselves on the beaches. Masked boobies courted practically under foot. Among the rocks at the water's edge lived the black iguana, the only marine lizard in the world. In the surrounding seas were stingrays, white-tipped sharks, sea turtles, and the Galapagos penguin. Dozens of endemic species were found here and nowhere else on earth.

And here she was, standing where Charles Darwin had stood 150 years before. Darwin's theories of evolution had depended heavily on his insights into the origins of the life forms on the Galapagos. He had questioned where these animals had come from. How could the flora and the fauna of islands so near one another be so different and yet strangely so similar? Each island seemed to have its own variety of tortoise, its own type of marine iguana, even its own form of prickly-pear cactus.

The finches were particularly interesting. These relatively nondescript birds had beaks with amazing adaptations to eat different types of food. Although most of them were seed-eaters, Darwin had discovered that one of the finches had specialized by using small sharp sticks to probe the recesses of cactus plants for grubs. A woodpecker finch he called it. How could these animals and plants be due to simple creation? Wasn't it more reasonable to think that mainland species had arrived on the islands eons ago and became specialized for different environmental conditions on the different islands?

Kate knew the answers now to Darwin's questions, and yet the islands didn't seem old enough to account for the spectacular diversity she saw all around her. She knew that the Grants, the husband and wife team from Princeton University, were working on a nearby island to resolve the question of the speed of evolution. She had heard at the Charles Darwin Research Station that they had been impressed with the rapid changes that seemed to be brought about by the El Niño climate shifts in the last couple of decades. She resolved to look into this more closely. But right now she had to get back to the research station—gray storm clouds were closing in fast.

Study Questions

1. How did the Galapagos Islands come into existence?
2. Were plate tectonics involved?
3. How old are the Galapagos Islands?
4. What kinds of animals and plants are endemic to the islands?
5. How do species become endemic?
6. Where did the original colonists come from and how did they get to the Galapagos?
7. What kind of special adaptations do the animals and plants have? How do adaptations evolve?
8. How did these islands figure into Darwin's ideas on evolution?

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Part II – Darwin's Finches

"So, Kate, what do you think of the islands?" asked Miguel.

"I think they're fantastic. The Spanish were right to call them 'The Encantadas'." Kate had just entered the library of the Charles Darwin Research Station to find its director sitting at a table.

"Yes, 'The Enchanted Isles' does seem to suit them. The volcanoes have always seemed bewitched to me. Sit down for a minute and tell me how your plans are shaping up." Miguel gestured toward a chair across from him.

"Well, I was on Albemarle two days ago, and I think I could get my research done up there. The chance to study character displacement on the five volcanoes is really exciting. Imagine, five different races of tortoises on the same island. A lot of the tortoises seem to have already been marked by previous researchers, and you seem to have a good handle on some of the history already."

"Yes. In addition, we have some good DNA data on the tortoises here, especially those in our breeding pens. You've seen them, I'm sure."

"Yes, I have. I think it's a terrific breakthrough that at last you can identify which islands some of these animals came from. In fact, it should be possible to identify the parents if enough data were collected. But, who's doing this work? Is it done here at the station?"

"No. We send tissue samples out to labs in the United States for DNA fingerprinting. We don't have the lab facilities here to do Southern Blot procedures or PCR. But tell me, are you committed to working on the tortoises? There are a lot of easier things to study here. The iguanas and the birds are more accessible."

"I've thought about that, especially since the Grants have been so successful working on the finches. How's their work coming?" Kate leaned forward eagerly.

Miguel removed his glasses, tilted his chair back, and began: "I'm sure you know that Peter and Rosemary started trapping and banding all of the finches on Daphne Major over 20 years ago. Sometimes they had only 200 birds on the island; sometimes there were over 2000. And they could recognize them all! The Grants have been able to watch evolution happen; something that Darwin could only imagine."

"He thought evolution was too slow to see," Kate said. "In fact, Creationists have argued that neither evolution nor Divine Creation could be tested. The Grants' work certainly puts a lie to that."

"Yup. Darwin certainly underestimated the speed of evolution. These islands appeared less than five million years ago, and life is evolving here as fast and furiously as the volcanoes because life forms are trapped on separate islands. The top of each volcano is a prison for most of the creatures."

"There never was a bridge to the mainland, was there?"

"No. Anything that has arrived here had to cross at least 600 miles of water from South America. That's how the first finches arrived here, presumably blown off the mainland during a storm."

"So, in the space of a few million years all of the different species had to have adapted to the different conditions on the different islands."

"That's true, but realize the differences are not all due to adaptations and natural selection. I figure a lot of it has to do with genetic drift."

"Of course. But whatever was going on, no one figured it would be as fast as the Grants have discovered. I think one of the neatest techniques that the Grants brought to their study was a way of measuring how the seeds of the different plant species vary in their hardness."

"I agree with you, Kate. Peter and an engineer at McGill University designed a nutcracker, a sort of pliers with a scale attached. They found small soft seeds of *Portulaca* needed only a force of 0.35 newtons to be cracked. Any of the finch species could do that. But the big hard seeds of *Cordia lutea* needed 14 newtons force and only a few large finches can muster that much force. Once they knew how to measure hardness, the Grant team could check the abundance of the seeds and see exactly what the birds selected and ate."

"But that varied with the season, didn't it?"

"Exactly. In the wet season, when small seeds were abundant, the average seed hardness was 0.5, but in the dry

season it jumped to over 6 newtons. Lots of finches couldn't eat many of those seeds. If it hadn't been for the fact that the six species began to switch to other foods, severe starvation would have occurred. A great example of resource partitioning—one of your pet subjects, Kate.

“In fact, Rosemary Grant found that switching even occurred among individuals of a single species. In times of plenty, all cactus finches eat the same seeds, but when these seeds are scarce, things change. Those with long beaks open the fruits and probe the cactus flowers, while those with larger, deeper beaks crack the big tough cactus seeds, and those with still deeper beaks strip the bark from the trees to get grubs.”

“Everything gets worse when a severe drought happens, doesn’t it? Natural selection really gets intense.”

“Absolutely. It virtually wipes out the birds with the smaller beaks. The great drought of 1977 taught the Grants that. The population plunged to 200 birds. Before the drought, the average beak size of the *fortis* species was 10.68 mm long and 9.42 mm deep. After the drought, it was 11.07 mm long and 9.96 mm deep. Variations too small to see with the naked eye made the difference between life and death. It altered the sex ratio, too, since males have larger, stronger beaks. After the drought, there were seven times more males than females! In the years following the drought the competition between males for mates was fierce. Amazingly, the females started choosing the males with the largest beaks for breeding. The smaller-beaked males didn’t have a chance to mate at all.”

Kate nodded. “That’s a perfect example of sexual selection in action. Both natural election and sexual selection were working in the same direction: producing birds with large beaks. But were these genetic differences or were they due to the food supply? I mean, wouldn’t you expect the well-fed birds to have larger bills, and then they would be the ones to breed and successfully raise young?”

“Of course. One of their graduate students wanted to test that, but it didn’t work out, so they have had to resort to indirect evidence to demonstrate that the changes were genetic.

“But let me tell you about the big El Niño events of 1983,” Miguel continued. “A huge amount of rain fell that year, a once-in-a-century event! The island went from a desert to a jungle in a few weeks. Food was everywhere.

The birds started breeding like crazy and there were suddenly 2000 finches on Daphne Major. When normal, dry conditions returned, there suddenly wasn’t enough food to go around. The birds had overshot the carrying capacity of the island.

“But here’s the interesting part: now, birds with smaller beaks were favored. Big males and big females started dying because of insufficient food. That’s because there were a lot more small seeds than large ones lying around. The floods of El Niño had washed away many of the large seed-producing cactus trees. Even though the big birds could eat small seeds, they were at a disadvantage because of their size. They had to eat more to survive.”

“A lot of hybridization started occurring after El Niño, didn’t it?” Kate said.

“Yes, to everyone’s great surprise. Hybrids were rare during the lean years. The reproductive barriers kept the species distinct. The isolating mechanisms were primarily differences in song and beak size. But once the conditions dramatically improved, diversity was favored. A lot of finches began to breed with individuals of different species. They didn’t seem to care as much what kind of song or beak their mate had. Some people even speculated that the mutation rate actually increased when environmental conditions shifted dramatically.

“Take a look at the finches outside the window,” Miguel added. “Here at the research station it’s hard to separate the different species because of the hybrids. They sort of fuse together here, where conditions are

always good because people feed them. Kate, if you really want a great thesis problem, you couldn’t do much better than study finch hybridization around the village. I’m sure that humans are having a terrific impact on both speciation and extinction.”

Study Questions

1. What is DNA fingerprinting and how is it done?

2. How can we measure evolution?
3. What is the difference between natural selection and evolution?
4. What is genetic drift and how could it be involved in evolution?
5. What is resource partitioning and character displacement?
6. What is sexual selection?
7. How might one test if beak size is due to genetic or environmental factors?
8. If hybridization occurs during good times, what does this suggest about the degree of genetic differences between species?
9. What are reproductive isolating mechanisms and how do they evolve?
10. Must populations of finches be separated in order to evolve into different species?
11. What causes an El Niño?

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Charles Darwin Research Station. http://www.darwinfoundation.org/.

Part III – The Tortoise and the Sea Cucumber

Kate was tired. The last few nights she had stayed on late at the station, typing up her field notes. Her research on the breeding practices of the giant land tortoises in the wild was going well. She had been observing them for a four-month period, primarily in the Alcedo Volcano area on the island of Isabela, home to about 4,500 tortoises. But she was worried that mounting tensions between local fishermen and the Ecuadorian government might disrupt her work. The year before, in response to a decision by the President of Ecuador to cut short the sea cucumber season, armed fishermen had stormed the research station and taken several scientists hostage.

Kate's biggest concern at the moment, however, were the goats on Isabela. With human settlement of the islands had come new kinds of animals—cats, rats, dogs, donkeys, pigs, and goats. The number of goats on Isabela had increased from less than a dozen in 1982 to over 100,000. They were literally eating the tortoises out of house and home, foraging on the shrubs and bushes growing on the mountain's slopes, competing with the tortoises for food, causing widespread erosion of tortoise habitat. Besides the damage done by goats, wild dogs and pigs dug up the tortoises' nest and ate their eggs in addition to preying upon their hatchlings. On Pinzon Island, another introduced species, the black rat *(Rattus rattus)*, had killed every tortoise that had hatched on the island in the last 100 years.

It seemed sad to Kate that the islands' natural heritage was slowly being destroyed by the hand of man. The Galapagos had been named in 1535 by a Spanish navigator, Tomas de Bertanga, for the then-prevalent giant tortoises. When Darwin visited in 1835, he reported tortoises on all of the islands. Since then their populations had dwindled at an alarming rate, and several subspecies had become extinct.

Lately Kate had begun to feel almost a personal responsibility to save the endangered tortoises. She considered the plight of Lonesome George, perhaps the most famous resident at the Charles Darwin Research Station, so named because he was the last surviving member of his subspecies *G. e. abingdoni*. One of the major initiatives of the research station was its captive breeding and rearing program, which was already racking up successes.

The tortoises of the island of Espanola *(G. e. hoodensis)* had been teetering on the verge of extinction. When captive breeding began for this subspecies, only two males and twelve females remained. Later, a third male was returned to the islands by the San Diego Zoo. Since then well over 300 young tortoises had been bred and repatriated, and some of these were now breeding back on the island. Kate was proud that her fieldwork was part of this effort.

Kate switched off her computer. She stuffed some papers into her backpack and the last bite of her sandwich into her mouth and got ready to leave. She thought of stopping by her friend Stephen's house on the way home. Stephen had been a full-time rancher, part-time naturalist in New Zealand before visiting the Galapagos some 15 years before. Enchanted by the place, he had simply stayed on, becoming one of the first government-licensed tour guides.

Much of the islands had been designated a wildlife sanctuary in 1934 by the government of Ecuador. Uninhabited areas were declared a national park in 1959. In 1986, the Galapagos Marine Resources Reserve was created, administered by the Ecuadorian government with the help of the research station. The reserve made up about 97 percent of the islands' land and 50,000 square kilometers of the surrounding seas. Tourism throughout the islands was strictly controlled. Tourists weren't allowed to wander around. Instead, they had to be accompanied by a licensed tour guide when visiting wildlife sites, and they had to stay on assigned paths. Many islands were off limits entirely.

As she walked to Stephen's house, Kate thought it was ironic that one of the few places on earth where aboriginal man never existed, one of the least-visited corners of the earth for much of modern history, should be practically overrun now by human beings. Last year over 50,000 tourists had visited the islands. Many conservationists were voicing concerns over the impact of tourism on the islands. Still, most scientists agreed that 15 years of tourism hadn't done one-tenth the damage of the recent fishing boom and the mass immigration from the mainland that came in its wake.

Although certain fisheries were long established in the Galapagos and sanctioned by the government, the sea cucumber fishery had become a sort of "gold rush" phenomenon. Fishermen from the mainland had descended on the islands to harvest them illegally from the protected waters. Considered a delicacy in Asian cuisine, sea cucumbers were also in demand throughout the Orient for their purported aphrodisial properties.

Kate thought them one of the more unattractive animals she'd ever encountered. Ranging in length from two inches to five feet, they had soft bodies and a leathery, somewhat slimy skin. Some species were warty.

The role they play in ocean ecology wasn't fully understood. Marine biologists likened them to earthworms. They spent most of their time on the sea floor, where they sucked up mud and sand, from which they extracted nutrients. Kate had overheard one of the researchers at the station saying that sea cucumbers often made up 90 percent of the animal biomass in marine systems. Many scientists feared that a rapid decline in their numbers might have serious consequences for the survival of other species in the food chain.

Harvesting of the *Isostichopus fuscus* sea cucumber had begun in the waters surrounding the Galapagos in 1988 but had been banned by the government in 1992, although illegal fishing continued. The Ecuadorian government simply didn't have the resources to effectively patrol miles of open ocean. In response to increasing pressure from local fishermen, the government lifted the ban and granted a three-month season for harvesting sea cucumbers, beginning in mid-October of 1994. Kate shuddered, picturing the tortoises that reportedly had been found dead, hanging from trees—the form of political pressure the local fishermen had allegedly resorted to. The total take wasn't supposed to exceed 550,000 sea cucumbers, but in the first two months alone an estimated seven million were harvested from the sea floor.

The government stepped in and shut down the fishing season a month early, touching off a series of violent protests that had culminated in several fishermen, wielding axes and machetes, taking hostages at the research station. Government troops had been called out, and the hostages—including Lonesome George—were freed without further violence. In the weeks that followed, the Ecuadorian government placed a moratorium on the sea cucumber fishery until scientists could determine an annual catch that wouldn't wipe out the species. The government asked ORSTOM, the French overseas research agency, and the Darwin Foundation to study the problem.

When Kate got to Stephen's house she found him all worked up over the media's coverage of the crisis in the Galapagos. He was upset because the news stories seemed to imply that all of the inhabitants of the islands were anti-conservationists.

"Tourism brings in over $50 million dollars a year in revenue," he said. "Fishing isn't a major economic factor in the lives of most of the people who live here. Believe me, people here are not fools. They're only too aware that they must conserve the islands if they are to protect their livelihoods. These people—the fishermen and the politicians who support them and their violent tactics—don't represent the majority. They certainly don't represent me.

"In the short time you've been here, Kate, you've seen that the problems that beset these islands are not simple—they are very complex. We've been left to deal with the aftermath of an uncontrolled mass migration. We've gone from a population of 5,000 in the early '80s to over 15,000. This population explosion is putting enormous pressure on the islands—on other aspects of our economy, for one thing, like our traditional fisheries, which could be at risk next. And now that this ban has put our newest immigrants to the islands out of work, we've got rampant unemployment, and hard on its heels, an increase in crime.

"I'm sympathetic to the plight of these people," Stephen continued. "I know that the poverty they're fleeing from on the mainland is terrible. But I'm not sympathetic to their "get-rich-quick" mentality or their strong-arm tactics. The people from the mainland haven't grown up with an appreciation of the uniqueness of the reserve or the goals of the research station, or an understanding of the tradition of sustained subsistence fishing on the islands. They're just not as sensitive to the extraordinary biodiversity and the natural resources of these islands.

"The Galapagos economy, like that of the rest of Ecuador, is based on its natural resources. Victory for the conservationists is not a defeat for Ecuadorians. What many claim is a war against our own people is simply a refusal to defend the Galapaguenos' "right" to destroy their own future."
Kate sighed. She agreed with Stephen, but she couldn't help thinking of her neighbor Emilia, who had been so kind to her in so many ways. Emilia's husband Adolfo was the head of the fishermen's cooperative on Isabela.

According to Adolfo, the sea and its bounty were "the only way out" for the local people. Adolfo had cornered Kate a week ago, almost shouting at her as he waved his arms and argued his point: "The conservationists have to take into account that if they don't allow the development of any other industry, there is no way for us to survive. How are we going to feed our kids? We need to live!"

As Kate got ready to leave, Stephen asked her if she had heard that the Darwin Foundation had finally issued its report:

"It recommends restoring traditional fisheries in the Galapagos and helping poor fishermen return to mainland Ecuador. They intend to make the moratorium on the sea cucumber fishery a permanent thing. That could mean more trouble. Be careful, Kate."

That night Kate slept uneasily. Early the next morning she was wakened by the sound of someone banging on her back door. It was Emilia, carrying her youngest daughter in her arms. Emilia looked frightened. Kate had to ask her twice to repeat herself. When she finally understood what Emilia was trying to tell her, she was horrified. Apparently Congressman Eduardo Veliz and the fishermen he represented had taken over the islands' fisheries and the research facilities. And now they were threatening to set fi res, take tourists hostage, and kill rare animals (tortoises, Kate figured) unless the government complied with their demands to reopen the sea cucumber fishery and give local inhabitants of the islands more control over the national park.

Study Questions

1. Should Kate have chosen to work on a different species than the tortoises that are being threatened? Her thesis work might be destroyed by the politics of the islands.
2. Should Kate get involved in the politics of saving the islands, the way Dian Fossey did in trying to save the Mountain Gorilla?
3. Should fishing, tourism, or inhabitants be allowed in the islands?
4. How should the Ecuadorian government deal with the conflicts over the islands?
5. Extinction is a natural phenomenon. Why should we worry about whether a few species on some remote islands in the Pacific survive or not?

Instructions to Students

During the discussion period, each team of students will assume the role of a particular interest group vying for a piece of the action in the Galapagos: fishermen, storeowners, tourists, scientists, Sierra Club members, and politicians in Ecuador. When you receive your roles, you should research the case from your particular perspective and talk over your position within your group, developing a position paper. When we are ready for a general discussion, members of each interest group will be split up to meet with people from other interest groups, i.e., the instructor will form new consensus-seeking groups, each of which will have one member from each of the interest groups present. So, a consensus group will have a fisherman, a storeowner, a tourist, scientist, Sierra Club representative, and politician. The politician's job is to run a discussion to see if the group can come to some consensus on how to resolve the crisis and write a position paper laying out the group's plan.

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APPENDIX B

PRE-TREATMENT STUDENT SURVEY

Student Survey (pre-treatment)

Directions: Please take some time to thoroughly think about each question. Then select the position on the scale that best reflects your feelings. Please do **NOT** make your selection based on what you think I want to hear. Where applicable please write your response legibly.

Remember:

- All responses will be kept anonymous.
- Participation is voluntary; you may choose to not answer any question that you do not want to answer, and you may stop at any time.
- Your participation or non-participation will not affect your grade or class standing.
- There are NO right or wrong answers to this survey!

What class period are you in?

- Period 1-2
- Period 3-4

What is your ID number? ____________________________

(Note: this will ONLY be used to track responses from the pre- to the post-survey)

1.I like going to science class.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Follow-up question: Please explain your selection for question # 1:

2.I enjoy learning new science concepts.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Follow-up question: Please explain your selection for question # 2:

3.I enjoy science laboratory experiences.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Follow-up question: Please describe your typical laboratory experience in junior high? Explain the aspects of the process you liked as well as those you disliked.

4.I enjoy hands on activities more than book activities.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

5. The way laboratory experiences are conducted in schools is analogous to the research process employed by scientists.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

6. Please describe the research setting used by scientists to conduct their research.

7. I would rather learn biology/ecology concepts through laboratory experiences than by reading about the topics.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

8. The traditional learning process (textbook reading, lectures, and labs) is an effective method for learning science concepts.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

9. The traditional learning process (textbook reading, lectures, and labs) prepares me well for science tests/assessments.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

10. The traditional learning process (textbook reading, lectures, and labs) enables me to understand biology concepts 6 months from now.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

11. The traditional learning process (textbook reading, lectures, and labs) will enable me to understand biology concepts 4 years from now.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

12. The traditional high school science laboratory experience helps develop critical thinking skills.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

13. High school laboratory experiences should have a set procedure to follow.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

14. The information in a high school science textbook is absolute/concrete knowledge.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

15. Science research is full of complexity.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

16. The traditional high school science laboratory experience is full of complexity.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

17. Creativity is an essential component of science.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

18. Curiosity is an essential component of science.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

19. Creativity and curiosity are essential components of the traditional high school laboratory experience.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

20. The same data can result in multiple solutions.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

21. Science research should only have one variable.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

22. Science concepts can be learned through the use of laboratory experiences.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

23. High school laboratory experiences should have a more open-ended procedure.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

APPENDIX C

POST-TREATMENT STUDENT SURVEY

Student Survey (project endpoint)

Directions: Please take some time to thoroughly think about each question. Then select the position on the scale that best reflects your feelings. Please do **NOT** make your selection based on what you think I want to hear. Where applicable please write your response legibly.

Remember:

- All responses will be kept anonymous.
- Participation is voluntary; you may choose to not answer any question that you do not want to answer, and you may stop at any time.
- Your participation or non-participation will not affect your grade or class standing.
- There are NO right or wrong answers to this survey!

What class period are you in?

- Period 1-2
- Period 3-4

What is your ID number? ______________________________

(Note: this will ONLY be used to track responses from the pre- to the post-survey)

1. I liked coming to science class more during the Problem-Based Learning (PBL) portion of the Ecology unit.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Follow-up question: Please explain your selection for question # 1:

2. I enjoyed learning new science concepts through the Problem-Based Learning (PBL) model.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Follow-up question: Please explain your selection for question # 2:

3. I enjoy the one-day science laboratory experiences (that are typical of the traditional learning model lab experience).

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

4.I enjoy hands-on activities more than book activities.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

5.I enjoyed the hands-on Problem-Based Learning (PBL) model experience.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

6.Please describe the research setting used by scientists to conduct their research.

7. The "traditional" laboratory experiences conducted in schools are analogous to the research process used by professional scientists.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

8. The Problem-Based Learning (PBL) process is analogous to the research process used by professional scientists.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

9. I would rather learn biology concepts through PBL experiences than by reading about the topics.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

10. The Problem-Based Learning model "lecture" day activities (such as the wolf or species interaction activities) are better than a traditional lecture day.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Follow-up question: Please explain your selection for question # 10:

11. The traditional learning process (textbook reading, lectures, and one-day labs) is an effective method for learning science concepts.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

12. The PBL learning process (using big picture problems/questions) is an effective method for learning science concepts.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

13. Science concepts can be learned thoroughly by trying to solve real problems.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

14. The traditional learning process (textbook reading, lectures, and one-day labs) prepares me well for science tests/assessments.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

15. The Problem-Based Learning (PBL) process prepared me well for science tests/assessments.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Follow-up question: Please explain which process—traditional or PBL—prepared you better for assessments:

16. The PBL learning process enables me to understand biology concepts 6 months from now.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

17. The PBL process helps develop critical thinking skills better than traditional high school science laboratory experience.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

18. High school laboratory experiences should have a set procedure to follow.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

19. I prefer the open-ended procedure of the PBL model.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

20. The information in a high school science textbook is absolute/concrete knowledge.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

21. Science research is full of complexity.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

22. The traditional high school science laboratory experience is full of complexity.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

23. The PBL learning experience is full of complexity.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

24. Creativity and curiosity are essential components of science research.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

25. Creativity and curiosity are essential components of the traditional high school laboratory experience.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

26. Creativity and curiosity are essential components of the PBL learning experience.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

27. I would like to continue learning biology concepts using a Problem-Based Learning (PBL) model in the future?

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

APPENDIX D

MID-POINT FORMAL STUDENT INTERVIEW QUESTIONS

MID-POINT FORMAL STUDENT INTERVIEW QUESTIONS

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

1. Do you enjoy coming to science class? Please explain.
    a. What do you like most about science class?
    b. What do you like least about science class?
2. What are your impressions of Problem-Based Learning (PBL)?
    a. What do you like most about the PBL process? Please explain your reasoning.
    b. What do you like least about the PBL process? Please explain your reasoning.
3. Which learning method, traditional (*i.e.* textbook reading, lectures, and one-day labs) or PBL, enabled you to understand concepts better? Why do you think that is?
4. Which learning method, traditional or PBL, required more time to understand concepts? Why do you think that is?
5. Did the PBL process prepare you well for the quizzes/test?
6. What is your opinion of the "lecture day" activities when you looked at and answered the big questions?
7. Which learning method, PBL or traditional, do you think more closely aligns with the way science is conducted in the real world? Please explain.
8. Do you prefer traditional labs or the PBL process? Why?
9. Has the PBL process taught you anything about yourself as a person? As a learner?
10. How do you think I could improve the PBL process in the future?
11. Would you like to add anything else?

APPENDIX E

END-POINT FORMAL STUDENT INTERVIEW QUESTIONS

END-POINT FORMAL STUDENT INTERVIEW QUESTIONS

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

1. Which method of learning science is more effective for you, traditional or PBL? Please explain.

2. What are your impressions of the Problem-Based Learning (PBL) process?

    a. Would you like to learn concepts using the PBL model again? Please explain.

3. Which learning method, traditional (*i.e.* textbook reading, lectures, and one-day labs) or PBL, enabled you to understand concepts better? Why do you think that is?
    a. Which process do you think will allow you to recall concepts better in the future?
4. Which learning method, traditional or PBL, required more time to understand concepts? Why do you think that is?

5. Which method, traditional or PBL, better prepared you for the quizzes/test?

6. Remember when I gave you the handouts on the GYE wolf population growth and the species interactions activities before we did notes. Do you think those activities enabled you to understand the concepts better? Please explain.

7. What are your feelings about developing the PBL artifact (writing a scientific paper)?

8. How did you feel about being able to update/fix your PBL artifact (scientific paper)? Did the redo process teach you the nature of science?

9. Which learning method, PBL or traditional, do you feel more closely aligns with the way science is conducted in the real world? Please explain.

10. Do you prefer traditional one-day labs or the PBL process? Why?

11. Has the PBL process taught you anything about yourself as a person? As a learner?

12. How do you think I could improve the PBL process in the future?

13. Would you like to add anything else?

APPENDIX F

TEACHER JOURNAL PROMPTS

JOURNAL PROMPTS

Journal entries were completed following each 85-minute laboratory period on Mondays and Wednesdays during both the treatment PBL and non-treatment traditional instruction.

1. What went well in today's class?
2. What did not go well with today's class?
3. Did anything else of interest occur today?

APPENDIX G

SUMMATIVE ASSESSMENT TREATMENT PHASE PART I

PBL TREATMENT PHASE SUMMATIVE ASSESSMENT

ECOLOGY QUIZ

1. **Biology is the scientific study of**:
   a. The land, water, and air on Earth. c. The universe
   b. Animals. d. Life
2. **The branch of biology dealing with interactions among organisms and between organisms and their environment is called:**
   a. economy c. recycling
   b. modeling d. ecology
3. **A group of interbreeding organisms of the same species is called a**:
   a. community c. ecosystem
   b. population d. biome
4. **The process by which plants remove carbon dioxide from the atmosphere and create food is called**:
   a. combustion c. photosynthesis
   b. fossil fuels d. respiration
5. **A group of interacting populations which are in an ecosystem is called a**:
   a. community c. biome
   b. population d. ecosystem
6. **The movement of organisms OUT OF a given area is called**:
   a. immigration c. population shift
   b. emigration d. carrying capacity
7. **If a population grows larger than the carrying capacity of the environment, the**:
   a. death rate may rise c. population will grow faster
   b. birth rate may rise d. carrying capacity will change
8. **What can cause a population to grow**?
   a. the birthrate becomes higher than the death rate
   b. the birthrate stays the same, and the death rate increases
   c. the birthrate becomes lower than the death rate
   d. the birth rate and the death rate remain the same
9. **Population growth that fluctuates around a carrying capacity is called**:
   a. random growth b. exponential growth c. logistic growth
10. **Explosive population growth is called**:
    a. random growth b. exponential growth c. logistic growth
11. **Human population is demonstrating this type of population growth**:
    a. random growth b. exponential growth c. logistic growth
12. **A squirrel and an oak tree are both examples of individual**:
    a. genes b. organisms c. ecosystems d. cells
13. **The amount of light and temperature are examples of**:
    a. Methods of energy production.
    b. Characteristics of living things.
    c. Abiotic factors.
    d. Biotic factors.
14. **Organisms that obtain nutrients by breaking down dead material are called**:
    a. decomposers c. omnivores
    b. herbivores d. producers
15. **Which of the following is NOT a density-dependent factor?**
    a. lack of nesting sites c. food shortage
    b. drought d. overcrowding

16. **Which is a <u>biotic</u> factor that affects the size of a population in a specific ecosystem**?
    a. average temperature of the ecosystem
    b. type of soil in the ecosystem
    c. number and kinds of predators in the ecosystem
    d. concentration of oxygen in the ecosystem
17. **Different species can share the same habitat, but competition among them is reduced if they**:
    a. reproduce at different times
    b. eat less
    c. increase their population
    d. occupy different niches

APPENDIX H

SUMMATIVE ASSESSMENT NON-TREATMENT PHASE

NON-TREATMENT SUMMATIVE ASSESSMENT
CLASSIFICATION, ANIMAL AND PLANT KINGDOM TEST

For questions 1-6, match the Kingdom with the appropriate defining characteristic (answers may be used more than once):

A. Protista **B.** Plantae **C.** Monera **D.** Fungi **E.** Animalia

1. Cell wall is made of Chitin
2. Comprised of prokaryotes
3. Algae fall into this Kingdom
4. No cell wall
5. Cell wall is made of cellulose
6. “Garbage” Kingdom

---

7. **The classification scheme used in biology was developed by**:
   a. Darwin c. Aristotle
   b. Linnaeus d. Mendel
8. **Scientist assign each kind of organism a universally accepted name in the system known as**:
   a. mumbo-jumbo c. binomial nomenclature
   b. the three domains d. cladistics
9. **All organisms in the kingdoms: Protista, Fungi, Plantae and Animalia are**:
   a. multicellular organisms c. eukaryotes
   b. photosynthetic organisms d. prokaryotes
10. **Two organisms that can reproduce and produce fertile offspring would have to be in the same:**
    a. class c. genus
    b. order d. species
11. **The scientific name of an organism is composed of**:
    a. genus and species c. class and order
    b. genus and family d. phylum and kingdom
12. **A genus is composed of a number of related**:
    a. kingdoms c. phyla
    b. orders d. species
13. **Based on their scientific names, you know that the baboons (a type of ape) *Papio annubis* and *Papio cynocephalus* belong to the same:**
    a. class c. family
    b. genus d. species
14. **In binomial nomenclature, which of the two terms is capitalized**?
    a. the first term only c. the second term only
    b. both the first and second terms d. neither the first nor second term
15. **Which classification level was added to the scheme within the last few decades**?
    a. Division c. Species
    b. Domain d. Class
16. **Which of the following categories contains the greatest number of different kinds of organisms**?
    a. genus c. phylum
    b. family d. class

For questions 17 – 22, use the choices on the right: Answers may be used more than once or not at all

17. the Tuberculosis bacteria
18. a Geranium plant
19. a tarantula spider
20. diatoms
21. a puff ball mushroom
22. a yeast cell

A. Monera
B. Protista
C. Fungi
D. Plantae
E. Animalia
AB. none of these

23. **If an organism is eukaryotic, heterotropic, multicellular, and moves, what kingdom would you put it into**?
    a. Fungi   b. Protista   c. Plantae   d. Animalia   e. Monera
24. **Solely from its name, you know that *Rhizopus nigrans* must be**:
    a. a plant   c. in the family *Rhizopus*
    b. a fungus   d. in the species *nigrans*
25. **Which of these categories of classification contains organisms that are most closely related**?
    a. family   c. order
    b. class   d. genus
26. **As we consider the animal kingdom from phylum to species, there is a(n)**:
    a. Decrease in the size of animals
    b. Increase in diversity
    c. Increase in the relationships of the organisms
    d. Increase in the different kinds of organisms
27. **In general, the greater the difference in the cytochrome C protein between two species, the**:
    (Note: cytochrome C is a protein found in all living organisms)
    a. The later they diverged (broke apart)
    b. Earlier they diverged
    c. Closer they are related
    d. Greater their similarity
28. **In the modern system of classification, each order is subdivided into:**
    a. Classes   c. Genus
    b. Species   d. Families
29. **Only 5% of all animals have**:
    a. Backbones
    b. DNA that is not inside the nucleus
    c. Eukaryotic cells
    d. Cell membranes
30. **An animal that has distinct left and right sides shows**:
    a. Radial symmetry
    b. Segmentation
    c. Several planes of symmetry
    d. Bilateral symmetry
31. **Some type of body symmetry is found in all invertebrates <u>EXCEPT</u>:**
    a. Cnidarians   c. Sponges
    b. Mollusks   d. Flatworms
32. **A vertebrate is any chordate that has a**:
    a. Backbone   c. Tail that extends beyond the anus
    b. Dorsal, hollow nerve cord   d. Pharyngeal pouche
33. **Which of the following habitats do arthropods occupy?**
    a. the sea   b. the land   c. the air   d. all of the above   e. only a and b

34. **Echinoderms and Chordates are considered**:
    a. Deuterostomes c. Mesoderms
    b. Protostomes d. Endoderms
35. **Mammals are characterized by each of the following EXCEPT**:
    a. mammary glands. c. generate their own body heat (endotherms)
    b. hair. d. three-chambered heart
36. **The three main groups of mammals are**:
    a. monotremes, marsupials, and placental mammals
    b. platypuses, echidnas, and marsupials
    c. rodents, carnivores, and primates
    d. kangaroos, koalas, and wombats
37. **Which animal phylum contains the largest number of animals (over 75% of the animal kingdom)**?
    a. Nematoda c. Mollusca
    b. Arthropoda d. Cnidaria

For questions 38-43, please MATCH each animal to the phylum in which it is classified. The phyla may be used more than once or not at all.

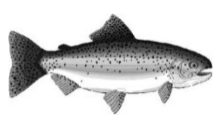
A. Porifera **D.** Molluscs **AC.** Echinoderms
B. Cniderans **E.** Annelids **AD.** Chordates
C. Platyhelminthes **AB.** Arthropods

38. exoskeleton made of chitin
39. highly cephalized invertebrates, some possess shells externally others internally
40. Simple, skeleton supported by spicules, mostly filter feeders
41. segmented body, jointed legs. Examples include arachnids and crustaceans
42. water vascular system, tube feet
43. radial symmetry, tentacles. Examples include sea anemones and coral

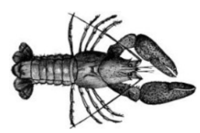
---

44. Which organisms shown to the below are considered invertebrates? *Mark all that apply.*

a.



b.



c

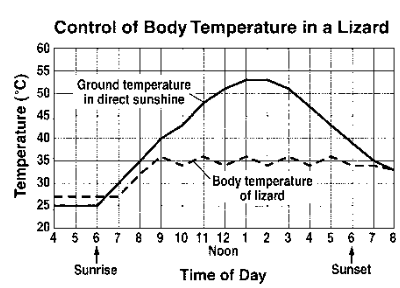
d.

For questions 45-49, Match each characteristic to the class of vertebrates that it describes. *Each class may be used more than once or not at all.*

A. Chondrichthyes **C.** Amphibia **E.** Aves
B. Osteichthyes **D.** Reptilia **AB.** Mammalia

45. Platypus, kangaroo, cow
46. has a slimy, naked skin, eggs laid in water
47. sting ray, shark, dogfish
48. internal fertilization, lays eggs that have a tough covering on land, cold blooded, scales
49. Bat

For question 50, please refer to graph on the right:



50. The dependent variable is shown on the graph above as the:
    a. Temperature on the y-axis
    b. Time of Day on the y-axis
    c. Temperature on the x-axis
    d. Time of Day on the x-axis

---

51. **A plant is a**:
    a. Unicellular prokaryote c. Unicellular eukaryote
    b. Multicellular prokaryote d. Multicellular eukaryote
52. **Which of the following is an example of a *gymnosperm*, which literally translates to "naked seed"**?
    a. An apple tree b. A moss c. A fern d. A white pine tree
53. **Xylem and phloem are NOT**:
    a. Conducting tissues that move materials up and down the plant
    b. Vascular tissues
    c. Present in ferns
    d. Present in mosses
54. **Phloem conducts sugars in which direction within a plant**?
    a. Up c. Up and down
    b. Down d. from the roots into the ground
55. **Oxygen and carbon dioxide move in and out of a leaf through the**:
    a. Stomata c. Phloem
    b. Roots d. Spongy layer
56. **One of the main functions of stems is to**:
    a. Carry out photosynthesis
    b. Transport substances between roots and leaves
    c. Store carbohydrates
    d. Store water
57. **Ferns are a type o**f:
    a. vascular plant c. seed plant
    b. angiosperm d. gymnosperm
58. **The male part of a flower that produces sperm is called the ____________**.
    a. pistil c. sepal
    b. ovary d. stamen
59. **The stigma, style, and ovary make up the ____________**.
    a. pistil c. stamen
    b. anther d. filaments
60. **Plants use the energy from sunlight to**:
    a. exchange gases with the atmosphere c. carry out cellular respiration
    b. take in water from the soil d. carry out photosynthesis
61. **If some of the xylem of a young oak tree were destroyed, it would most likely interfere with the tree's ability to**:
    a. conduct sugars to the roots c. absorb water from the soil
    b. absorb sunlight d. conduct water to the leaves
62. **All of the following are fruits except**:
    a. tomato b. corn c. carrot d. pumpkin

Short Answer – **Be sure to write legibly, please!!**

Correct the scientific names in any way that you see necessary (spelling and order are already correct): (1 pt. each)

63. cornus <u>florida</u> =
64. Acer rubrum =

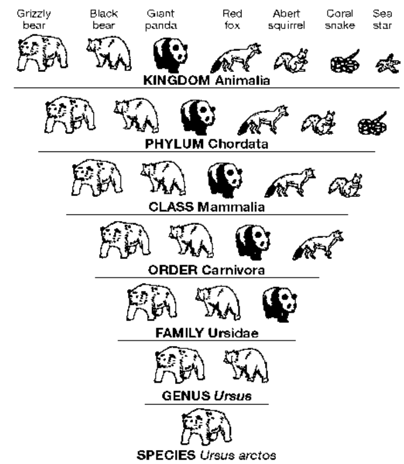
---

65. **The science of classifying organisms is known as (1 pt.): ____________________**

66. **Which two kingdoms are 100% heterotrophic** (2 points):
67. **List the current level scheme for classification in order starting with the broadest category.** (8 points)

68. **What TWO (2) fundamental characteristics distinguish animals from plants**? (4 points) ***Please be sure to compare AND contrast by listing the characters of BOTH, otherwise you will NOT get full points.***

For questions 69-72, Use the diagram below: (1 pt. each)



69. What is the scientific name for the Grizzly bear?

70. Do all of the organisms belong to the order Carnivora also belong to the phylum Chordata?

71. Do all of the organisms that belong to the class Mammalia also belong to the genus *Ursus*?

72. Which level of taxonomic category shown contains the greatest number of different organisms?

APPENDIX I

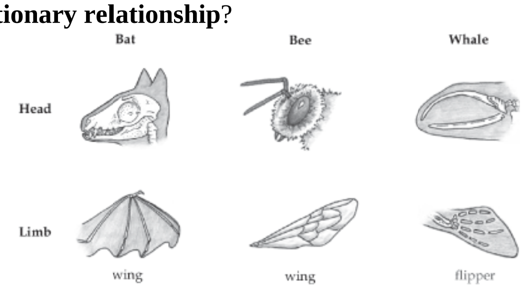
SUMMATIVE ASSESSMENT TREATMENT PHASE PART II

SUMMATIVE ASSESSMENT PBL TREATMENT PHASE

EVOLUTION TEST

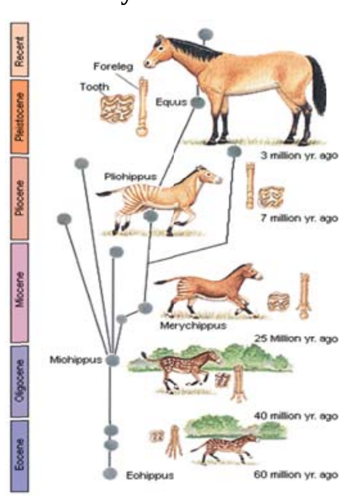
1. **Which of the following is the correct order for the time periods of Earth from oldest to youngest?**
   a. Cenozoic, Paleozoic, Mesozoic, Precambrian
   b. Mesozoic, Precambrian, Cenozoic, Paleozoic
   c. Precambrian, Paleozoic, Cenozoic, Mesozoic
   d. Precambrian, Paleozoic, Mesozoic, Cenozoic
2. **What conclusion may be drawn when comparing fossils found in layers of sedimentary rock**?
   a. Fossils in the upper layers are younger than those in the lower layers.
   b. Fossils in the upper layers are older than those in the lower layers.
   c. Fossils in the upper layers are generally less complex than those in the lower layers.
   d. There are no fossils in the upper layers that resemble those in the lower layers.
3. **The Cambrian "explosion" occurred approximately:**
   a. 3.5 billion years ago c. 65 million years ago
   b. 540 million years ago d. 1.5 billion years ago
4. **Which evolved first**?
   a. vertebrates b. insects c. invertebrates d. chordates
5. **The Mesozoic Era occurred**:
   a. before Precambrian Time c. during Precambrian Time
   b. after the Paleozoic Era d. after the Cenozoic Era
6. **During his voyage on the HMS Beagle, Charles Darwin's most famous observations were**:
   a. in England c. on the Galapagos Islands
   b. in North America d. in Asia
7. **An example of a group of homologous structures is**:
   a. arms, paws, tails c. wings, feet, teeth
   b. arms, bat wings, flippers d. flippers, hoofs, beaks
8. **Body parts with similar functions but different ancestors and different structures are**:
   a. analogous structures. c. homologous structures.
   b. vestigial structures. d. crestalogous structures
9. **Natural selection means that those organisms that survive**:
   a. possess characteristics that enable them to be better suited to their environment
   b. have characteristics that enable them to survive in all environments
   c. are selected randomly
   d. have characteristics that will never be altered.
10. **The differences that occur among individual organisms of a species is called**:
    a. variation c. selection
    b. survival d. evolution
11. **A rat's tail is cut off. Those who believe that the rat's offspring will be born without tails are following:**
    a. natural selection c. artificial selection
    b. the inheritance of variations d. believed that organisms did not change
12. **When a farmer breeds his or her best livestock, the process involved is**:
    a. natural selection c. artificial variation
    b. artificial selection d. survival of the fittest

13. **Which of the following 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 of evolution
14. **Charles Darwin's observation that finches of different species on the Galapagos 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. descend from a common ancestor
15. **According to Darwin's theory, what determines whether a variation is favorable or not?**
    a. the organism's chromosome number.
    b. the size of the organism's gene pool.
    c. the number of favorable variations the organism possesses.
    d. the environment in which the organism lives.
16. **Which type of selection acts against the dark-colored and light-colored butterflies and favors intermediate-colored butterflies**?
    a. stabilizing selection
    b. directional selection
    c. disruptive selection
17. **Evidence for evolution includes all of the following EXCEPT**:
    a. similarities and differences in protein and DNA sequences between organisms
    b. homologous structures
    c. embryos of many organisms look similar
    d. acquired characteristics within the lifetime of an organism
18. **Students used the three organisms shown below to study evolutionary relationships. Which of these structures is the best evidence of an evolutionary relationship**?
    a. bat wing and whale flipper
    b. bat lower jaw and whale lower jaw
    c. whale flipper and bee wing
    d. bat wing and bee wing



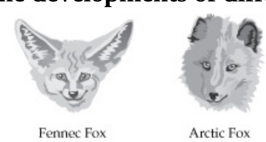
Use the diagram on the right to answer questions 25 & 26:

19. **Scientists have never seen the ancient horses shown in the figure above. What do you think was the main type of evidence scientists used to prepare these diagrams**?
    a. fossil evidence
    b. embryological evidence
    c. vestigial structures
    d. fur samples



20. **According to the figure, how did the number of toes of Miohippus compare with that of Equus, the modern horse**?
    a. the number of toes increased
    b. the number of toes decreased
    c. the number of toes stayed the same

21. **Natural selection operates because members of a population**:
    a. are all alike
    b. are equally able to survive
    c. differ, so some survive
    d. do not adapt to environmental change
22. **Our present day horse is much larger than its original ancestors. Which statement below would BEST explain this change based on Darwin's reasoning**:
    a. sometime in the past a mutation occurred
    b. early horses had to run fast to escape their enemies thus they developed longer legs
    c. larger horses survived, smaller horses perished, thus leaving only the larger ones
    d. they needed to change, so they did
23. **The ears of foxes help to regulate body heat. The fennec fox lives in the North African desert and has large ears that release body heat. The arctic fox lives in cold climates and has small ears that conserve body heat. Which of these processes led to the developments of different ear sizes in foxes?**
    a. artificial selection   c. natural selection
    b. succession   d. mutualism



A population of land snails colonized a field of dark colored grasses. At first, the population contained two types of snails: one with brown shells and another with yellow bands on their shells. After 10 years, most of the snails had shells that were brown.

24. **What is the most likely reason that there are more brown snails present in the grassland**?
    a. the brown snails were less visible to predators
    b. the brown snails were better at acquiring food
    c. the brown snails were infected more by parasites
    d. the yellow banded snails were less visible to predators

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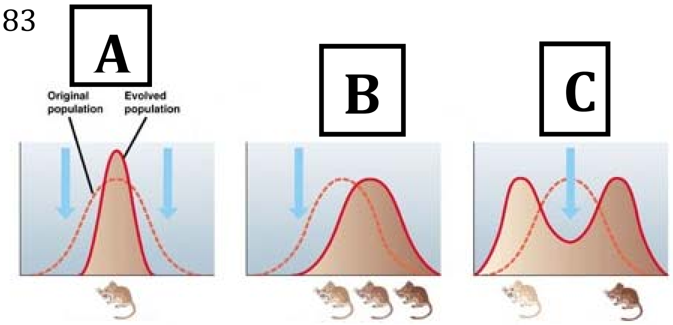
25. **New species cannot usually form without**:
    a. Vestigial organs   c. clones
    b. Homologous structures   d. some type of isolation
26. **A group of similar-looking organisms that can breed with each other, produce fertile offspring and live in the same area make up a**:
    a. niche.   c. gene pool
    b. population   d. ecosystem
27. **Marine and land iguanas are two different species that inhabit the Galapagos Islands. Some scientists believe that both species diverged from a common ancestor. Marine iguanas eat algae. Land iguanas feed on cacti. Algae are more abundant in the ocean than cacti are on the islands. Both species lay their eggs in the sand. Which of the following explains how the two species of iguanas came to be on the islands**?
    a. two different species of iguana swam across the ocean from Ecuador and landed on two separate islands.
    b. two separate species were brought over by humans.
    c. one species of iguana somehow came over to the Galapagos Islands, and through time, diverged into two separate species due to their environments
    d. one species of iguana, through selective use and disuse of organs over time, became the land and marine iguana species



For questions 28-30: Match the natural selection graph with the appropriate name:

28. Stabilizing graph
29. Disruptive graph
30. Directional graph

For questions 31 –46, Match the definition with the appropriate word(s):

Choices can be used more than once

A. Fossils **B.** Absolute (radioactive) dating **C.** Homologous structures **D.** Analogous structures
E. Embryological similarities **AB.** Vestigial structures **AC.** Relative dating

31. Remnants of structures that functioned in ancestral form
32. Use of Carbon-14 to determine the age of fossils.
33. Traces or remains of organisms
34. Organisms that have similar structure but different function.
35. The coccyx (tail bone) in humans and pelvic bone in whales.
36. An octopus eye and human eye.

True/False – Please Use "A" for True, "B" for false:

37. Comparing embryos of different animals provides evidence of evolution.
38. More organisms are produced than can survive.

A. Coevolution	B. Mimicry
C. Variation	D. Adaptation
E. Speciation	AC. Camouflage

For questions 39 –43, Match the definition with the appropriate word:

39. An acquired trait that *improves* an organism's chances for survival.
40. A species that resembles another species.
41. Differences within a population.
42. When *two* species evolve structures and behaviors in response to each other.
43. The formation of a new species.

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44. On the graph below, draw a typical curve showing a typical population of finches, measuring the beak shape. Label the axes of the graph as they would be labeled in a NORMAL distribution curve using the following terms: "Frequency of finches," "small beak size," and "large beak size." Give the graph a title **(8 points)**.

    Now, using **DOTTED LINES**, DRAW A NEW GRAPH OVER THE TOP OF THE OLD one showing what the population of finches would look like if El Nino destroyed all of the medium sized seeds on the Galapagos.

    What trait is being selected AGAINST? ________________________________

45. **Define evolution (2 points)**:

APPENDIX J

INFORMED CONSENT FORM

INFORMED CONSENT FORM

Authorization for a minor to serve as a Research Participant

The purpose of this research project, entitled "The Effect of Implementing A Problem-Based Learning Model on Student Attitude and Performance in High School Freshman Biology," is to examine the use of Problem-Based Learning (PBL), a respected student-centered, active learning instructional paradigm, and its effect on student learning, content understanding, assessment performance, science attitude, and teacher instruction.

For this project, students will be asked to engage in small group work, data collection, formative classroom assessments, summative unit assessments, a student Likert scale survey, and formal student interviews. All of these data collection instruments fall within the area of common classroom assessment practices.

Identification of all students involved will be kept strictly confidential. All of the students involved in the research will not be identified in any way. However, ten students will be randomly selected to participate in an interview concerning the PBL process and assess their attitudes toward science class. Nowhere in any report or listing will students' names or any other identifying information be listed.

There are no foreseeable risks or ill effects from participating in this study. All treatment and data collection falls within what is considered normal classroom instructional practice. Furthermore, participation in the study will in no way affect grades for this or any course, nor will it affect academic or personal standing in any fashion whatsoever.

There are several benefits to be expected from participation in this study. First, there may be an increase in your child's learning and understanding of the course concepts. Second, the student-centered nature of the project may result in an improved attitude toward engaging in science. Third, the study will allow me, as a science teacher, to improve and grow in my professional career. Finally, this study will enable me, as a student of Montana State University, to complete my final Capstone Project. This required project must be completed in order to fulfill the requirements for a Master's of Science in Science Education from Montana State University.

Participation in this study is voluntary, and students are free to withdraw consent and to discontinue participation in this study at any time without prejudice from the investigator.

Please feel free to ask any questions of Mr. Matthew D. Sloan (freshman biology teacher) via phone, (847)784-7636, email, sloanm@newtrier.k12.il.us, or in person before signing the Informed Consent form before or at any time during the study.

Student Signature: ____

Parent/Guardian Signature______________________________________

Date: ____