Equitable Access to Rigorous Biological Education

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This curriculum unit is recommended for Diploma Program (DP) and Middle Years Program (MYP) International Baccalaureate (IB) Biology and Environmental Systems and Society Courses; Advanced Placement (AP) Biology and Earth/Environmental Science

Keywords: Problem Based Learning (PBL); Evolution; Darwin; Common Vertebrate Body Plans; Darwin's Finches; QTEL; AVID

Teaching Standards: See Appendix 1 for teaching standards addressed in this unit.

Synopsis: This curriculum unit includes a problem-based learning project which address topics in the International Baccalaureate (IB) Diploma Program (DP) at the higher level (HL) in the content area of biology. I use a variety of teaching strategies including inquiry based learning, quality teaching of English language learners (QTEL) and advancement via individual determination (AVID). I chose these strategies and approaches to learning because they are research based and have been documented as best practices for all learners. Two of the IB DP biology topics are covered in this curriculum unit: topic 5-evolution and biodiversity and topic 11-animal physiology. Within each of the stated topics, there are subtopics that include the nature of science (NOS), understandings, theory of knowledge (TOK), international-mindedness, utilizations (real world applications), and applications and skills that serve as specific teaching points or standards to be addressed in a unit or task. I have chosen to ground the two topics in my curriculum unit within one of the seven questions that drive developmental biology. Each learning task will fall within "questions of evolution".

I plan to teach this unit during the coming year to 48 students in IB DP biology HL I and II.

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Introduction

Rationale

"...and the process of what is told and not told is often a function of power."[1]

How often do we truly understand the connections of what we are learning to life as we know and understand it? Connections to the multitude of perspectives involved in our reality? How can we know what we don't know, and rectify the unknown of our reality? I believe this is accomplished by teaching students to always question their worlds; their home life, school life, social lives, community lives, all of the 'different' types of lives they lead on a day to day, week to week, month to month existence. Part of asking questions, is asking the hard questions, the ones about uncomfortable topics; religion, race, evolution, global climate change, privilege, and politics to name a few. Yet, we do not intentionally and explicitly teach students how to ask such questions nor to debate such topics in an organized, methodological way. I believe that we must take time in our lessons to allow students the opportunities to venture into the uncomfortable, whether it be a social justice issue or it be a scientific issue, such as evolution and climate change or stem cell research and human cloning. Offering this experience, guiding students as they design and create their arguments helps to prepare them to become advocates for themselves, their communities, and the larger global society.

In regards to this line of thinking, I have chosen to teach evolution as the content topic of my curriculum unit. Many people tend to think of this science topic as an antagonist in the interplay of science and society, in which social issues play the protagonist. For example, evolution is the antagonist to religious beliefs. However, instead of an antagonist protagonist relationship, students need to understand that social issues can be supported and even strengthened with science.

To accomplish this, I have designed problem based learning projects which address topics in the International Baccalaureate (IB) Diploma Program (DP) at the higher level (HL) in evolution. I use a variety of teaching strategies including inquiry based learning, quality teaching of English language learners (QTEL) and advancement via individual determination (AVID). I chose these strategies and approaches to learning because they are research based and have been documented as best practices for all learners.

School and Student Demographics

School History and Student Demographics

Harding University High School is a title I high school in Charlotte, North Carolina. Harding has a rich history in Charlotte. It was the first public high school to be desegregated in 1957 with the admittance of four African American students. Harding's present student population is one in which 93.36% of students come from low socio-economic (status) families, and are on free/reduced lunch; 98% of the student population is non-white (African American and Hispanic races make up the majority of the student population). Harding's graduation rate for the 2018-2019 school year was 55% and from the incoming freshman of the same school year, only 36% of students were 'high school ready'.[2]

Unit Goals and the International Baccalaureate Program at Harding

The International Baccalaureate Program

I teach in the International Baccalaureate (IB) program at Harding. There are two programs or divisions of IB at Harding. One is our middle years program (MYP IB) which encompasses grades 9 and 10. The second is our diploma program (DP IB) which includes grades 11 and 12, and is a 2-year program. I teach MYP IB earth and environmental science (EES) and MYP IB biology. The students in MYP IB EES (fall semester) loop with me to MYP IB biology in the spring semester of the school year. The students in our DP IB Biology I and II HL (higher level) have me for both their junior (biology HL I) and their senior year (biology HL II). The DP courses can be taken for college credit if student scores reach the requirements set by the university or college students are applying the credits towards. International Baccalaureate is a unique program in that it requires inquiry based, problem solving, and critical thinking approaches to curriculum and teaching. IB also mandates that the content is connected to world wide events, societies, and situations in hopes of building globally aware citizens.

Unit Goals

There are two separate tracks in IB DP biology, standard level (SL) and higher level (HL). There are six topics in standard level biology: topic 1- cell biology; topic 2- molecular biology; topic 3- genetics; topic 4- ecology; topic 5- evolution and biodiversity; and topic 6- human physiology. In higher level biology, there are an additional five topics that must be covered: topic 7- nucleic acids; topic 8- metabolism, cell respiration, and photosynthesis; topic 9- plant biology; topic 10- genetics and evolution; and topic 11- animal physiology. Beyond these eleven topics, there are four optional topics (A- neurobiology and behavior; B- biotechnology and bioinformatics; C- ecology and conservation; and D- human physiology), one of which must be covered during the two year period.

One of the IB DP biology topics are covered in this curriculum unit: topic 5-evolution and biodiversity and topic 11-animal physiology. Within each of the stated topics, there are subtopics that include the nature of science (NOS), understandings, theory of knowledge (TOK), international-mindedness, utilizations (real world applications), and applications and skills that serve as specific teaching points or standards to be addressed in a unit or task.

Problem Based Learning Projects

I have chosen to ground the two topics in my curriculum unit within one of the seven questions that drive developmental biology. Each learning task will fall within "questions of evolution". Students will address subtopics from topic 5 (evolution) and topic 11 (animal physiology) by participating in a problem based learning (PBL) project. Problem based learning projects are driven by questions. Sometimes the questions are student generated, however for the purposes of my curriculum unit, I created the question: ***How can I, as a prosthetist, use my knowledge of the evolution of vertebrate limbs, antagonistic muscle groups, and synovial joints to design and build a functional prosthetic for a member of the Charlotte community?***

In answering this question, students will use the knowledge and skills gained from the subtopics from topic 5- evolution and biodiversity and topic 11- human physiology. Those specific subtopics can be found in Appendix 1. The entire PBL project is planned to take four weeks of instruction time. Because CMS operates IB classes on an A-day/B-day schedule, four weeks aquates to ten classes of 90 minutes each. This paper details three of the ten days of my PBL project, focusing on topic 5- evolution and biodiversity. The following sections lay out the content research used to support the IB topics and sub-topics taught and three days of lessons and activities.

Content Research

"Arrival of the Fittest"[8,9]: The union of developmental biology and evolution

Evolution is change over time. Evolutionary developmental biology "views evolution as a result of changes in development."[3] The amalgamation of developmental biology and evolution is a relatively new science and is referred to as evo-devo within the field.[3] Evo-devo explores new models of evolution, integrating developmental biology, paleontology, and population genetics to explain, explore, and redefine the diversity of life on our planet.[9,10,11,12,13] Introducing students to this new field of study will help them better understand how new knowledge and understandings change science; that science is adaptable to new findings from research and responds to real time information as it is acquired and verified across many different disciplines. It will also demonstrate to students that there are new acumen of evolution, moving perceptions from "survival of the fittest" to "arrival of the fittest."[8,9]

General Evolution of Vertebrate Limbs

The macroevolutionary change of fin-to-limb transition was one of the most important that took place in the evolution of vertebrates.[14] Researchers have documented that early events in vertebrate development have allowed for a body plan that gives rise to multiple models with the ability to combine these models into a complete system.[14] This is possible because vertebrate embryos are "dissociated into developmentally autonomous compartments."[14] This allowed for the amassing of variation without affecting the general body plan which, in turn, led to greater morphological diversity.[15]

Researchers have been spending large amounts of time and funds investigating the molecular pathways that led to the aforementioned fin-to-limb transition. This trajectory of research in evo-devo is being done in order to draw a molecular map detailing the pathways of this imperative morphological transition.[14] As a result of this ongoing research, scientists have identified genes expressed in both teleost fins and tetrapod limbs. They are: *Shh, Ptc1, Bmp4, Fgfs, Pitx1, Dlx, Bmp, Hoxa, Hoxd, Hoxc6, Msx, En1, Sal1, Gli3, dHand, Tbx, Meis,* and *Wnt*.[14] Studies have documented that similarities in molecular construction (including the presence and absence of gene expression), as well as, "their spatial distribution in the early fin bud (of the fin of the teleost fish) bears a striking resemblance to those found in tetrapod" limbs.[14]

Darwin's Finches

Darwin's finches were collected by Charles Darwin during his voyage on the Beagle (circa 1835). Darwin used his observations of these finches to assist him in framing his theory of evolution, specifically his argument of descent with modification.[16,17] One hundred eighty-four years later, darwin's finches are still regarded as an unrivaled example of adaptive radiation and natural selection.[16,17] There are currently fifteen recognized species of darwin's finches found in the Galápagos archipelago and Cocos island.[18]

Evolutionary biologists have spent almost as much time researching how darwin's finches have evolved. Researchers have shown that the major speciation event for darwin's finches was the divergence of the cactus finches and the ground finches.[19] The evolution of the cactus finch and ground finch resulted in two different beak shapes and uses (structure and function). Over time, the cactus finch developed narrow, pointed beaks allowing them to utilize their beaks as tools to penetrate into cactus flowers and fruits in search of insects and flower parts.[16,17] In contrast, ground finches developed deep, broad beaks which allowed them to split seeds apart.[16,17]

The phenotypic differences of the cactus finch and ground finch beaks are caused by differences in gene expression and provides one explanation for the role of natural selection on these organisms.[20] Research has indicated that the differences in the beak patterns is caused by changes in the growth of the cells that form the facial bones (neural crest-derived mesenchyme of the frontonasal process).[19] We know that the frontonasal mesenchyme produces "two modules that form the adult beak" in Darwin's finches.[3] The first is the premaxillary bone and the second is the prenasal cartilage.[3]

Beak development, specifically beak shape, in Darwin's finches share a similar gene to that of fin-to-limb development; the family of genes called *Bmp*. Researchers have found a statistical relationship between beak shape and timing and amount of *Bmp4* expression.[20] The impact of *Bmp4* on species-specific beaks were documented in research conducted by Abzhanove et al. in which they found the expression of *Bmp4* started earlier in ground finches and was expressed at higher levels in cactus finches.[20] Regardless of the species of finches, *Bmp4* expression patterns correlated with the depth and breadth of the bird's beak.[20]

Research teams have also found that a protein called *Calmodulin* was expressed at a higher rate (15 times higher) in the beak primordia of cactus finches in comparison to the beak primordia of the ground finches.[3] Studies indicate that when *Calmodulin* is upregulated in chick embryos, the chick beaks became long and pointed, much like that of the cactus finch.[3] The research conducted on *Bmp4* and *Calmodulin* depict two genetic targets for natural selection.[26] These two genes also explain the shape variations seen in two of the fifteen species of Darwin's finches.[26]

Evidence of Evolution

The evidence of evolution that will be discussed in the following sections are the fossil record, common structures, artificial selection, embryology, and advancements in molecular biology. An overview of these pieces of evidence for evolution will be highlighted and discussed.

The Fossil Record

Since the 1790's, scientists have documented that organisms on Earth have changed over long periods of time. They have done so by studying the layers of rocks and fossils found in sequential order in the layers of the Earth.[27] Many of the evolutionary transitions have been documented in well-dated rock layers and sequences. As such, fossils have, and still do, provide unfailing evidence of methodical change throughout time (also called descent with modification).[27]

Common Structures

Comparative anatomy supports the data collected from the fossil record, confirming that organism structure changes over time. The structures of different organisms that have similar structure but a different function are called homologous structures. For example, a bat wing and human hand are similar in structure, but humans cannot fly and bats cannot play the piano. Scientists do not just study homology in bone structure, but in other parts of the body, documenting and researching relationships between structures and the degrees of similarity in those structures between organisms.[27] Comparative anatomists and paleontologists share important results of their work which provide complementary evidence of evolution.

Artificial Selection

"Selective breeding of domesticated animals shows that artificial selection can cause evolution."[22] Humans have been selectively breeding animals and plants for at least 15,000 years if not longer.[22] We breed for specific characteristics in these organisms. For example we may breed a dog for speed or a plant for high yield. Whatever trait we artificially select for is passed down generation after generation. This change over time is evolution and this is why artificial selection is evidence for it. However, the change in the organism via artificial selection is not driven by an environmental pressure, which is natural selection. Therefore, while artificial selection is evidence of evolution, it is not evidence of evolution by natural selection.[22]

Embryology

“The presence of similar genes doing similar things across a wide range of organisms is best explained by their having been present in a very early common ancestor.”[27] Descent with modifications can be observed in embryonic development. In fact, Darwin noticed and documented his observations of descent with modification in the homologies between the embryonic and larval structures of different phyla.[3] Recently, evolutionary developmental biologists established that large morphological changes can emerge during development because of modularity and molecular parsimony, both of which are foundational in the development of all multicellular organisms.[3]

Modularity in embryology are changes that occur because “development occurs through a series of discrete and interacting modules.”[30, 31, 32] This leads to stages of development (even early stages) being altered to produce new evolutionary changes.[30,31,32] Molecular parsimony, or small toolkits means that development within lineages uses the same types of molecules, even if the developmental differences from lineage to lineage are large.[3] Examples of these small toolkits are: transcription factors, paracrine factors, adhesion molecules, and signal transduction cascades.[3] These toolkits are uncommonly similar from one phylum to another.[3]

Advancements in Molecular Biology

Findings from molecular biology have been used to augment the fossil record and strengthen the corresponding fossil evidence for evolution.[27] Scientists have used DNA technology to map the evolution of certain proteins such as hemoglobin and cytochrome c.[27] Another example of how techniques in molecular biology are evidence to support biological evolution is the comparisons of milk proteins (specifically beta-casein and kappa-casein) have confirmed that whales descended from land mammals that had returned to the sea.[27] This molecular evidence combined with the fossil record confirm the relationship between whales and their closest living land relatives, even-toed hoofed mammals, more specifically the hippopotamus.[27]

Teaching Strategies

QTEL

Quality Teaching for English Learners (QTEL) is a curriculum developed by WestEd. QTEL is based on sociocultural and sociolinguistic theories of language development.[28] QTEL curriculum is founded upon the following five principles: (1) “sustain academic rigor by promoting deep disciplinary knowledge and developing central ideas of a discipline,”[28] (2) “hold high expectations by engaging students in tasks that are high challenge and high support,”[28] (3) “engage in quality interactions defined as the enactment of interactions that are sustained, deep, and build knowledge in relevant aspects of the discipline,”[28] (4) sustain a language focus by explicitly developing disciplinary language, discussing how language works, and highlighting the characteristics of different disciplinary genres and discourse”[28] and (5) “develop quality curriculum that has long-term goals, is problem-based, and requires sustained attention beyond a single lesson.”[28]

While I teach a high population of ELLs (English Language Learners) I believe that QTEL is best practice for all learners. It is especially impactful in the sciences because of the tier III (jargon) vocabulary load placed on students, no matter their native language. I have had great success using QTEL strategies in my classroom. I use a number of QTEL strategies in this curriculum unit and have included links in the bibliography and student/teacher resource page for further viewing.

AVID

Advancement via individual determination (AVID) is a curricular program that aims to increase the number of college and career ready students in a school population. AVID targets students who are intrinsically motivated and plan to pursue a career or attend college after graduating from high school. AVID curriculum is based on five components or strategies: **w**riting, **i**nquiry, **c**ollaboration, **o**rganization and **r**eading or WICOR. This is Harding's first year as an AVID school. As a school community, Harding is focusing on the **w**riting and **o**rganization components of WICOR. As such, I incorporate as much writing and organization tasks as possible in my learning tasks.

Student Learning Experiences

In the first five days of this curriculum unit, students will have two minor products/deliverables. The major product of this PBL is the completed and functional prosthetic. The minor products and DP subtopics will take approximately five days to teach. Each class period is a 90 minute block. Students in my class are placed in groups of three to four and are seated at lab tables. Make sure that your students are placed in groups that work for the physical layout of your classroom and number of students you teach.

Day 1: Entry Event

The problem based learning (PBL) driving question should be written on some type of medium (poster board, colored card stock, etc.) and placed somewhere in the room that can be viewed by all students throughout the 'life' of the project. Cover the driving question so that students are unable to see it until you are ready for the reveal. The PBL question driving learning task 1 is: ***How can I, as a prosthetist, use my knowledge of the evolution of vertebrate limbs, antagonistic muscle groups, and synovial joints to design and build a functional prosthetic for a member of the Charlotte community?***

For the entry event to this PBL, students will engage in a see, think, wonder activity[4]. I use see, think, wonder activities[4] not only to introduce new content or a new PBL project, but to assess students' prior content knowledge, gauge students' current skills needed for group discussion and working with their peers, and to determine how students connect academic content with real world application. In regards to learning task one, find pictures of limb bones for five different vertebrate organisms and paste them onto a large sticky note (25 x 30 inches). I use the human arm and hand, the fin of a dolphin, the limb of a turtle, the wing of a bird, and the full body skeleton of a snake (while a snake does not have limbs like the other organisms in the list, this contrast of locomotion will spark interesting discussions among students). The protocol for see, think, wonder can be found in appendix 2.

After students complete the see, think, wonder activity, reveal the PBL driving question by having a student read it aloud to the class. After the student reads the question aloud, pose the following questions to students orally and written (on the board or a powerpoint slide): (1)What are the different pieces of knowledge or content that you need to know and understand to answer the driving question?; (2) What resources and/or materials will you need access to in order to answer the driving question?; (3) What steps will you need to take in order to successfully complete the PBL project and answer the driving question? Allow students to turn to their elbow partners and discuss their answers to the questions (2-3 minutes). I encourage students to write down what they discuss with their partners on sticky notes. This way, students can refer to their discussions for the next steps of the process. Following the initial discussion with their elbow partners, instruct students to create a plan of action as a group (I group my students by fives. I have 6 groups of five in each of my preps.). The plan of action should flow from the questions students have already discussed with their elbow partners. After their initial group discussion, instruct students to use resources such as the internet and their IB DP Biology HL textbook to assist them in developing their plans. Have students write down their plan of action on large sticky notes, and place on a wall in the classroom so they are able to refer to their plans throughout the life of the PBL project.

As a closing activity for today's lesson, students will participate in an activity called snowball. Instruct students to half a sheet of white printer paper with their elbow partner (elbow partners of three will half the sheet into thirds). Students are to write one thing they want to learn by the completion of the PBL project. Once each student has done this, have them ball up the piece of paper and on the count of three, throw the "snowball" around the classroom. After students have thrown their snowball, they are to pick up another student's snowball and take it back to their seat. Each student will open the snowball they chose and read what is written on it to their table group. This is done in a round robin format in which each student reads without being interrupted by a classmate. After all students have read, they have small group discussions on the different information they gained from their classmates.

Homework Assignment

Because CMS utilizes an A-day, B-day schedule for IB courses, I tend to assign longer reading assignments for homework, essentially flipping the classroom. I use this approach so that students have been pre-exposed to concepts, allowing me to employ the entire 90 minute block for application of skills and content knowledge. The reading homework assigned is accompanied by a QTEL strategy for either preparing the learner, interacting with the text/content, or extending the understanding. The homework reading in preparation for day two is chapter one in Jerry A. Coyne's *Why Evolution is True*[7]. Students will read pre-made packets while completing a strategy called 'reading with a focus'[6]. This QTEL strategy prepares the learner by having students read while thinking about and answering a thematic question or questions.

When utilizing 'reading with a focus'[6] choose a short text that will provide background information for the lesson or have students only focus on the beginning of a core text. It is recommended that you generate one question for students to focus on (usually the main idea)[6] but I sometimes choose more than one question depending on how long the reading is and how complex the concepts are. Once I have created the question(s) that the students will focus on during the reading, I post them on google classroom. You can also write the question on the board, on a slide, or on a sheet of paper. Whichever approach best serves your teaching style and the learning needs of your students. After students have read the selection and pondered the question(s) posed, have them write down their answer(s). I usually have students write their responses in google docs and share the doc with their lab group table members. This sets the stage for the next day's preparing the learner component of my lesson.

Chapter one of Coyne's book is titled *What Is Evolution*. Coyne begins the chapter with a quote from Jacques Monod, "*A curious aspect of the theory of evolution is that everybody thinks he understands it.*"[7] As students read through their packet, I have them write this quote at the top of their google doc notes. I intentionally call their attention to this quote in hopes of sparking their interest in the topic of evolution and to demonstrate that it is a complex, yet foundational concept in the biological sciences, that many struggle to fully understand it; including a nobel laureate in biochemistry (Jacques Monod).

The following are the questions that I pose to my students for the 'reading with a focus' activity.[6] **Coyne writes on page three, "Life on earth evolved gradually beginning with one primitive species -- perhaps a self-replicating molecule -- that lived more than 3.5 billion years ago; it then branched out over time, throwing off many new and diverse species; and the mechanism for most (but not all) of evolutionary change is natural selection."[7] How can natural selection be the mechanism for most but not all evolutionary change? According to the text you read in your reading packet, what drove the branching of species over time Coyne discusses in the above quote? How do the tenets of evolution play a role in this branching process? Make sure your answers are supported by evidence directly from your reading packet, including page numbers. Do not forget to share your google doc with the members of your lab table.**

Day 2: Students will be able to: (1) understand that evolution occurs when heritable characteristics of a species change (5.1.U1) and (2) list and explain the different types of evidence used to support the theory of evolution, focusing on the fossil record (5.1.U2) by completing the QTEL activities.

Task 1: Do Now

Students will begin today's lesson (do now, anticipatory set) responding to their table mates' answers to the homework assigned on day one of the PBL project. Think of this as an online discussion thread. Each student will respond to at least two table mates. Students turn on the editing filter in google docs so that each response is shown in a different color and can be tracked. This allows students to not only share their thoughts on the reading assigned, but allows me to see how they are forming an understanding of what evolution is and the tenets of evolution. This **pre-assessment** helps me to identify misconceptions that my students hold allowing me to formulate ways to deconstruct them. This activity and the homework assigned from day one also allow students the opportunity to understand that evolution occurs when heritable characteristics of a species change (5.1.U1). I give students approximately twenty minutes to complete this task in the lesson.

Task 2: Interacting with the Content- the different types of evidence used to support the theory of evolution, specifically the fossil record.

The second learning task in today's lesson is called an 'oral development jigsaw'[6] In preparation for this task, you will need to prepare five different images (the number of images corresponds with the number of students in each group) that represent the evidence of biological evolution (1) the fossil record, (2) common structures/common descent/homologous structures, (3) distribution of species/biogeography, (4) similarities during embryonic development, and (5) genetic evidence from molecular biology. Artificial selection will be discussed at a later time. On each image put a small color dot in a corner on the back of the picture (green, yellow, blue, red, and orange). In each table group, have students choose one of the colors.[6] This is the image they will move to when instructed. Have students move to the 'jigsaw' group based on the color they chose. Once students are settled in their jigsaw group, instruct them not to touch any materials until you have completed all of the directions. Explain to students that they will be looking at a picture and describing what they see to their jigsaw group members. They can only describe what they see (observations) and can not use inferences or assumptions in their descriptions. For example, none of their sentences should include "I think…" or "Maybe…"[6] Once these directions have been given, have the groups turn over the picture on the table and quietly exam it for about three minutes. Then have students describe what they saw to their jigsaw group members in a round robin format. I usually give students about fifteen minutes to complete this part of the task and actively monitor the groups to make sure students are not making inferences or assumptions.

Once students have completed their descriptions of the picture to the jigsaw group, instruct them to return to their original home base groups. In a round robin format, have each student describe the picture they viewed in as much detail as possible. Once this is complete, explain to students that their next step is to create a story providing the "creative glue"[6] to link the images that they each viewed. The story can be told in any order (description of the pictures), but must make sense. The story must have a title, characters, plot, climax and conclusion. The story will be written on google docs and one student from each lab group will submit a completed copy to a dropbox on google classroom. Students have approximately 25-30 minutes to complete this task. We close this task by having a whole class discussion on what the pictures were of and what next steps we are taking in learning more about evidence for biological evolution.

Task 3: Extending Understanding- the different types of evidence used to support the theory of evolution, specifically the fossil record.

For the final learning task, students will be reading chapter two from Rob Wesson's book, *Darwin's First Theory: Exploring Darwin's Quest to Find a Theory of the Earth.*[21] Chapter two is titled *Field Trip with a Master: The state of geology.*[21] I explain to students that we are going to focus on the fossil record and how it supports the theory of biological evolution. I ask my students to keep this in mind as they begin their reading. As students read, they will complete a triple entry journal.[6] I have my students create the journal table in their composition notebooks. This is where they keep all of their notes. Students are instructed to create a table with three columns. The first column is titled "What I read that got my attention." The second column is titled "What it made me think about" and the third column is titled "What I think now that I found out more."[6] An example template of the triple entry journal can be found in appendix 3. As students read, they are to write down in column one any facts, statements, quotes, information, etc., that catch their attention, along with the page number of the text they found it on. I recommend to students that they write down information relating to fossil evidence and biological evolution, but do not make this a hard requirement. After the student writes down something that catches their attention in column one, they move horizontally to the right, to column two. In column two, they write down what the statement in column one makes them think about. This can be anything. For example, in column one a student wrote, "Already a pattern was emerging: the oldest rocks contained a few, if any, fossils, while the fossils in the younger and younger rocks represented increasingly complex forms of life.[21] Found on page 29." In column two, the student may write "This reminds me of the movie 'Journey to the Center of the Earth' starring Will Ferrell." Column two is where students make personal connections to the statement they wrote in column one. In the third column, students are to use other resources (internet, text book, notes from previous lessons, articles given to them, etc.) to investigate and find out more information about the original statement written in column one. The new information students find is written down in column three. Students are instructed to site where they got the new information they put in column three. Following our example, a student could write "One thing that Darwin noticed on his travels, and that people continue to notice today, is that fossils in the bottom layers are very different from the organisms alive today; Darwin didn't even recognize them. As one looks farther up, at younger and younger rock layers, the fossilized plants and animals become more and more familiar until they are a lot like organisms that are around now. The organisms also tend to become more and more complex. From this, Darwin concluded that organisms have not remained the same since Earth's beginning, and that they have changed a lot, gradually becoming more and more complex. He also realized that as new species arise, other ones become extinct. I found this from a website: https://necsi.edu/fossil-layers."[5]

Using the triple entry journal method[6], students write down pertinent information from the text they are reading, they make a personal connection, and then expand their understanding by researching the information using resources outside of the text they are reading. I find this method helpful to students in understanding complex content. For this particular assignment, I have students write down six "What it made me think abouts." Another way to think about this is students create six rows that they fill in with information from the text. Students work on this task until the bell rings which is approximately forty minutes.

Homework Assignment

The homework I assign for day two of this PBL is for students to read and take notes from their textbooks. At Harding, we use the *Oxford 2014 Edition IB Diploma Program Biology Course Companion*[22] for the textbook in IB DP biology HL I and II. Students are instructed to read pages 242-249 and take notes in their composition notebooks. Students are also to complete the database questions in google docs (to be submitted via google classroom) on pages 243, 244 and 248. The textbook is designed to prepare students for their external exams which they take in May of their senior year. The external exam for biology is over a two day period and consists of three separate tests or papers. The information on the topics is focused, short and succinct. The database questions are good practice specifically for paper 3 of the external exam.

Day 3: Students will be able to: describe and understand changes in beaks of finches on Daphne Major (5.2.A1).

Task 1: document changes in beaks of finches on Daphne Major through the concept of adaptive radiation.

For task 1, students will be given a copy of the article *Possible Human Impacts on Adaptive Radiation: beak size bimodality in Darwin's Finches*[23] and asked to read and annotate the article. Once students have completed the reading, they are to answer the following theory of knowledge question: **Evolutionary history is an especially challenging area of science because experiments cannot be performed to establish past events or their causes. There are nonetheless scientific methods of establishing beyond reasonable doubt what happened in some cases. How do these methods compare to those used by historians to reconstruct the past?** (5.1.TOK). Based on the reading and using two other articles written by the Grants, *High Survival of Darwin's Finch Hybrids: Effect of beak morphology and diets*[24] and *What Darwin's Finches Can Teach Us about the Evolutionary Origin and Regulation of Biodiversity*[25] students will prepare a debate discussing the evidence for evolution and current experiments done by the Grants and their field teams. Students will need to identify the different methods used in each of the papers and document in their notes the pros and cons of each methodology, as well as, the results found by each research team (from each paper). I allow approximately forty-five minutes for task 1.

Task 2: describe and understand changes in beaks of finches on Daphne Major

Using the research they conducted in task 1, students will prepare a speech detailing which methodology is the 'best' to document evolution 'in action' (i.e.- see the studies conducted by the Grants research teams). In their speech, students must support why the methodology they chose is the best, what they mean by the best, and what the best is meant in fields of scientific research. Students must also include evidence for how Darwin's finches and the work that Peter and Rosemary Grant have done over the last 60 years documents evolution 'in action'. Students speeches cannot exceed 3 minutes. This task will take approximately 45 minutes to complete. If I run out of time I have the remaining students finish their speeches during the next class meeting.

Task 3: comparing how scientific methods of the 21st century are different (or not) than those in the past

This task will be completed for homework. Students are to respond to the quote from Mary Shelly's Frankenstein in an essay. The directions and the quote are below.

Write an essay in a google doc explaining your answers to the following prompt. This is a formal IB writing assignment. After reading this passage, I want you to think about what scientific discoveries occurred during the time period that Shelly was writing and publishing her seminal work of "Frankenstein". How did these discoveries impact her writing? How would this passage be written differently if she was writing in 2019? What other naturalist (that we have studied in depth) was also writing at this time and may have influenced Shelly's thinking?

"The ancient teachers of this science," he said, "promised impossibilities, and performed nothing. The modern masters promise very little; they know that metals cannot be transmuted, and that the elixir of life is a chimera. But these philosophers, whose hands seem only made to dabble in dirt, and their eyes to pore over the microscope or crucible, have indeed performed miracles. They penetrate into the recesses of nature, and show how she works in her hiding places. They ascend into the heavens: they have discovered how the blood circulates, and the nature of the air we breathe. They have acquired new and almost unlimited powers; they can command the thunders of heaven, mimic the earthquake, and even mock the invisible world with its own shadows."[29] The rubric for assessing student essays can be found here.

Appendix 1

Topic 5.1 Evidence for Evolution

Essential idea of topic 5.1: There is overwhelming evidence for the evolution of life on Earth.

Understandings:
5.1.U1- Evolution occurs when heritable characteristics of a species change.
5.1.U2-The fossil record provides evidence for evolution.

Theory of Knowledge:
5.1.TOK- Evolutionary history is an especially challenging area of science because experiments cannot be performed to establish past events or their causes. There are nonetheless scientific methods of establishing beyond reasonable doubt what happened in some cases. How do these methods compare to those used by historians to reconstruct the past?

Topic 5.2 Natural Selection
Essential idea of topic 5.2: The diversity of life has evolved and continues to evolve by natural selection.

Applications:
5.2.A1- Changes in beaks of finches on Daphne Major.

I have attempted to make one-to-one connections between the standards stated above and the content research and learning tasks in this curriculum unit. Much more content research on the topic of evolution and evo-devo exists, but it would take volumes to represent that information. Dr. Kern did an amazing job during our seminar in connecting high level developmental biology concepts with our curriculum topics and standards. I attempted to create rigorous and deeply connected activities that allow students to scaffold their own understanding of the IB DP topics. I find the topic of evolution fascinating and wish I could spend an entire semester (seeing my students every day instead of every other day) teaching them about evolutionary concepts.

Appendix 2

See, Think, Wonder Protocol

What do you see? **What do you think about that?** **What does it make you wonder?**

Purpose: What kind of thinking does this routine encourage? This routine encourages students to make careful observations and thoughtful interpretations. It helps stimulate curiosity and sets the stage for inquiry.

Application: When and where can it be used? Use this routine when you want students to think carefully about why something looks the way it does or is the way it is. Use the routine at the beginning of a new unit to motivate student interest or try it with an object that connects to a topic during the unit of study. Consider using the routine with an interesting object near the end of a unit to encourage students to further apply their new knowledge and ideas.

Launch: What are some tips for starting and using this routine? Ask students to make an observation about an object – it could be an artwork, image, artifact or topic – and follow up with what they think might be going on or what they think this observation might be. Encourage students to back up their interpretation with reasons. Ask students to think about what this makes them wonder about the object or topic. The routine works best when a student responds by using the three stems together at the same time, i.e., "I see…, I think…, I wonder …. " However, you may find that students begin by using one stem at a time, and that you need to scaffold each response with a follow up question for the next stem. The routine works well in a group discussion but in some cases you may want to ask students to try the routine individually on paper or in their heads before sharing out as a class. Student responses to the routine can be written down and recorded so that a class chart of observations, interpretations and wonderings are listed for all to see and return to during the course of study.

Appendix 3

Triple Entry Journal Template

What I read that got my attention	What it made me think about	What I think now that I found out more
Already a pattern was emerging: the oldest rocks contained a few, if any, fossils, while the fossils in the younger and younger rocks represented increasingly complex forms of life.[21] Found on page 29.	This reminds me of the movie 'Journey to the Center of the Earth' starring Will Ferrell.	One thing that Darwin noticed on his travels, and that people continue to notice today, is that fossils in the bottom layers are very different from the organisms alive today; Darwin didn't even recognize them. As one looks farther up, at younger and younger rock layers, the fossilized plants and animals become more and more familiar until they are a lot like organisms that are around now. The organisms also tend to become more and more complex. From this, Darwin concluded that organisms have not remained the same since Earth's beginning, and that they have changed a lot, gradually becoming more and more complex. He also realized that as new species arise, other ones become extinct. I found this from a website: https://necsi.edu/fossil-layers.

Student and Teacher Resources

I have chosen to combine the student and teacher resource page. Because the content in IB DP biology HL I and II is collegiate level, I find that the same resources I use are great for my students to also utilize, thus my reasoning for combining the student and teacher resource pages.

Biology for Life https://www.biologyforlife.com/

Biology for life is my go to web page for everything IB DP biology. It is run by a teacher in Washington state named Gretel von Bargeng. She not only has great advice for teachers and students, but has pacing guides, activities, trips, and how tos on anything and everything IB DP biology.

QTEL Website https://www.qtel.wested.org/

The QTEL website is a great place to learn more about quality teaching for English learners. If you are interested in attending a WestEd professional development, that information can be found at this site.

CMS EL Services Three Moments in a Lesson Website
https://sites.google.com/cms.k12.nc.us/pacetoolkit/curriculum-resources/three-moments-of-a-lesson?authuser=0

I can not say enough wonderful things about this resource. If you need an idea for a strategy this is the place to go. I also have students visit this site when I assign them topics to teach throughout the semester or year. There are clear teacher and student directions for each activity or strategy, as well as, examples of student work and templates for worksheets.

Coyne, Jerry A. *Why Evolution is True*. Penguin Group, New York, NY, 1994.

This is a great read for anyone interested in evolution. Coyne writes for the general public in this book, but it is not only well written but also well researched. I recommend that this be part of students summer reading either as rising juniors into the IB DP program or as rising seniors into the second year of the program.

Wesson, Rob. *Darwin's First Theory: Exploring Darwin's quest to find a theory of the earth.* Pegasus Books. New York, NY, 2017.

I wonder how many people know that Darwin was interested in geology before he even stepped foot on the *Beagle*? I know for me, it is not the first thing that pops into my head when I think of Darwin. Wesson's book details Darwin's love of geology and fossils in this book.

Endnotes

1. Theoharis, *Use and Misuse of Civil Rights,* 2018
2. NCDPI, *North Carolina Department of Public Instruction Website*
3. Gilbert & Barresi, *Developmental Biology,* 2018
4. Visible Thinking Website, *See, Think, Wonder*
5. New England Complex Systems Institute Website
6. Three moments in a lesson (CMS EL Department)
7. Coyne, *Why Evolution is True*, 2009
8. Gilbert & Epel, *Ecological Developmental Biology*, 2015
9. Carroll et al., *From DNA to Diversity,* 2005
10. Raff, *The Shape of Life,* 1996
11. Hall, *Evo-devo,* 1999
12. Arthur, *Biased Embryos,* 2004
13. Kirschner and Gerhart, *Plausibility of Life,* 2005
14. Abbasi, *Developmental Dynamics,* 2011
15. Wray, *Cis-regulatory Mutations,* 2007
16. Weiner, *Beak of the Finch,* 1994
17. Grant and Grant, *How and Why Species Multiply,* 2008
18. Sangeet et al., *Evolution of Darwin's Finches,* 2015
19. Schneider and Helms, *Beak Morphology,* 2003
20. Abzhanov et al., *Bmp4,* 2004
21. Wesson, *Darwin's First Theory,* 2017
22. Allott and Mindorff, *Biology Course Companion*, 2014
23. Hendry et al., *Human Impacts on Adaptive Radiation*, 2006
24. Grant and Grant, *High Survival of Hybrids*, 1996
25. Grant and Grant, *Evolutionary Origin and Regulation of Biodiversity*, 2003
26. Abzhanov et al., *Calmodulin Pathway,* 2006
27. National Academy of Sciences, *Science and Creationism*, 1999.
28. Quality Teaching of English Learners Website
29. Shelly, *Frankenstein,* pg.44, 1831
30. Riedi, *Order in Living Systems,* 1978
31. Bonner, *Evolution of Complexity,* 1988
32. Kuratani, *Modularity, Comparative Embryology and Evo-Devo*, 2009

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