ABSTRACT
Combining the TimeTree of Life database with the skill set of a naturalist, transitional changes, speciation, and evolutionary concepts emerge as a process in which students create and are fully engaged in a narrative & theme-based lesson plan/lab that merges with a scientific drawing experience that shadows the life of the naturalist and author Vladimir Nabokov. The interdisciplinary story and science of Nabokov offer a glimpse into applied arts as an exploratory scientific practice that encourages creativity and evolutionary thinking.

Key Words: drawing-for-evolution; TimeTree of Life; naturalists; macroevolution; characters; butterflies.

Imagine a modern taxonomist straddling a Wellsian time machine. Going back millions of years (to the Cenozoic), he would end up at a time when only Asian forms of the butterflies existed. Then, moving forward again, the taxonomist would see five waves of butterflies arriving in the new world.

—Vladimir Nabokov

Introduction
The TimeTree of Life (TTOL) database is a public database created by Blair Hedges and Sudhir Kumar, which provides divergence times of species from published studies in the database and allows for a search and comparison of two species’ divergence times. It also permits easy access for educational experiences with evolutionary concepts such as speciation and geological time scales. The TTOL can be easily accessed at http://www.timetree.org/ (Hedges & Kumar, 2009). The software delivers a “big picture” experience of timing for junior high school, high school, and college courses that teach evolutionary concepts and encounter topics in bioinformatics, phylogenies, and “tree-like” thinking. The TTOL gives students the opportunity to instantaneously explore two species, like “cat” and “dog,” and their relationship in the abstract concept of geological time (Metzger, 2011).

The database experience is a unique, exploratory one of genomic data and nodes of departure for new species in the often difficult to grasp 4.5 billion year timeframe, stimulating interest in evolution, biodiversity, and phylogenetics. It can be further expanded and deepened by merging it with the hands-on processes and “slowed down” methods of naturalists and the arts. The naturalist experience allows students to generate their own original observations, drawings, and concepts about variation in nature, and ponder evolutionary time and processes, leading up to the exercise of building phylogenetic trees and engaging with the TTOL database. But what are the best practices that benefit students in discovering the natural world and developing passion for it in a time when “nature deficit disorder” abounds (Driessnack, 2009)? Naturalists employed the descriptive practice of drawing with astute and often direct observation of nature. With the re-emergence of the art/science paradigm and so-called STEAM (Science, Technology, Engineering, Art, and Math) education movement, what practices lead students in the direction of self-discovery and the development of their own descriptive drawing and writing skills?

The complexity of thought that goes into the observant analysis of nature through drawing processes makes the TTOL database experience even more thought-provoking. Students, today, however, spend
less time than ever in nature, fewer hours observing its complexity and processes, and instead, dedicate an almost excessive amount of time to screen technology (Rowan, 2010). Technology used for educational purposes, such as the TTOL database, may become muddled experiences, with students becoming adrift in the onslaught of apps and easy online access. Simultaneously, students may lose sight of the complexity, variation, subtleties, and sensory feeling of nature that builds deep, creative knowledge bases. To introduce the naturalist concept within the evolutionary learning domain, and lead up to using the TTOL database, we choose to have students shadow a particular polymath who contributed to the field of biology through their combined disciplines and love of nature. Santiago Ramon Cajal, Leonardo DaVinci, Joseph Leidy, Valdimir Nabokov, and Maria Sybilla Merian came to mind, all with excellent merged skills and passions for picturing nature. In exploring their work and life, students may observe the art and science union over a lifetime and come to see a way of thinking and learning that has long departed but continues to offer great satisfaction for the learner.

Our first choice for evolutionary concepts was the famous novelist Vladimir Nabokov (Blackwell & Johnson, 2016). Nabokov’s work with species Polymatus blues is an excellent real-life example of a highly successful merger of unscripted, scientific art, note-taking, creativity, and passionate writing centering on nature and a love of nature, resulting in powerful scientific reasoning and an often forgotten but worthy message regarding astute observation and excitement for natural complexities and beauty, and how they come to inspire creative scientific practices. Nabokov religiously made extremely detailed anatomical drawings of butterfly genitalia, wing venation, and wing patterning of the Polymatus blue butterfly. With only his eyes, drawings, and reasoning, he formulated and hypothesized that the blue butterflies had migrated from Asia to North America and then South America in five waves over a 14-million-year period (Blackwell & Johnson, 2016). In 2011, DNA results of the Polymatus blue butterfly evolution made news as Nabokov was declared “vindicated,” and two of his hypotheses regrading butterfly evolution confirmed (Blackwell & Johnson, 2016). This vindication also demonstrated how the conceptualization of innovative thought about speciation, classification, biophilia, and evolutionary process can emerge from internalizing the domains of the artistic and scientific as applied to the natural world in a personal paradigm rather than a standardized, compulsory experience.

**Method**

Exploring and modeling his prolific work with blue butterflies and their evolution is a time portal into the creative processes of science and, as Nabokov alluded, “traveling back in time,” which essentially is what evolutionary thinking requires. This is an exceptionally important experience for students, revealing the power of something as simple as taking notes and observing nature. The sequential narrative of Vladimir Nabokov’s life also frames the artistic-scientific merger in the context of storytelling, offering an alternative to PowerPoint presentations and formats that emphasize linear thinking and visually homogenized diagrams and illustrations about biology. Through an introduction to Nabokov’s life, methods, and notebooks, students are exposed to his intimate knowledge acquired through writing, observing, and drawing nature, and are asked to take the role of an apprentice to Nabokov, imagining themselves as Nabokov, or shifting their perspective entirely and viewing evolution of the Polymatus blue butterfly from the perspective of the Polymatus blue butterfly and its 14-million-year evolutionary journey. They copy portions of Nabokov’s notebook images of butterfly wing patterns and reproductive parts, attending to pattern shapes and reoccurring configurations in forms in their drawings, while imagining themselves as the apprentice, the writer, or the butterfly moving through the five migrations of its evolution and using the technique of drawing on notecards to organize their ideas as Nabokov did. Their experience will also involve investigating the divergence times of the butterfly family tree through the TTOL database, and their work will culminate in the future, where they predict the evolutionary fate and paleoecology of the planet with the outcome of the butterfly’s phenotype, recording that fate in their naturalist’s notebooks. Students provide evolutionary reasoning skills and evidence for their hypothesis through a unique perspective that also involves applying an evolutionary word bank to their writing.

For this lesson plan, we recommend a film on Nabokov, My Most Difficult Book (Sykes, 1989), readings from his fictional works or of a review of his work, The Gift (Davydov 1985), his biography, Fine Lines (Blackwell & Johnson, 2016), and his scientific studies, which can be found in Fine Lines—all prior to the exercise, along with weekly nature walks and nature journaling experiences. We also introduce biological/anatomical drawing prompts, role playing, and sample lecture board layout for instructors to illustrate as part of classroom storytelling, with teachers modeling drawing and noticing skills for their students. Our suggested lesson plan for educators is as follows:

**Plan for Naturalist’s Notebook in Evolutionary Time:**

1. Start with reading from Nabokov’s book, The Gift, which has some interesting references to evolution. This review of The Gift discusses the evolutionary concepts that shaped Nabokov’s thinking: https://onlinelibrary.wiley.com/doi/pdf/10.1111/1467-9434.00275
2. Then a short movie on his life, as well as an introduction to complete metamorphosis in insects and butterflies, will assist in engaging students.
3. Display some or all of the chalkboard drawings of Nabokov and his contributions to both taxonomy and evolutionary thinking (Figure 1). By illustrating his portrait, we give a face to our scientist/artist. You can then pose questions to students that have a humanistic component, such as:
   - Why was a writer so interested in butterfly evolution?
   - Butterflies are very speciose. What process of speciation may have occurred?
   - Butterfly fossils are 40–50 million years old. What other organism’s evolution may have sparked their diversification?
   - Insects like butterflies go through a metamorphosis. What might be the adaptive advantages of this?
4. An introduction to nature drawing and to naturalists and their study, leading to Nabokov as an example, will help students develop a “feel” for a particular individual. It is important to
include other naturalists such as Beatrix Potter, Rachel Carson, John Audubon, Lois Agassiz, Ernst Haeckel, and Leonardo DaVinci. Showcasing the naturalists' combined skills of observation, drawing, and keeping notebooks sets the tone of keeping notebooks in all biological investigations and is useful for other labs. Also, in this discussion we examine the ecological problems facing pollinators, including pesticide use, loss of wildflowers, and loss of habitat. It is good to also bring up current issues with this discussion, such as recent news from the World Health Organization announcing how dangerous pesticides are to human health and to butterflies and other pollinators. This helps show the interconnectedness of our lives with other living systems, and helps students reflect on the world they live in today.

5. You may want to take a nature walk first, or after you introduce the drawing of insects and butterflies as well as wildflowers without going into any more detail about them. Use the “deconstruction” exercise provided (Figure 2), then move to drawing caterpillars and the biology of butterflies. I suggest including at least two drawings of flowers and their parts, a basic drawing of the life cycle of butterflies, a basic drawing of a butterfly, and a few other insects. Also helpful are frequent one-hour or two-hour silent nature walks with limited talking and limited or no photography. These walks would include a nature journaling experience of observing and drawing specimens of interest.

6. Once students have taken a nature walk and tried their hand at some drawing, you can hand out notecards and provide a sample Nabokov notecard drawing for students to copy (Figure 3), as well as clear photos of butterfly wings and scales to draw.

7. You can have them work in pairs, alone, or in groups. Once students familiarize themselves with the variation in butterfly wings, they can discuss the details of what they observe with each other and compare their drawings. Comparing drawings allows students to see how each of us interprets visual data differently. You can also ask them to examine variation in other structures or characters such as seashells to simply exercise their ability to observe variation.
8. If you have run out of time, save the nature walk journals for another class. You can also give this as a homework assignment, where students can enjoy scrapbooking their own drawings using personal supplies or adding personal touches without time constraints. Besides butterflies, students can include tree leaves, clover, dandelions, or any abundant botanical specimens in their scrapbook. Students may also observe variations in sparrows or pigeons by simply having a feeder available.

9. Once you have done the drawings and notecards and created scrapbooks, students explore the butterfly phylogenetic tree with the TTOL database, comparing the blue butterfly to local species, especially those they have seen on nature walks or have studied. They can also hand-draw their own phylogenetic trees in their notebooks. The TTOL experience can be an entirely separate experience or a homework assignment, or both.

10. The final component involves predicting the future as Nabokov did. Students can keep their nature journals in the perspective they have chosen and create a “climate of the future,” for which they predict the changes that will occur and the phenotype of the future Polymattus blue.

**Figure 2.** Copying from a Naturalist master. In this exercise students deconstruct an image created of a butterfly specimen from the 18th century. This exercise allows students to directly experience a particular type of drawing, one that is typically created by naturalists when they studying anatomical parts and looking for patterns. Copying the classical colored butterfly wings on this page and following the simple steps provided will assist students, especially those who find drawing difficult, in mastering the coordination necessary to observe and to draw, and to toggle between those two components of the naturalist drawing methods. Going back and forth between observation and drawing is a skill that develops with practice. In this quick lesson, the idea of basic shapes, negative space, and finalizing the observation with the details are introduced to students and encourage a similar procedure when observing real specimens.

**Figure 3.**

**Art Skills for Biology: Art Processes, Change, & Evolution**

Although Nabokov was considered an “average” artist, he demonstrated that an artisan method of drawing ideas as well as actual forms would be his method of choice for examining the wing scales, veins, and genitalia of the butterflies he studied under the microscope. For him, drawing these variations and the changes
in anatomy and pattern enabled the discoveries and confirmed the “infinite trek of living systems through time.” To further engage students with species identification, species divergence, and the concept of descent with modification, unifying all life on earth through time, these drawing experiences have been designed to magnify the concept of “modification.” The hands-on practice of drawing consecutive images with subtle changes in each drawing, slows down the process of the change-over-time concept for students (Jones, 2008). Animating processes can also reveal developmental, growth, metabolic, phenotypic, ecological, and molecular changes and decomposition, and are incredibly well suited for manipulating and refining the concept of change over time, but fundamental drawing and noticing skills are a necessary requisite for even the simplest animation.

As Blackwell and Johnson stated in their book Fine Lines (2016), Nabokov’s descriptive and creative drawing and writing approach revealed his complex crossover of art and science, and his ability to problem-solve with enhanced creativity from both disciplines: “these theoretical contributions [Nabokov’s novels] to evolutionary and biogeographical thought were as significant as his descriptive ones in systematics and taxonomy (Blackwell & Johnson, 2016). It has always been known that drawing requires a focus and is particularly important in studying biological form. Picture taking appeared to supplant drawing to capture images, but it has not been able to replace the process of drawing, and that process is where focus and true noticing skills develop (Quillin & Thomas, 2015). Evolution, like many biological processes, is motion in time and, therefore, requires a sequential visualization of change. The cinematographical method can benefit students in imaging change over time, but noticing skills of detail and variation among individuals are the antecedents of dynamic “change over time” thinking (Bergson, 1911). Nabokov’s drawing methods utilized grids and patterns to track the occurrence of the evolution of wing maculation, as well as wing venation, and wing patterns (see Figure 3). He also used what he termed “magic triangles” to measure change in reproductive parts, attempting to quantify the qualitative nature of drawing and observing. Nabokov’s use of color and attention to pattern, two largely artistic areas of knowledge, were as pivotal in his scientific discovery process as his drawing practice, novel writing, and scrap-booking method of analyzing his visual data. Providing students with similar drawing and artisanal experiences with actual physical data, fossils, and forms in nature will enhance the drawing-for-evolution experience. Drawing, of course, is more difficult for some than others, and is a matter of practice and skill development, so students should not be evaluated on the aesthetics of their drawings but only that their drawings contain important elements of detail and form. Likewise, instructors can practice drawing themselves and present those embedded drawing/biology lessons in class to encourage students to draw.

Biology Teachers Drawing: An Exercise for Educators

Drawing for your students is an excellent way to model the drawing-for-evolution experience. Students value what their teacher puts on the board and anticipate exams based on it. I have constructed an easy-to-follow white board or chalkboard drawing layout that can serve as an exercise and interactive discussion on naturalist’s drawings and notebooks as well as facilitate students drawing on their own (Figure 4). The layout for lesson plans are usually on a white-board or chalkboard drawing. Start your layout on paper, where concepts of significance are illustrated as part of the lecture, in this way you can tailor make it for your class. Students can follow along with the drawing and the unfolding narrative, making this a highly interactive lecture experience. The basic layout is provided in this paper (see Figure 2).

From Nabokov to Molecular Evolution

Nabokov published many of his findings at a time when DNA was on the cusp of becoming the central dogma of the biological sciences, set to transform Darwinian evolution. Nabokov died in the same year that Carl Woese and George Fox published a short paper on the small rRNA subunit that was to re-write the tree of life in a tripartite world, the formally known Five Kingdoms of Life. The first gene sequence-based quantitative assessment of phylogenetic (evolutionary) relationships between representatives of the major known kinds of organisms (Woese & Fox, 1977). And so began the debate of molecular phylogeny versus morphological taxonomy, with questions arising at the most fundamental level of how to define a species and if, in fact, there really was a “tree of life” that could be plotted and dissected. The construction of a metaphoric tree tunneling into deep time was supported by the similar sequences of SSU rRNA throughout life forms, supporting some concept of a tree metaphor: “Even those elements of the translational apparatus that are most susceptible to HGT (the aminoacyl-tRNA synthetases) show that the canonical pattern of the rRNA tree is largely preserved” (Pace et al., 2012). For Nabokov, this information may well have been disregarded, even though it was total genomic DNA of Polymaths blue butterflies and mitochondrial markers that validated his hypotheses. One might ask why, if computational biology built on the SSU rRNA is so powerful, would we need naturalists like Nabokov and his slow, hands-on methods? And the answer would be, for the same reasons we
need drawing, noticing skills, an appreciation of beauty, and most importantly a sense of wonder. If students cannot grasp far-reaching concepts—like geological time, speciation, and extinction—then we complicate their comprehension and appreciation of these monumental forces on Earth by adding terminology that bypasses the fundamental questions that have still and may never be fully answered. Winding back the clock to Nabokov’s methodology may offer incubation, reflection, and a chance for students to ponder major questions about life and how it evolves.

○ Role Playing

Artists often “enter their characters” through role-playing and switching perspectives (see Figures 5 & 6). Drawing and observing can be very objective practices, but they also encourage a deeper inspection of their subject, often shifting to the perspective of the subject (Ahn & Filipenko, 2007). Asking students to imagine themselves as a character like Nabokov or a butterfly can shift thinking and reframe the question and problem, often resulting in an alternative perspective that becomes an eye-opening experience. It also encourages students to become more invested in what they are trying to convey as this other “being” is articulated from their physical presence. Theater and acting, as well as dance, writing, and visual art require shifts in points of view, and “entering” into characters. Encourage students to choose to be the apprentice to Nabokov, Nabokov himself, or the well-studied butterfly, or more specifically, the blue butterfly. Be sure to include nature walks as often as possible, as they are raw material of creative thinking and enhance the discussion on Nabokov’s life. Supplementing the experience with a take-home article that provides background to Nabokov and butterflies with images of his work is also very helpful. Students will find that the experience of switching identities and even species is fun and enjoyable; “Role-playing can be so enjoyable that sometimes students might think they are just having fun and not realize the amount of learning that is occurring” (Howes & Cruz, 2009).

○ Materials

This is a relatively inexpensive experience in terms of supplies. Students will need notecards of various sizes, scrapbooking tape, larger poster board or larger and stiffer layout paper to place their cards on, sketchbooks, tape, colored pencils, and images from Nabokov’s notebooks to copy. I also suggest giving clear photographs of butterfly wings so students can use them in place of real butterfly wings. You can also apply this technique to studying seashells, leaves, or any naturally occurring object that is easily accessible.

○ Artisanal Exercises for Nabokov’s Butterfly Notebook

After acquainting students with Nabokov and his life, ask students to start a journal entry as if they were working alongside of Nabokov (apprentice), actually being Nabokov, or as stated earlier, assuming the perspective of a Polymattus blue butterfly. Let them discuss their ideas together or alone, show at least one video of metaphors and the complete life cycle of the insect, including its migration patterns and food sources. Butterflies are one of the best studied invertebrates so a great deal of information is available. At least a page of their introduction should reflect the perspective they have taken, with a description that clearly indicates who or what they are. Any other observations in nature should also be part of their work. Keep the notebook “open” to whatever the student might find interesting to draw or observe in nature.

○ Using Nabokov’s Notecards

Nabokov did most of his drawings on 3×5 notecards. This process assisted him in organizing his thoughts. Students should create at least ten individual drawings of the same specimen or organism, and construct or look for relationships within their drawings. There is no “right” way to do this; however, the concept of using notecards to organize ideas is useful and fun, and allows students to externalize ideas about their own work.

○ Biodiversity and Evolutionary Thinking

A campus embedded in nature is the ultimate “classroom” experience. The lesson of the naturalists—from Racheal Carson, to E. O. Wilson, to Vladimir Nabokov—is that if you stay close to nature and develop the skills to “read” nature—such as drawing, noticing, and writing—you can unravel mysteries, become inspired, and without coercion, expand your sense of wonder. In the practice of drawing nature is the enlargement of a student’s scope and depth of interest in evolutionary thinking. Even in urban environments or boring, sterile classrooms, students will develop a tropism for being out and interested in the natural world. All walks will become nature walks, and with art as a personal tool, students will see nature and living systems, and contemplate evolutionary process wherever they are, despite the concrete edifices that appear to obscure them. A shift in focus along with drawing can stir thoughts about change in nature. Even neuroscientists like

Figure 5. Sample drawing exercise for life cycles.
Santiago Cajal were inspired by nature and their surroundings, and utilized the arts to investigate biological phenomena:

The love of Cajal for the beauty of nature and his passion for painting, drawing, and photographing nature's sceneries demonstrated his exquisite sensitivity and the depth of his perceptive feelings for all things aesthetic. This aspect of his personality was fundamental to his acquisition of scientific knowledge, because Cajal observed and admired nature through an artist's eye. (DeFelipe et al., 2014)

The appreciation of the subtleties that exist in other species by drawing them will over time convey the concept of variation, patterns, textures, and relationships to students. It also points to the immense importance of intact ecosystems and biodiversity for cognitive inspiration. When students engage with technology such as the TTOL database, they will have more vested interest in their searches and in the questions they pose regarding phylogenetic relationships and divergence. Equipped with only pencils and paper, students also will gain a renewed interest in their capacity to guide their own learning experiences. Enhancing the evolutionary learning environment by allowing succession on campus, wild spaces, and habitat has many benefits for many organisms, and allows students connections and opportunities to write, illustrate, and contemplate evolution and nature, just as Vladimir Nabokov once did with his beloved blue butterflies.

**Conclusions**

The TTOL database makes an enjoyable and stimulating experience for students in all levels of biology, which can become even more engaging and deeply significant when coupled with the work of polymaths like Nabokov and venturing into the realm of the arts. Drawing outdoors and in the lab, biodiversity, variation in nature, and artisanal knowledge-based skills support the experience of using the TTOL database. The pleasure of drawing in science is satisfying and the rewards for students, stimulating. Nabokov's legacy of the blue butterflies also lends itself well to the diminishing

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**Figure 6.** Sample notebook page on drawing butterflies (Monarchs are a good example). You can use this as a sample notebook page so students have some reference. You can also show pages from Maria Merian's notebooks: A branch of sweet cherry and the metamorphosis of a caterpillar into a butterfly, drawing on parchment with watercolor and gouache by Maria Sibylla Merian, 1679. https://www.britannica.com/biography/Maria-Sibylla-Merian.
habit of pollinator species and the timeliness of preserving biodiversity wherever possible. Applying this lesson plan on Nabokov’s butterflies may inspire a campus to build its own biophilia-based habitats and wild areas where students can experience the naturalist’s unstructured and personalized interaction with nature. Making and exploring evolution and speciation in deep time through art experiences can provide inspiration and foster creative as well as scientific writing experience for students. Nabokov’s vocation with blue butterflies through his handwork, his deliberate and detailed focus of butterfly anatomy, and his parallel interest in science and art fostered a testable hypothesis that validated his methods, making him a role model for STEAM and the natural experience of wonder and creativity. When students have an opportunity to become naturalists at the schools they seek knowledge from, the knowledge found in observing and drawing the life around them will instill a skill and way of thinking that will grow and inspire their creativity, and make evolutionary patterned and process thinking an underpinning of all their biological knowledge.

○ Resources


○ Evolution terms for student to apply to their notebook descriptions:

Natural Selection, mimicry, divergence times, maculation, scales, venation, migrations, selection, splitting, convergence, divergence, DNA sequences, mutation, speciation, extinction. For a full list, or to make up your own list, see “Evolutionary Resources: Definitions of Evolutionary Terms,” The National Academy of Sciences (2018), http://www.nas.edu/evolution/Definitions.html

References


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