FEATURE ARTICLE

Molecular Memories of a Cambrian Fossil

CARYN BABAIAN
AND SUDHIR KUMAR

Abstract

Evolutionary evidence is important scientific background for appreciating the theory of evolution. We describe a STEAM-based lesson plan that uses paleontological drawings and a modern evolutionary database to explore and understand fossil, morphological, and molecular evidence. Together, with a focus on arthropods and the Cambrian explosion, students experience a heuristic process common in scientific reasoning, guiding them toward practices that synthesize knowledge and invite questioning in the life sciences.

Key Words: *Cambrian fossil; molecular characters; arthropods; TimeTree; drawing heuristic; morphological characters; storytelling; evolution.*

> There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved.
>
> Charles Darwin

○ Introduction

The cross-pollination of art and science is not new. Like a forked road that converges once again, they are interrelated from the beginning. Art might even be described as the spark that ignited and illuminated our vision of the natural world, inspiring the scientific process. The emergence of the domains of science depended heavily on artisanal skill sets, more so than we acknowledge. One of those ancient disciplines is natural history and its observations of the magnificent diversity of nature throughout time (Smith, 2018). Reconstructing the planet's past and lost worlds involves a coherency of two or more subjects, complementing and informing each other in a narrative that communicates effectively to other scientists, to students, to educators, and to general audiences. This process transforms specialized domains into public domains, and the knowledge they transmit into a part of culture. Artists like Charles R. Knight (a painter of prehistoric life) and Benjamin Waterhouse Hawkins (a sculptor who created life-sized dinosaurs for the Crystal Palace Park in South London in the mid-1800s) shaped the way we imagine geological time and prehistory. Artists have been key and central in the collaborative scientific method of paleontology (macroevolution) just as they were in the anatomical sciences. To create the hypothetical phylogenies and track the divergences of organisms, scientists must fuse fossil data, morphological data, and molecular data, along with biogeography, to assemble lineages and predict evolutionary patterns. To give students a broad exposure to evolutionary science, in this article we merge the competencies of paleontological artists with a modern species database to encourage a reconstructive drawing paradigm that builds a descriptive, heuristic skill set, thus promoting the inference of form and pattern through drawing. Students work with concepts of parsimony and "most likely" outcomes in their observation of morphological data, gaining insight into evolutionary thinking and the complex process of reconstructing the past.

> *"This arts-based heuristic, combined with the modern database TimeTree: The Timescale of Life, will allow students to make predictions about current taxa."*

○ Evidence of Evolution & Evolutionary Concepts

The teaching of evolution typically starts with a brief history of Darwin and his theory of natural selection, followed by evidence to support the theory. Most biology textbooks organize an introduction to evolution by examining the evidence early in the chapter (Swarts, 1994). Students memorize those pieces of evidence but rarely get to experience them. Students may even work with phylogenetic

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tree-building software without any knowledge of the philosophies and methods behind them. Students may not be aware of how the patchy, messy business of decision, assumption, inference, prediction, revision, and multiple types of evidence come to illuminate the relationships that build the tree(s) of life. "Our ability to correlate biological evolution with climate change, geological evolution, and other historical patterns is essential to understanding the processes that shape biodiversity. Combining data from the fossil record with molecular phylogenetics represents an exciting synthetic approach to this challenge" (Parham et al., 2011).

In the lesson plan described here, students will have an opportunity to experience prediction, assumption, inference, reevaluation, and synthesis through the paleobiological artistic process. For teaching evolution, we introduce the *biological artistic drawing heuristic*. This concept applies coherent logic in stages to the process of observation and the implementation of the drawing and artistic skill sets. This arts-based heuristic, combined with the modern database TimeTree: The Timescale of Life (http://www.timetree.org), will allow students to make predictions about current taxa. In the roles of a scientist of the past and a modern scientist of today, students will explore fossil morphology and the morphology of living organisms as their only evidence. They will follow this up with searches in TimeTree, which contains thousands of published studies of relationships and divergence times of major groups of organisms, resulting in a community agreement on those times and an appreciation of the geological time that encompasses them (Hedges et al., 2006; Kumar et al., 2017).

○ Synthesis in Science

A grasp of synthesis in evolutionary science serves to broaden students' views of scientific collaborations and of the evolutionary process. Toggling between morphological drawing and the modern database, students will experience very different methods that may complement or refute their hypotheses about a particular taxon. Fossil drawing offers an opportunity to examine the traits and morphology of extinct organisms and incubate ideas about relationships based on that morphology, perhaps seeing similarities or considering a possible ancestor to their living taxa. Students may not be aware that fossils of known ages serve to standardize and adjust relationship groupings and divergence times. This process is known as *calibration* and can be used in multiple ways within an already existing tree (Parham et al., 2011). We present this lesson as a narrative for exploring and reconstructing the past by traveling back to the Cambrian and its rich wealth of fossils to investigate the phylum Arthropoda in the present.

We connect this broad past to the living descendants of arthropods today through these two heuristics – *descriptive heuristic drawing methods* and *a modern database*. Both processes unite to help students evolve the story of reconstructing the past in the present. One related phylum, Onychophora (velvet worms), provides a sample decendant of the now extinct, unfamiliar, and peculiar-looking Cambrian animal *Hallucigenia*. We chose to include this onychophoran's link to genus *Hallucigenia* because this relationship helps students see how researchers refine and organize relationships between ambiguous species like onychophorans and the arthropods of today. The ambiguity of velvet worms offers a glimpse into the imperfect work of classifying ever-evolving organisms, which then require reevaluation. Following their drawing experience, students will test their morphological guesses with averaged divergence time data in TimeTree.

○ Morphological & Molecular Characters

In this lesson plan, we link morphological evidence (physical structure, external form, and appearance), fossil evidence, and molecular evidence (genetic code of nucleotide sequences, amino acids) for evolution through a descriptive, elucidatory practice of drawing the extinct ancestors of the Cambrian and their modern arthropod relatives. We consider the historical process of studying fossils, revealing the relationships of extinct species by studying similarities and differences in their fossilized skeletons. The most widely used method, called *parsimony*, produces phylogenetic trees by minimizing the relative number of skeletal differences between species to organize animals into nested groups. In the words of Stewart (1993), "parsimonious reasoning is a fundamental way of knowing in comparative evolutionary biology, whether the raw data are molecular, physiological, morphological, or behavioral." Similarly, molecular methods also produce parsimony trees that assume the fewest possible changes, using DNA sequence data based on protein molecules instead of physical morphological characters (Stewart, 1993).

○ Drawing & the Parsimony Principle

Morphology can be broken down into characters, which can then be compared to other species, resulting in a hypothesis of relatedness. However, with many missing pieces in the fossil record, paleobiology is a heavily interpretive science (Ortega-Hernandez, 2012). Similarly, homologous sequences of DNA can be aligned and compared, also resulting in a hypothesis of relatedness (Kumar & Filipski, 2001). "The parsimony principle directs us to choose the simplest scientific explanation or the best tree that fits the evidence," writes Stewart (1993). "The best tree or best hypothesis is the one that will require the fewest evolutionary changes." To facilitate an awareness of the complex synthesis of multiple scientific perspectives, and to establish a general knowledge of computational concepts such as parsimony, we ask students to use anatomical or morphological drawing in a "parsimonious way." Scientific drawing applies parsimony in the process of producing accurate images, which requires forethought and judgment based on visual data and prior knowledge. In the drawing process lies the investigative heuristic and skill set (Northcutt, 2004). In the case of a fossil, the model is partially an assumption and partially physical evidence. The process of investigating this unresolved state requires inferring form from a variety of perspectives. If considered as an ancestor, that form must imply, through the process of revealing its structure, relationships to living forms. This process, when directed to the physical evidence, allows the artist to create multiple possibilities (drawings/concepts) and then choose the one that best fits the data.

In observing and comparing morphology by drawing, and establishing their guesses in a concrete way, students can later

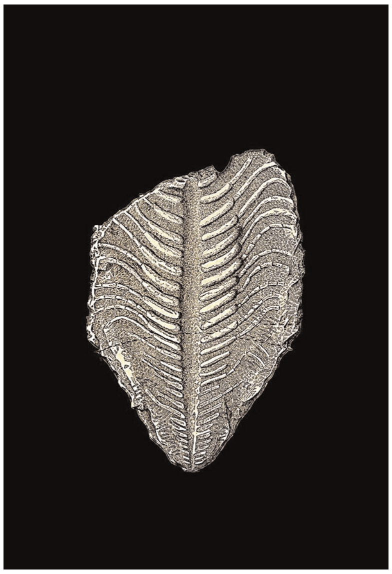

Figure 1. A practice exercise in which students predict the rest of this fossil by drawing in the remaining anatomy. Instruct the students to think carefully about what appears to be missing and how the information we have might inform a prediction, considering other living forms.

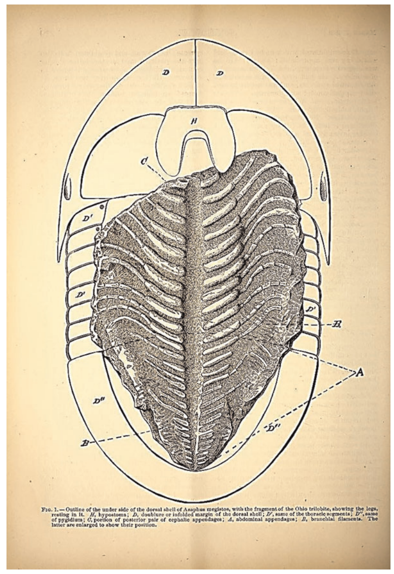

Figure 2. Trilobite sketch and morphological analysis and reconstruction from a fossil in the 1800s. Share this with students to remind them of the heuristic of skillful drawing used in evolutionary sciences and to test their drawing inference skill from Figure 1. If fossils are available, have students make an effort to infer, through drawing, the rest of an incomplete fossil. The demonstration will reveal some of the processes of drawing as discovery.

ponder and predict other, less tangible characters, like behavioral activity and the biogeographic location of that theoretical organism. We guide students through drawing to use morphological characters that are shared between species and to also infer relationships within a phylum. We suggest using a grasshopper as a representative of phylum Arthropoda for reference. We ask students to engage with TimeTree to search for relationships of major groups or taxa and their divergence times as part of their scientific inquiry. TimeTree is based on sequence data and calibration of fossils, but it does not rely on visual, morphological analysis of structure. Since students are often exposed to the evidence of evolution – including fossil, comparative, biogeography, embryological, and molecular evidence – using three of these types of evidence permits a level of critical thinking they may not have encountered previously. Since there are no "correct" or "incorrect" answers in this lab experience, students can be assessed for a general collection of drawings in a portfolio format.

○ Descriptive Drawing of Morphological Characters

The eloquent and illustrative scientific drawing of the past that documented fossil characters and actual living organisms reminds us that we all have the potential to interpret the natural world through drawing and the arts. Students may have forgotten that they are inherently equipped with drawing skills and that, even if they feel they cannot draw, it is a skill that can be cultivated, enjoyable, and highly self-instructive. For this exercise, students will be drawing claws, mouth parts, and body plans by focusing attention on the *process* of drawing for the study of morphology. They will also be reconstructing a whole organism from a fossil image (Figure 1). The act of drawing, noticing, inferring, and asking questions about characters and their variations also encourages students to see deviation from the average among a set of established characters and to identify characters that appear to be related, introducing the concepts of convergent evolution, homologies, and vestiges. It also reveals that even detailed morphological similarity in nature can be misleading. In the broadest context, once a visual hypothesis has been generated, inference regarding biogeography, behavior, and ecology will play a role in the decisions made while drawing and develop along with the process.

If we look at a trilobite engraving and its predictive drawing done in the 1800s from a fossil fragment (Figure 2), we can immediately identify the artistic heuristic in this image. The artist was presented with a fossil, much of which was missing. The missing parts had to be inferred or extrapolated from the fossil, considered in three dimensions, and compared and referenced to personal experience or to a human "database" of living knowledge of related specimens. The artist-scientist must develop the ability and insight to decide what is morphologically consistent and harmonious with the fossil, considering similarities to other organisms, and deduce the rest of it to produce a complete picture. Each small piece of the anatomy has to be considered as well. Is the anatomy fused? Is it jointed? If there are many specimens, the average form must be considered the most likely. If there are outliers in the form, do they represent disease or simply variation? Physiology, ectothermy or endothermy, and coloration must all be inferred on the basis of prior knowledge or living organisms. Ask students to think about the image of the fossil or the morphology before they begin drawing. We offer a "how-to" example for drawing a trilobite. Have students create a sketchbook of possibilities and variations. In Figure 3, the Cambrian animal *Opabinia* is sequentially explored.

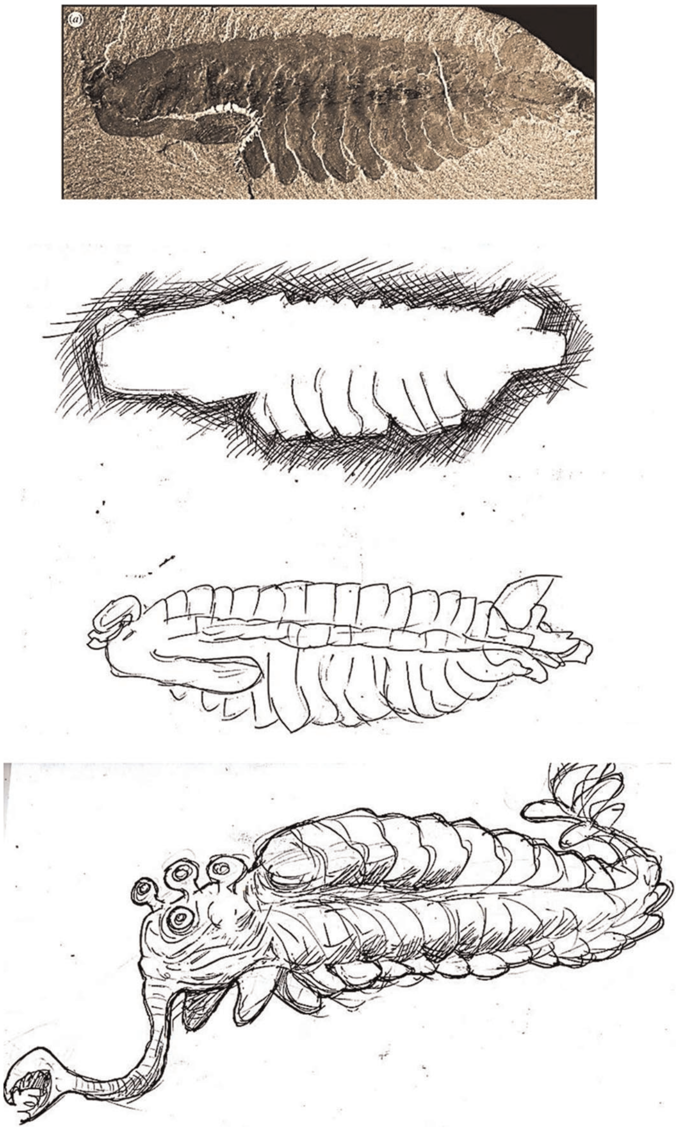

Figure 3. Students should be given one fossil card, which the teacher has created. This example depicts the Cambrian animal *Opabinia*. Students are asked to study its structures and then attempt to extrapolate the anatomy, considering that this animal was compressed and deformed in the fossilization process. Finally, they can infer, through their drawing, how the actual living animal might appear. This process requires sketching out ideas, visualizing the organism in three dimensions, and considering its habitat. Ask students to evaluate the body type, the appendages, and any questionable anatomy. They can make a list of the apparent "parts" and recognize those as characters that may reveal relatedness.

Its general shape, appendages, adaptations for aquatic life, and observable details are extrapolated. Consideration is given to its desiccation in death, compression, and other factors, which enable the artist to speculate about the living form. Students will be given their own fossil card (which you can easily make from images) to explore this process themselves. In reconstructions of entire periods like the Cambrian, a multiplicity of inferences, data, and speculations must be evaluated.

Questions arise, such as what would be logical or possible, anatomically, given the visual data we have? While it takes many years to develop the scientific, paleo-drawing skill set, might students who draw appendages of arthropods be able to recognize that mandibles are actually modified legs if they can see the subtle similarities or modifications? Can a student see more deeply into structures by making focused drawings of them? We might ask, if students explore the carnival of unique and extinct forms from the Cambrian through the drawing process, will it help cement fundamental forms and the idea of segmentation genes and regulatory elements in their memory? If students utilize the drawing heuristic, will they make better predictions about relatedness based on morphological evidence, and make better predictions in scientific inquiries in general? Can students gain a greater appreciation and respect for these animals in time through the drawing of details? Will this deepen their interest in the natural world? To encourage drawing descriptively from fossils, we have provided step-by-step examples. We also provide "drawing prompt cards" (see Figure 4), or pattern guides for the modern arthropod groups.

○ The Cambrian Tapestry: A Yarn of Charismatic Creatures

There will always be unresolved questions in biology, and the phylogenetics of the Cambrian explosion is no different (Conway-Morris, 2003). The novel body plans and major lineages of this period exhibit extensive divergent morphological evolution within a geologically abrupt appearance of animals known as metazoans. This raises some questions about the rate of evolutionary change (Meyer et al., 2003) and the diversification of bilateral activity that sprang into action ~540 mya and that has shaped animals over time. The 13- to 25-million-year stretch of innovation established the animal body plan and reveals more than simply odd and unusual life forms (Butterfield, 2003). Most of the major invertebrate phyla appeared in this geologically short period, and many ecological behaviors and interactions became refined for persistence into the present. A large *assumed* apex predator of the Cambrian, *Anomalocaris*, looks like it is part pill bug and part giant sea louse – but is it really an apex predator? And what morphological characters contributed to this interpretation? If this interpretation is incorrect, then ideas about ecology and food chains in the Cambrian may be incorrect as well. Ask students to consider and evaluate plausible directional trends based on predation in the Cambrian and compare them to arthropod predators of today. Students may recognize morphological/functional traits such as claws, stalked compound eyes, antennae, segmented bodies, cryptic coloration, and predator–prey adaptations (Zhu, 2004). Hox genes can lead into discussions on identifying head, thorax, and abdomen, and the question as to whether or not the Cambrian can be inferred through a molecular phylogeny may surface during discussions. The Cambrian explosion and the preceding periods offer a valuable visual story that can weave evolutionary concepts easily and enjoyably into the classroom or lab. Through the apparently unique animals of the Cambrian, students may come to think more about morphological structure in a temporal framework, considering the way patterns are expressed in time, and perhaps even considering biogeographic changes that inspire those changes.

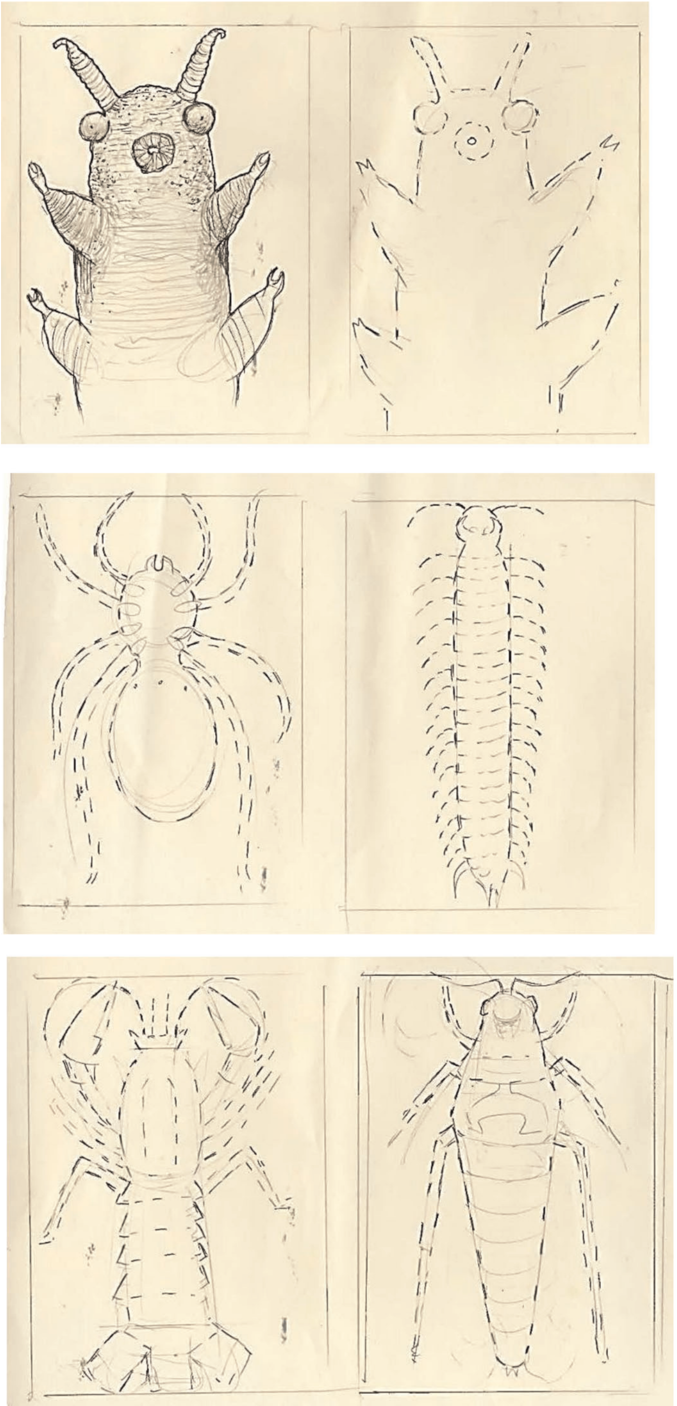

Figure 4. Drawing "prompt" cards help students draw the morphology of arthropods and observe details of characters. The top card features a velvet worm and the detail that students may want to achieve to understand morphology. Cards can be made on cardstock or index cards or printed on plain paper.

○ Telling It Like It Was

Fossil drawings can parallel systems biology thinking, in that they promote unified thinking, and drawing can operate as a heuristic that assists in recognizing patterned gradations of change over time. Fossils constitute another scientific, historical narrative – indeed, all evidence has some story to it. Scientists seek isolated facts about nature, but fossils invite the observer to tie them together with ideas and with molecular stories (Martin & Miller, 1988). Here, we provide the framework to initiate a scientific inquiry into morphological similarities through paleontological drawing in a unique way and as part of the unveiling of the fossil's narrative, widening our understanding of living relatives in the present. Fossils and molecular data are evolutionary indicators of the context of life on Earth. Although highly incomplete and piecemeal, fossils – compressed, embedded, or imprinted in rock, amber, or ice – are tangible objects that students can see and draw. Hence, they provide a segue into molecular evidence.

To assist teachers in presenting this narrative, we suggest setting the stage by recreating and drawing a scene from the Cambrian on the board. This can be prepared 20–30 minutes prior to starting class. Teachers can transform almost any review on the Cambrian explosion into a narrative simply by starting with a comprehensive image and an oral introduction. We also suggest having actual fossils as visual aids, to help answer students' questions about radio dating or how fossil and molecular data are combined.

○ Background on Arthropods

The phylum Arthropoda (the name means "joint" and "foot") contains many identifiable common invertebrates. Subphyla and their representatives include crabs (crustaceans), insects (hexapods), ticks (chelicerates), centipedes (myriapods), and their sister groups, which have some ambiguity in relation to the traditional arthropods (i.e., the onychophorans and the tardigrades). Velvet worms (onychophorans) present an interesting morphological conundrum for students. They look like worms with legs, so they have some annelid-like characteristics and some arthropod-like characteristics. Students can explore images of them and decide if they have a true head and are truly segmented. Their annelid characteristics can include eyes, segmented nephridia, and a simple gut; their arthropod characteristics include jaws (derived from appendages) and tracheae, just to name two.

Arthropods have bilateral symmetry, paired appendages, exoskeletons, striated muscle, and complete digestive tracts. They are extremely numerous animals. Beetles, butterflies, spiders, wasps, shrimp, and many others are readily available to observe. We created "arthropod image cards" to help students examine morphology. These are just index cards with pasted photographs of arthropods. We made approximately 50. Students can record and check off characteristics on the chart provided (Table 1) and then make their predictions. The connection to the Cambrian can also be made through the subphylum Trilobita. Extremely well studied and abundant in the fossil record, trilobites also peaked in the Cambrian and Ordovician and, along with velvet worms, help weave the story of present-day arthropods.

○ Moving from Fossil to Molecular through TimeTree

"Linking the evolution of particular morphological characters or key ecological innovations to geological, climatic or biotic events,"

Table 1. A reference chart for students to check off characters as present or absent in teacher-made "arthropod image cards" or from observations in nature or natural history museums.

Morphological Character	Present or Absent?			
	Card 1	Card 2	Card 3	Card 4
Bilateral Symmetry				
Triploblasty				
Jointed Limbs				
Segmentation				
Head, Thorax, and Abdomen				
Chitinous Exoskeleton				
Compound Eyes				
Antennae				
Modified Mouth Parts				
Respiration through body surface				
Hemocoelom				
Brain and Nervous System				
Specialized Sensory Organs				
Excretory System				
Reproductive System				

notes Forest (2009), "is much improved in the light of an evolutionary timescale." In terms of prehistory, fossils provide the only evidence for the sequence of branching and character acquisition for the arthropod stem group, which cannot be sequenced (Edgecombe, 2010). So, to construct a phylogenetic tree of extinct organisms, only fossil morphological evidence can be utilized, and this links morphological to molecular data. DNA from fossils is too fragmented and degraded to be used in the sequence data necessary for molecular-based phylogenies. TimeTree provides an opportunity to engage in a different kind of activity and access to information about when living species and their ancestors originated, which provides another tactic in resolving students' arthropod and fossil predictions (see Figure 6). Our exercise is primarily about developing a student's ability to observe closely, contemplate relationships, see trends, and predict outcomes. Once they have completed the drawings, familiarized themselves with the ancestor of arthropods, and made a check-list of characters, they can look at an arthropod phylogenetic tree. They can also observe whether physical appearance, through descriptive drawing, can be a predictor of function. Students can also construct multiple trees on paper to explore relationships in their hypothetical arthropod lineages.

○ Sequence of Activities

1. Start with the "Cambrian Tapestry" (the image shown at the top of this article) by placing it in a PowerPoint slide presentation, and on a whiteboard draw the Cambrian time line using a standard geological timescale.
2. Discuss the emergence of segmentation and other key events during the Cambrian period.
3. Teachers will have created 3 sets of index cards: printed out prompted drawing cards, varied arthropod cards, and varied Cambrian fossil cards.
4. Introduce real fossils, using trilobite fossils and Burgess Shale fossil images.
5. Show a few artists' reconstructions of those animals.
6. Define the differences between fossil data, comparative anatomy, and molecular data.
7. Place an arthropod tree on the board, including trilobites, and relate it to the Cambrian.
8. Follow that thread through by showing an image of a drawing of an incomplete trilobite fossil (Figure 1). Explain how a paleontologist/artist would have to infer the rest of that organism and then further suggest its live appearance (morphology).
9. Talk about the diversity of arthropods today, including convergent evolution in insects.
10. Explain the two outgroups (velvet worms and annelids) and ask students if they see similarities between them and arthropods. Ask students where they might place velvet worms in relation to arthropods.
11. Hand out drawing prompt cards of arthropods (Figure 4). Use these to practice drawing body parts, then hand out Cambrian cards with different Cambrian animal fossil

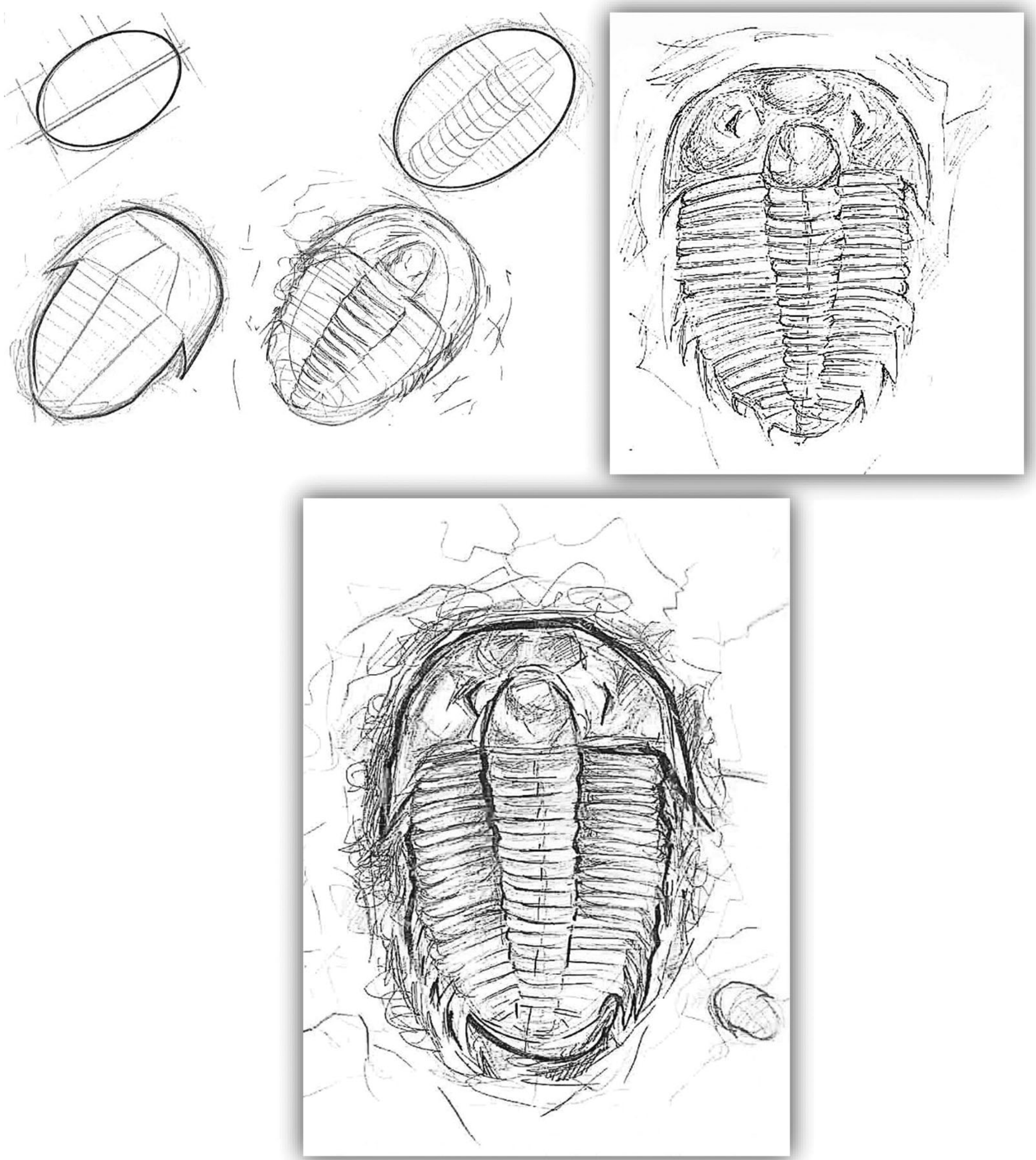

Figure 5. A practice fossil-drawing exercise to help focus students on the observation of structure in fossil evidence. Top left: a small step-by-step process of oval shapes, outer contour, and detailed exoskeleton. Top right: more emphasis and attention to the details of form. Bottom center: increased focus on shadows and depth. *Note:* When drawing fossils, which are mostly rock, it is critical to render light, shadow, and depth, which are very important because they reveal structure.

photographs (see Figure 3). Use the example of Opabinia for drawing steps. Ask students to follow the drawing example to reconstruct the organism from the fossil, looking closely at any anatomy that is distinct. Students can also practice this drawing method by using the trilobite example (Figure 5).

12. When drawing, it is very important to take time to evaluate and consider what you are looking at. It may even be better to hand the cards out a day ahead of class and have students think about the form. The exercise is not meant to produce an immediate result, but rather to allow the students to experience a process.
13. Once they have completed that assignment, let them look up their extinct Cambrian fossil to see how close they were to an artist's prediction of the same organism's complete form.
14. Go over the grasshopper anatomy as representative of a typical arthropod.
15. Hand out a check-list of arthropod characteristics.
16. Hand out drawing prompt cards for the four subphyla of arthropods (have enough copies printed and ready so that everyone gets a chance to draw) and ask students to complete them to familiarize themselves with arthropod anatomy.
17. Teachers can also take their students on a Nature walk or to a natural history museum to identify as many arthropods

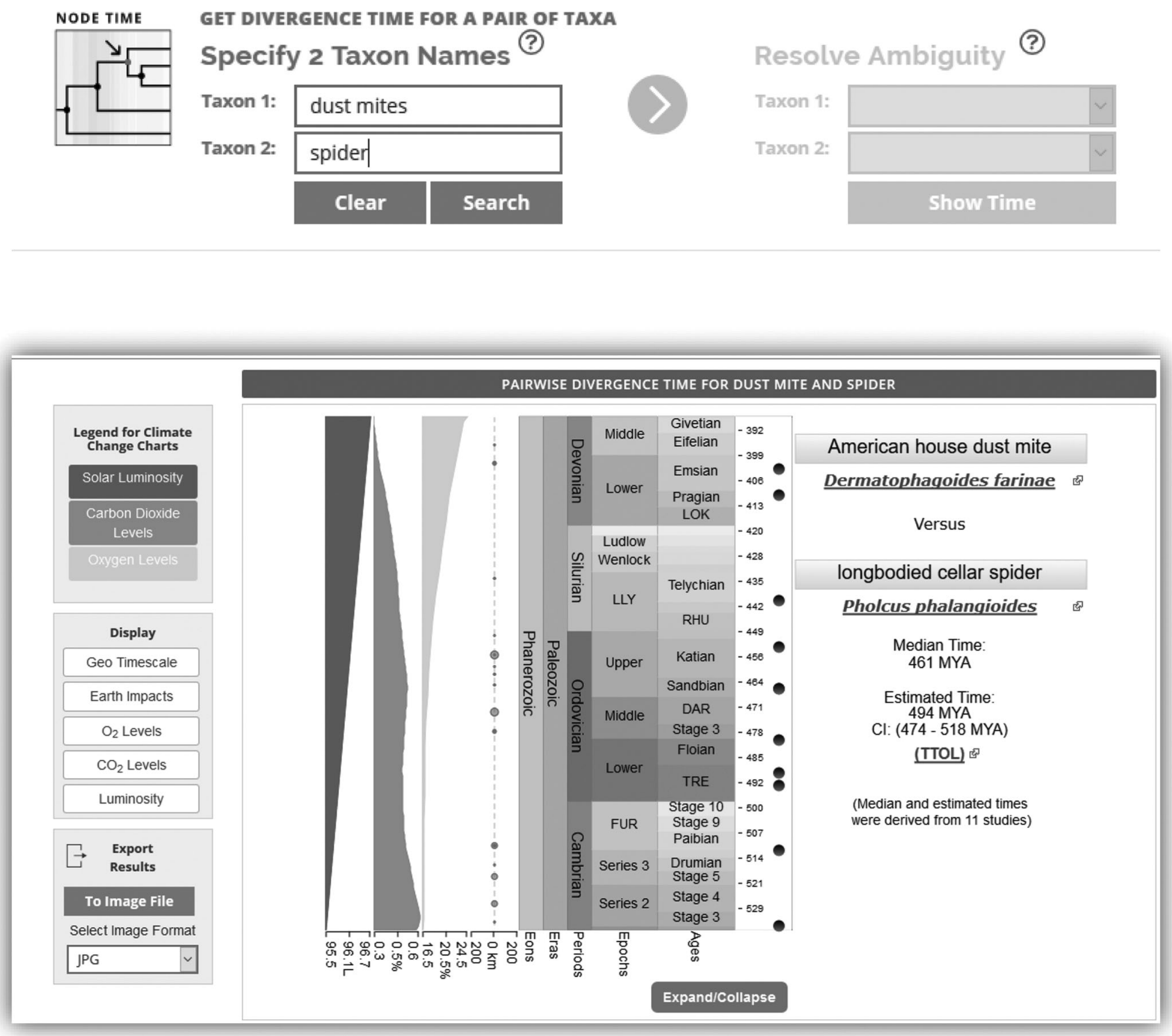

Figure 6. Top image: comparing dust mites and spiders using the TimeTree database (www.timetree.org; Kumar et al. 2017). Bottom image: median time of divergence for "dust mite" and "spider" is 461 mya, but compare "dust mite" and "cricket" and the divergence time will be 583 mya, revealing that the latter two are less related, thus confirming or rejecting a student's hypothesis of relatedness based on morphology alone. The sister group of velvet worms (onychophorans) reveal a 717 mya divergence, confirming that they are even less related; however, observing their morphology may be insightful with regard to patterns of change.

as possible, or they can make up a large compilation of arthropod pictures and put them on index cards.

18. Have students study the cards or any other representatives and decide what taxonomic groups to place them in (see Table 2).
19. When students have classified their arthropods, have them record the numbers in the chart provided (Table 2).
20. Post an answer key on the board showing the correct matches.
21. Have students go the TimeTree website and test their morphological guesses with averaged divergence time data. For example, if they placed a spider in the insect group, they would go to TimeTree and compare their unknown arthropod to a known arthropod, for example comparing "spider" to "blue crab" or "spider" to "grasshopper." They will thus find the divergence time for each. The shortest amount of time reveals the most relatedness or the last common ancestor. In this way, they can test to see if their guess was correct.
22. Use the questionnaire provided (see Appendix) to assess students' reactions to drawing and to the activity in general.

○ Conclusion

Once the students have explored what descriptive morphological characters are like and have engaged with the TimeTree database, it is time to revisit the Cambrian explosion and processes of

Table 2. Students decide which group their insect belongs to by writing the number on each "arthropod image card" in the subphylum or class they think it is related to and explaining their choice.

Arthropod Classification	Card 1 (representative)	Card 2 (representative)	Card 3 (representative)	Card 4 (representative)
Chelicerata (subphylum)				
Crustacea (subphylum)				
Millipede/centipede (class)				
Insect (class)				
Trilobita (subphylum)				

evolution, the idea of phylogeny, and the many methods used to reconstruct the past. The Cambrian story is one worth dedicating class time to, as it sets the stage and opens the curtain on Animalia – the biological kingdom that most students can best relate to. It also allows us to peer into the processes of reconstruction through paleontological drawing practice – a heuristic that is rarely encountered in the higher secondary grades or in college – along with the heuristic process of computational biology. Combined with narrative, these modes of learning encourage imagination, hone unique skills, and give students a chance to find a point of personal interest in the diverse and dynamic world of evolution and biology.

○ Further Notes & Resources

Students can work in groups for part of the activity, but since descriptive drawing practice requires focused attention and is a contemplative exercise, it should be done individually. Visiting a natural history museum with a wide array of fossils and organisms is highly recommended. Providing a library of reading material is also useful. There are several books on the Cambrian that can serve as excellent resources, one of which is *The Cambrian Explosion: The Construction of Animal Biodiversity*, by Douglas Erwin and James Valentine. The activity is also a good opportunity for teachers to model drawing as part of the biology class/lab experience, so that it might eventually become a common practice again. We also suggest using (in place of preserved animals) good plastic models, large colored pictures, and trilobite fossils, which are relatively inexpensive and always reusable – to encourage "zero waste" in biology classrooms and labs. Lastly, in the age of the Sixth Extinction, it is wise and prudent to tie this lesson plan to one on biodiversity. The rapid decline of many arthropods, including pollinators, and the overall loss of biodiversity contrasts sharply with the Cambrian explosion's diversity of animal types 540 million years ago, and sets another stage for a more somber but illuminating window into the future of extinction, speciation, and evolutionary process.

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CARYN BABAIAN (caryn.babaian@temple.edu) is a PhD candidate and SUDHIR KUMAR (s.kumar@temple.edu) is a Professor in the Department of Biology and Director of the Institute for Genomics and Evolutionary Medicine, Temple, University, Philadelphia, PA 19122.

Appendix: An Optional Questionnaire to Survey Students

(1) Did the drawing help you to focus on anatomy and morphology more? Explain.

(2) Would you describe drawing as discovery, based on your experience with reconstructing a fossil through drawing?

(3) In your opinion, what are the advantages and disadvantages of fossil evidence?

(4) Would multiple forms of evidence of evolution benefit predictions of life in the past? Explain why.

(5) Did TimeTree put your predictions into a geological context?

(6) Is morphology a good predictor of relatedness? Why or why not? Why is convergent evolution important in studying form?

(7) Did this assignment make sense and give you experiences you did not have before?