Wallace in the Amazon:
A Case for Teaching Taxonomy & Scientific Practices

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Introduction

Teaching the nature of science, while also teaching biological content, has always been challenging. However, the task has renewed importance with the recent emphasis on scientific practices and crosscutting concepts in the new Next Generation Science Standards in the U.S. (NGSS Lead States, 2013) and with similar goals in reform documents internationally (Brasil, 2000; Hodson, 2008; OECD, 2009). Here we present one such lesson on phylogenetic classification. It contextualizes active learning (inquiry) on taxonomy in a concrete historical context, fostering understanding of how science works in an authentic case.

Our case follows the work of Alfred Russel Wallace (1823-1913), famous among biologists for discovering, in parallel with Charles Darwin (1809-1882), the concept of evolution by natural selection. This case, however, focuses on the young Wallace, who voyaged to the Amazon in the late 1840s to collect natural history specimens. Wallace observed the fauna, flora, geology, climate, and native culture, and recounted his experiences in *A Narrative of Travels on the Amazon and Rio Negro* (Wallace, 1889), in the same literary tradition as Darwin's well known *Voyage of the Beagle*. Wallace also took particular interest in the palm trees and their role in local cultures. He summarized his observations in *Palm Trees of the Amazon and Their Uses* (Wallace, 1853). Wallace's scientific practices in documenting the various species and classifying them form the framework of our case, described fully below.

A Role for Historical Cases

Several educational contexts support consideration of historical cases for teaching the nature of science, or scientific practices along with crosscutting concepts about science as a human and cultural endeavor. First, substantial evidence from educational research and psychological learning theory supports the use of cases – or concrete, complex, contextualized examples – as vehicles for learning. By situating the concepts in real-world examples, case studies help students appreciate the relevance of the knowledge and thus help them build lasting cognitive links to concepts they already know. Case study learning is now widely familiar in law, medicine, nursing, and other professional settings, and is becoming more frequent in science education (Allchin, 2013a; Camill, 2006; Dinan, 2005; Fawcett & Fawcett, 2011; Herreid 2007). Second, narratives (or stories), by using a human and social context, foster student motivation and, later, retention of content knowledge (Herreid, 2007; Stinner, McMillan, Metz, Jilek, & Klassen, 2003; Yadav & Beckerman, 2009). Engagement and practice with problem-solving in cases can also enhance critical thinking skills. (Dori, Tal, & Tsaushu, 2003; Herreid, Schiller & Herreid 2012; Stake, 1983).

Our approach involved making special use of history as a guide (Allchin, 2013b, pp. 28-45). Historical narratives can vividly convey "science-in-the-making," or glimpses of authentic scientific practices. They also help render the human, social, cultural, economic and other contexts of science in ways not possible in exclusively student-based inquiry. Most importantly, perhaps, historical episodes can form a structure for organizing student inquiry (Allchin, 2012, 2014; Hagen, Allchin & Singer, 1996; Norris, Guilbert, Smith, Hakimelahi, & Phillips, 2005; Rudge & Howe, 2009). History thus provides a valuable method for integrating scientific content and scientific practices (via inquiry), along with reflection on the cultural and human dimensions of the nature of science (nicely exemplified in this journal by cases by Howe, 2007, 2009).

Adopting this perspective, we present a teaching learning sequence (Méheut & Psillos, 2004) that uses the historical case of Wallace and palm trees to teach about taxonomy and phylogeny, as well as aspects of data analysis and communicating of scientific ideas (through informative and accurate visualizations).

Wallace in the Amazon, 1848-1852

Wallace journeyed to the Amazon region in 1848, well before going to Malaysia, where he developed the idea of natural selection (Fichman, 2004). Inspired by contemporary travel narratives of the period, such as those written by Darwin and Alexander von Humboldt (1769-1859), Wallace decided to study the diversity of organisms in the tropics. But it was the 1847 book of William Henry Edwards (1822-1909) that led him to choose "Pará and Amazon rather than to any other part of the tropics." Edward's narrative provided decisive reasons for his choice, such as the grandeur of the vegetation, the kindness and hospitality of the people, and the low cost of living and traveling. Edward Doubleday (1811-1849), entomologist at the British Museum, assured Wallace that the journey could be successfully financed by the sale of rare and new species, because "all that northern Brazil was very little known." Wallace was convinced that this was the place "to go to if there was any chance of paying our expenses by the sale of our duplicate collections" (Wallace, 1905, p. 264).

At the beginning, Wallace was accompanied in the Amazon by Henry Walter Bates (1825-1892), another English naturalist and friend who became chiefly known later for his studies on the coloration patterns of butterflies. These studies gave rise to a concept later called "Batesian mimicry" (Bates, 1863). Wallace and Bates met in Leicester, England, around 1845. At the time, Wallace was teaching drawing and arithmetic at a local school. With Bates, Wallace extended his avid interest in plants to include insects, and he became a professional specimen collector. While collecting beetles and butterflies, he learned the specialized techniques for fixing, preserving, and storing them.

Other factors, besides the inspiration from literature, contributed to the two young friends' decision to travel to a tropical region like the Amazon. With no job security, but with an interest in studying animal and plant diversity, they glimpsed the possibility of subsidizing the trip by selling exotic specimens collected in that region. Both were already familiar with the practice of collecting specimens in England.

For the first two years, between 1848 and 1850, Wallace and Bates worked together, collecting different species of organisms in the region of the lower Amazon and Tocantins Rivers. Through a London agent, Samuel Stevens, the two "enterprising and deserving young men" sent two parcels of insects from different orders, "containing about 7,000 specimens in very fine condition, and a vast number of novelties, besides other very rare species" (Wallace, 1849, p. 74). After receiving the parcels, Stevens announced them in the *Annals and Magazine of Natural History.*

In early 1850, the two naturalists decided to work separately in order to expand the collection of species from different regions. Bates explored the Rio Solimões while Wallace decided to follow the Rio Negro, the largest tributary of the Amazon River (Brooks, 1984; Marchant, 1916). In the four years he spent in this region, Wallace observed, described, designed, and collected specimens of different types of animals and plants. He also investigated the morphology, distribution, and habits of a wide variety of species, among them palm trees, butterflies, beetles, monkeys, and different types of birds and fishes. Through his studies, Wallace emerged as an expert observer, collector, and researcher (Carmo, 2011).

Wallace returned to England in July 1852. Due to custom problems in Belém, only two earlier shipments of specimens collected with Bates had been forwarded onward, July of 1848 and July of 1849. All the material he collected alone had accumulated there at the port. So he loaded them on the ship with him. Once at sea, however, the ship caught fire and burned completely. Wallace managed to escape alive, along with the crew, but he lost two years' worth of valuable collections. He had time only to carry his diary and a few drawings of fishes and palm trees to the lifeboat (Fichman, 2004; Marchant, 1916; Wallace, 1905; recently, the fish drawings have been published in an outstanding edition by Ragazzo, 2002).

In the months after his return to England, Wallace devoted himself to the publication of his Amazonian studies. This was possible because he had sent letters to family and friends while still in the Amazon, had saved his diary from the ship's fire, and still recalled details from his experience. Six articles were published by the Zoological Society of London, the Entomological Society of London, and the Royal Geographical Society. Wallace discussed the habits, geographical distribution, and morphological characteristics of butterflies, fishes, and monkeys along the banks of Amazonian rivers. He also published two further books in 1853. One contained a description of his journey, *A Narrative of Travels on the Amazon and Rio Negro, with an account of the native tribes, and observations on the climate, geology, and natural history of the Amazon valley* (a second edition appeared in 1889). Today, it is because of this publication that we know about the Amazon during this period, from its physical geography and geology to the habits of the indigenous tribes that Wallace encountered (Camerine, 1996).

Wallace's travel narrative also provides accurate information about his native collaborators, who assisted in his studies and collections. As was the case with many other foreign naturalists who visited Brazil in the nineteenth century, Wallace relied significantly on contributions from local cultures in developing "his" scientific knowledge of the Amazon. Like others, Wallace also used "networks formed by interaction with the communities living in the areas visited." The locals not only facilitated the fieldwork for foreign scholars, but even made it altogether possible (Moreira, 2002, p 41; Martins, 2011).

The local communities were composed of members of different indigenous groups, “caboclos” (white and Indian mestizos), Portuguese settlers, and slaves. They guaranteed logistical support and infrastructure by providing food, transportation, and other material resources. They also worked as guides, carriers, rowers, interpreters, assistants contacting indigenous groups, and teaching their languages. On other occasions, they contributed knowledge about hunting, fishing, and agricultural crops; conservation of collected materials; protection against harmful insects; animals and plants as food sources; and the species identity and geographical distribution of different plants and animals. Thus, the native knowledge of these residents, with their long experience in the forest, was then reorganized and incorporated into European scientific knowledge (Moreira, 2002, p. 42).

Wallace’s interest in palm trees also led him to write a small book entitled *Palm Trees of the Amazon and Their Uses*, which included the drawings saved from the fire and other information he remembered. The book brings together original drawings of forty-eight species of palms found along the Rio Negro and the Amazon River, between the years 1848 and 1852. In addition to botanical details and the geographical distribution of different species of palms, Wallace also described the many uses of their leaves, fruits, seeds, stems, and roots by local indigenous and settler populations (Wallace, 1853).

For students in Brazil, where this case was developed, the occurrence of palms in gardens and in urban and natural landscapes is familiar. Students in southern states in the U.S. can also readily appreciate Wallace’s work, although applied to different palm species. In other regions, one can easily highlight the analogous role of local tree species and their historical uses by native cultures, such as wood for building; bark from birches; edible acorns and nuts from oaks, walnuts, chestnuts, buckeyes, and pines; fruits; fuel; medicines; and so forth.

The Teaching Learning Sequence

The development of the teaching learning sequence (TLS) is based mainly on the work of Martine Méheut and Dimitris Psillos (2004, 2005). For them, a distinctive feature of the teaching learning sequence should be the possibility of research based on the analysis of the students’ learning process (rather than its products). Both scientific and student perspectives matter when faced with specific content to be taught, on the one hand, and learned, on the other.

The guiding biological theme (conceptual content) of the TLS is phylogeny. This is organized through the historical framework of Wallace’s case, using his original data and drawings from 13 of the 48 palm species that he studied (Brooks, 1984; Camerine, 1996; Fichman, 2004; Marchant, 1916; Martins, 2011; Moreira, 2002; Wallace, 1843, 1849, 1879, 1905). The specific historical and scientific content of the classes were:

a) Wallace’s work on the palm trees of the Amazon in the context of scientific expeditions in 19th-century Brazil;
b) observation and description of palm trees;
c) classification and identification, using dichotomous keys;
d) taxonomy, addressing taxonomic criteria by comparing classification based solely on similarities and differences and classification based foremost on evolutionary relationships; and
e) principles and procedures for phylogenetic classification and the construction of phylogenetic trees from some of the palm trees studied by Wallace .

The lessons are targeted for grade 11, ages 16-17, and designed for 8 successive class periods of 50 minutes each. All the required teaching materials (lecture notes, images, student handouts and guides) are available online at http://shipseducation.net/modules/biol.wallace.htm.

On the first day, students are introduced to Wallace and his voyage through an illustrated lecture (as described above). Students also map his travels (Figure 1). On the second day, students take a field trip on campus to observe palm trees, as Wallace did, draw them, and label the key parts of the plant (Figure 2). The next day they compare their own work to Wallace’s and to modern descriptions, and consider, for example, the relative roles of diagrams and photos (Figure 3). On Day 4, students build simple taxonomic models of the palms, based on their informal impressions of similarities and differences. The following day, they use dichotomous trees to identify and classify the palms based on contemporary classifications. Day 6 is a more conventional lecture on evolution and the principles of phylogeny. This leads to 2 days in which the students construct a phylogenetic matrix on a computer spreadsheet and then use the results to construct a phylogeny (Figure 4), which they then compare with their earlier classifications based on more traditional methods. The unit ends with a short historical reflection on following in Wallace’s footsteps, along with an explicit review and commentary on the scientific practices.

The overall plan of the learning sequence, including the scientific concepts and scientific practices addressed, is summarized in Table 1. The history, along with parallel student activities, enabled us to integrate scientific concepts with scientific practices and crosscutting concepts (summarized again in Table 2 according to the framework of the NGSS). It is interesting to note that explanation was not one of Wallace's objectives on this occasion. His goal was merely to document observations and collect specimens, an essential step in science which only later led to concepts on evolution by natural selection.

Conclusions

The teaching learning sequence produced several positive effects, especially in terms of motivation for learning. Students were highly involved in almost all activities. Only in one class it was observed a slightly lesser involvement, to conduct the identification of palm trees with dichotomous key (class 5). The lack of interest seems to have been due to the difficulty of the activity that required prior knowledge about the nomenclature of plant structures, which had not been previously taught, such as bract, trunk, infructescence, among others

A questionnaire about students' motivation for learning biology (Tuan et al., 2005) was applied in two moments of the teaching learning sequence (before the first class and the end of the eighth and final class). Students were very encouraged by the learning environment. About 70% of students agreed that they felt motivated to participate in the biology class because different teaching strategies were used.

The participation of students during classes was significant. They asked a lot about the naturalistic studies of Wallace, comparing what he did in the nineteenth century with the legal restrictions on gathering organisms in the wild nowadays in Brazil.

Teacher: *Then they collected, but collected two [exemplars] of everything they found in Brazil!*
Student A: *Why?!*
Teacher: *Why?! To send to London and sell...*
Student B: *Male and female?*
Student C: *But they were allowed to do so?! Come here and collect species???*
Teacher: *Yes, they could!*
Student C: *And the IBAMA* [Brazilian Institute of Environment and Renewable Natural Resources]*?!?*
Teacher: *There was nothing like that, right folks?!* [lots of laughs in general].
Teacher: *We are talking about the nineteenth century, the mid-nineteenth century and that was it, their role. Many naturalists, including Darwin, made a trip around the world collecting everything. Collecting, collecting, collecting ... That was the key! Today there are many laws that control the gathering of organisms, but [what they did] was essential in the knowledge that we have today.*

The students were very curious about the practical aspects of Wallace's travel by boat and the long time to reach the Amazon. They discussed the travel through the rivers of the region, comparing them to the facilities and means of transport nowadays>.

Teacher: *Wallace was 25 [years old] and Bates was 23. In their prime! They came to Belém, at the time, the city of Para. It took a month to get here to Brazil from England!*
Student D: *Aff! A month??? How long!!!*
Student E: *By car?!*
Student C: *By car????!!! Your dumb, are you crazy????*
Students [in general]: *My God!!* [lots of laughs in class].
Student A: *By boat!! And by small boats in the rivers!!*

Students expressed great admiration for the way of life and scientific achievements of Wallace, when compared with the highly privileged economic status of Charles Darwin.

Teacher: *(...) Darwin, he is best known, and often the theory of natural selection is only assigned to him. Among biologists it is much more common to hear about the theory of Darwin and Wallace. Darwin and Wallace! But it is not like that for the general public, no! Wallace never existed ...*
Students [in general]: *Poor guy! How horrible!*
Teacher: *Yes, all that work for nothing! Here we have some Wallace pictures for you. He lived in the nineteenth century, as well as Darwin. He was 13 years younger than Darwin and both Wallace and Darwin were proponents of the theory of natural selection. Now, why did Darwin become famous?*

Student A: *This is not fair...*

The students were very impressed with the drawings prepared by Wallace. In carrying out the various activities, they preferred drawings to modern photos.

Teacher: *Let's show you several species of palm trees. This one is an example.*

Student E: *Wow! He can draw pretty well!*

Student C: *Wow, the guy was ninja in the drawings!! [lots of laughs around the room].*

Student A: *Guys, how beautiful!!*

In class 2 - Observing Like a Naturalist - students exhibited great pleasure in drawing palm trees found in the area surrounding the school. Students felt very much like a naturalist and identified with Wallace. Undertaking an activity similar to Wallace increased their self-esteem.

The present study shows that teaching phylogenetic classification can be motivated by historical contexts and exemplars. Wallace's journey in the Amazon and his studies of the palms trees turned out to be a good way to promote learning of evolutionary theory and classification, while also teaching students about scientific practices, or aspects of how science works. Our experience illustrates more generally how drawing on investigations of nature from the past can contribute to a more complete science education, as profiled in new curriculum standards.

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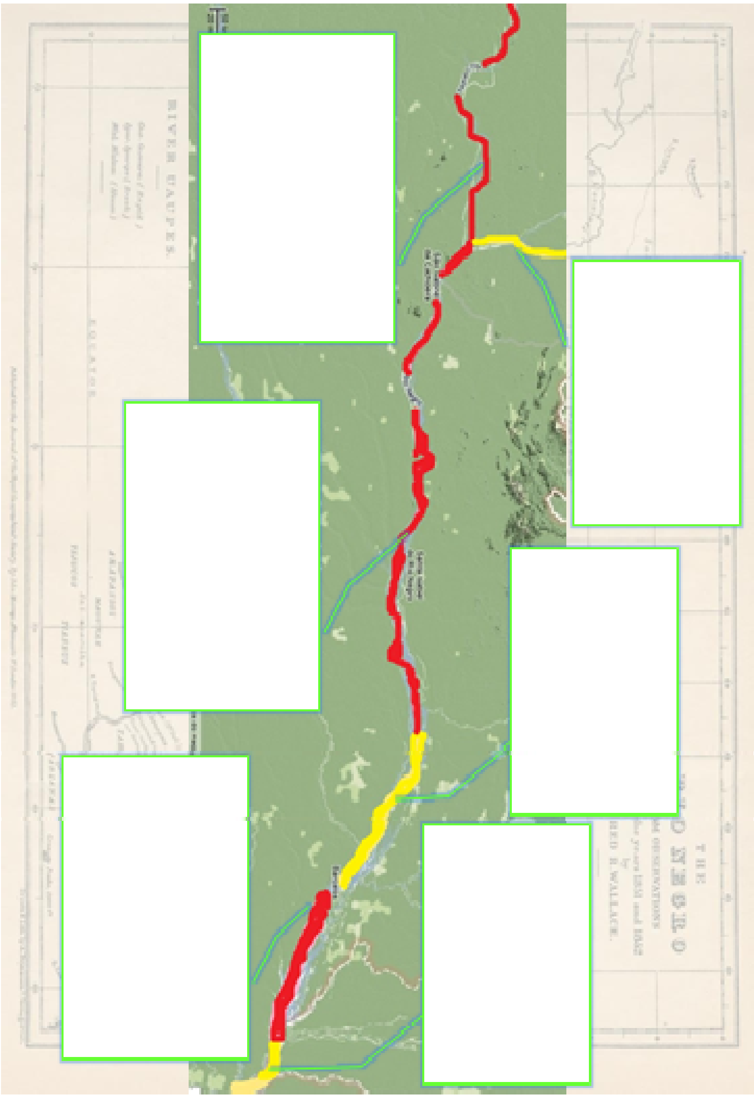

Figure1. Map of Amazonian rivers visited by Wallance.

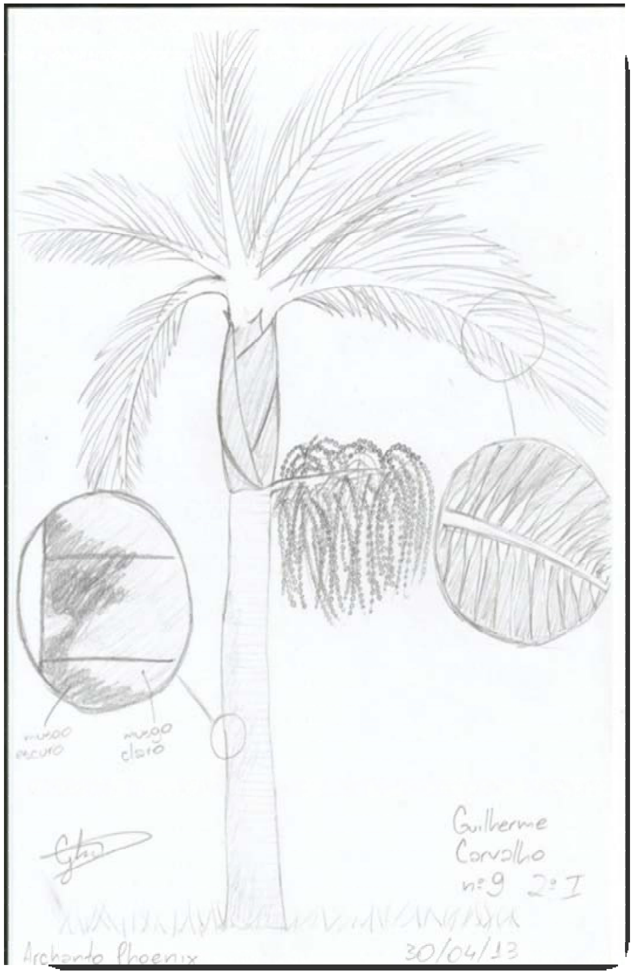

Figure 2. Drawing plant structures of a palm made by student

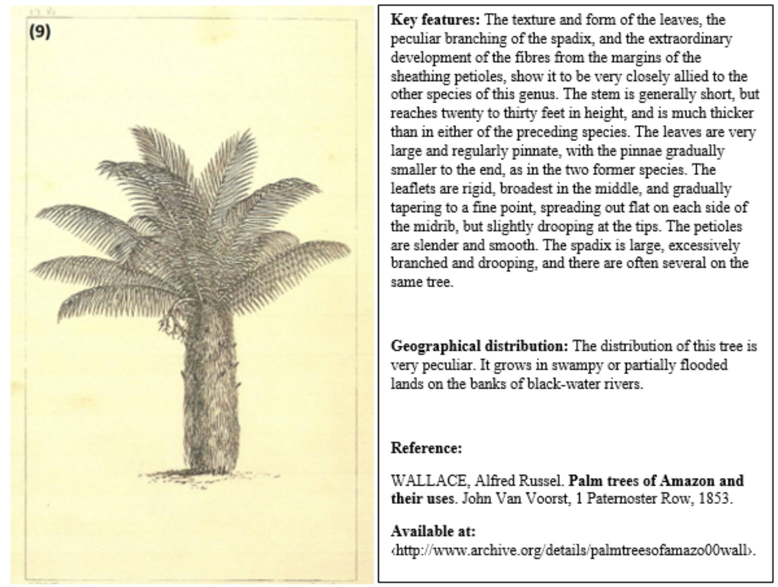

Figure 3. Cards palm images (Wallace´s drawing and photo of the current literature)

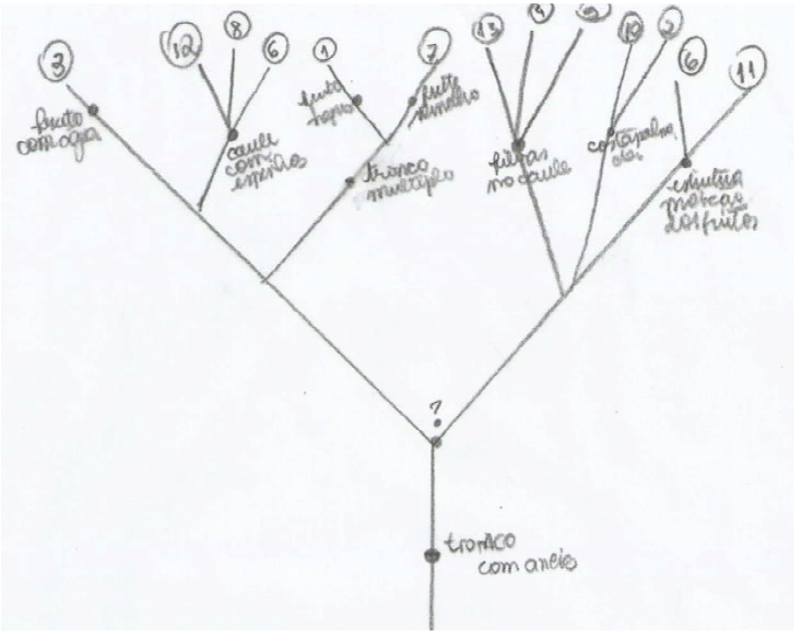

Figure 4. Phylogenetic tree elaborated by student

Table 1. Summary of daily learning objectives

Day	**Scientific Concepts**	**Scientific Practices & Crosscutting Concepts**
1. Traveling with Wallace	Geography Natural history	Funding research Planning logistics of field expeditions Collecting & preserving specimens Collaborating with other experts Reading maps and plotting data
2. Observing like a naturalist	Parts of a plant	Observing and describing distinctions Recording visual observations (drawing)
3. Assessing Wallace's description of palm trees	Geographical distribution and habitats	Comparing and assessing data
4. Classifying palms observed by Wallace	Levels of taxonomy and taxonomic criteria	Building simple models
5. Using a dichotomoous key to identify palm trees	Plant morphology and nomenclature	Applying existing knowledge to interpret observations
6. Understanding evolutionary phylogeny	Phylogenetic principles	Developing background knowledge
7. Building a phylogenetic matrix	Phylogenetic procedures and plant morphological traits	Using computational methods
8. Constructing a phylogenetic tree of palm trees	Comparison of phylogenetic and traditional taxonomy	Using computational methods Comparing & assessing alternative models

Table 2. NGSS scientific practices addressed in the Wallace case.

1. Asking questions

- [Wallace] Deciding to explore the Amazon (motivation)
- [Wallace] Securing funding for research - through sales of specimens.

2. Developing and using models

- Construct taxonomic models of palms.
- Compare and assess traditional and computer-generated taxonomies

3. Planning and carrying out investigations

- [Wallace & Bates] Planning voyage; organizing observational records (locations of species, behaviors, uses of palms)
- [Wallace & Bates] Collecting specimens -- fixing, preserving, storing.
- [Wallace] Arranging logistics to send specimens home (including customs!).
- [Wallace] collaborating with local experts

4. Analyzing and interpreting data

- Reading maps and plotting geographical data
- Comparing Wallace's drawings and data to modern photographs and data

5. Using mathematics and computational thinking

- Converting data into a phylogenetic matrix (data table) for analysis
- Using a computer program to generate phylogenetic tree

6. Constructing explanations

7. Engaging in argument from evidence

- Defending taxonomies based on similarites in data

8. Obtaining, evaluating, and communicating information

- Drawing and labeling palm trees to identify parts
- [Wallace] correspondending with Stevens, colleagues & family
- [Wallace] Documenting and clearly communicating morphology of tress (drawing)
- [Wallace] Writing and publishing investigative findings