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Be a Paleoanthropologist for a Day!

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The subject of human evolution is rarely taught with a lab, which leaves many high school students without a solid "grasp" of the subject. To fill this gap, this inquiry-based lab has students empirically measure three variables of hominin evolution. Hominin skull in hand, students take measurements on bipedality, prognathism/orthognathism, and encephalization. The lab's learning path of facts to data, information to knowledge, and knowledge to acceptance empowers students to themselves execute part of the science that underpins our understanding of hominin evolution. The result is a formative experience with a high degree of retention and epistemic depth.

Keywords: Human evolution, hominin evolution, paleoanthropology, inquiry-based learning, cranial capacity, bipedalism, maxillary angle

Introduction

Observing the finches of the Galápagos, Charles Darwin noted that their beaks were variously shaped — some broad, others elongated, still others small and short. He surmised that in spite of these differences, the island's finches were close cousins: "*Seeing this gradation and diversity of structure in one small, intimately related group of birds*," he wrote in The Voyage of the Beagle, "*one might really fancy that from an original paucity of birds in this archipelago, one species had been taken and modified for different ends*."

The question *'Where do we come from?'* is timeless. Today, the field of Paleoanthropology provides more answers than ever before, which, through an engaging lab, can be conveyed in your classroom. Students gain an appreciation for the morphological diversity and similarities of our hominin ancestors, and, like Darwin, may conclude that "*one species had been taken and modified for different ends*" and they are looking at close cousins.

In circa two classroom hours, students are able to empirically grasp the three main adaptations that became hallmarks of hominin evolution by taking measurements on the skull replicas: bipedality (determined by the position of the foramen magnum), prognathism/orthognathism (determined by the slope of the maxilla), and encephalization (determined by the shape and volume of the neurocranium). More specifically, these three variables involve the following measurements:

1. The *opisthion index* is a major indicator of bipedality, and the students must calculate it from two different measurements – the full length of skull and the distance of the foramen magnum to the rear of the skull (Russo, 2013). This index reveals the positioning of the meeting point of the spine and the cranium, where a larger number indicates a more centrally positioned spine, such as is found in an upright human.
2. The *maxillary angle* requires no additional calculations, but it does require the student to connect the data to qualitative features. The relative degree of prognathism or orthognathism can be measured from the angle of the upper jaw relative to the nose and cheekbones (van der Merwel et al., 2008). A more acute angle indicates more protrusion (prognathism), and this was also associated with other important features such as large teeth and robust lower jaws, implying specific dietary adaptations.
3. *The cranial capacity* is measured through a predictive volume measure (due to the fact that many of the skull fossils/replicas do not feature a cranial endocast). Students are asked to measure the cube around the cranium using calipers and then transform that data to the volume of the sphere within the box. Students can then statistically grasp what their eyes can see: an expansion of cranial capacity – encephalization – primarily within the genus *Homo* (Ruff et al., 1997).

After these measurements are taken, the question "why" the featured trait came about may be addressed, i.e. the morphological function of each of the three features: What are the evolutionary advantages and disadvantages of an upright posture (centering of the Foramen Magnum), a smaller jaw (maxillary orthognathism) and a bigger brain (cranial capacity)?

Thereafter, students suggest an approximate order of the hominin skulls, the age of the skulls is revealed and discussed. It then becomes apparent that the chronology of the three milestones of hominin evolution is: bipedalism, receding prognathism (increasing orthognathism), and finally, encephalization.

Lastly, the "how" questions may also be broached by investigating the interplay between traits, behavior and the environment. Cranial capacity growth, and the related brain size growth in *Homo*, was notably driven by a positive feedback loop with factors featuring cooperative behavior, diet quality and access, as well as cognitive abilities (Antón et al., 2012).

The hands-on format of the lab is accessible to the average high-school student. According to a cohort of teachers who witnessed the lab in action, most students were readily able to engage the lab's scientific process (Bayer et al., 2016). Furthermore, the interviewed teacher cohort unanimously agreed that the lab featuring hominin skull replicas and stimulating student inquiry was a pedagogically excellent method of delivering the subject of human evolution, and superior to the textbook-based pedagogy and content previously applied (see **APPENDIX B: Teacher Feedback**).

The lab's exciting and compelling pedagogy unlocks higher order thinking skills, effectively activating the cognitive, psychomotor and affected learning domains as defined in Bloom's taxonomy (Anderson et al, 1994). A tactile, hands-on approach is combined with inquiry-based learning.

As many biology teachers do not specifically have a physical anthropology or paleoanthropology background, the subject matter may be somewhat foreign at first. Therefore, we developed a detailed *Instructor Curriculum* to the instructor on how to effectively facilitate the lab (see **Notes for the Instructor**). Apart from familiarizing oneself with these course materials, there is virtually no set-up time required. Some teachers prefer the lab to precede the topic of evolution, others prefer to deliver it after the theory of evolution has been covered.

Student Outline
Be a Paleoanthropologist for a Day!

Handout #1: Introductory Questions

At the end of this inquiry-based lab – involving skull measurement exercises, discussions, and information presented by the instructor – you will be able to answer the following four basic questions. Keep these questions in mind, and when you think you know the answer, jot them down.

- What is Paleoanthropology?

- What kind of work does a paleoanthrolopologist perform?

- What is the difference between a fossil and a skull replica?

- On what continent do the majority of Hominin fossils originate?

- Place in chronological order these three milestones of hominin evolution:
  ( ) encephalization ( ) bidpedalism ( ) prognathism

- What are some characteristics that make the genus *Australopithecus* different from *Homo*?

- Where on the planet did *Homo sapiens* first live?

- For approximately how many years have *Homo sapiens* inhabited our planet ? __________________

Handout #2: Measurement Notes

In the course of the skull measurement exercises, take notes on the following three questions per feature being measured.

Feature	**How do you measure it?**	**How is it physically apparent in each specie?**	**What advantage did this trait likely provide?**
1. Position of foramen magnum			
2. Degree of prognathism			
3. Size of cranial capacity			

Handout #3: Discussion Notes

In the course of the lab, the following questions will be discussed in the classroom. Please note the answer.

Bipedalism

Refer to graph of data collected on position of the foramen magnum:

- Which of these hominins was potentially not bipedal?
- Based on the opisthion indexes, which hominin skulls are most similar to the *Homo sapiens* skull?

Maxillary Prognathism

Refer to graph of data collected on maxillary prognathism:

- Which genus had the largest maxillary prognathism?
- What other traits correspond with those species which have protruding upper jaws?

Cranial Capacity

Refer to graph of data collected on cranial capacity:

- Compare the size and shape of the cranial vault in the Australopithecus species with that of the *Homo* species. How are they different?
- Which species had the largest cranial capacity?
- How does the cranial vault vary in *Homo sapiens* compared to other members of *Homo*?

Group Discussion

- What are the advantages of bipedalism?
- What dietary adaptations led to the transition from robust *Australipithecus* to gracile *Homo*?
- What brain processes occur in the frontal lobe, the largest area of the modern human brain?

Handout #4: Information about the Fossil Discoveries

Table 1. Hominin species, discoverer, country and year of discovery**.**

Hominin Species	***Discoverer / Anthropologist***	***Country***	***Discovery Year***
Ardipithecus ramidus	Tim White and associates	Afar region of Ethiopia	1994
*Australopithecus aethiopicus**	Camille Arambourg and Yves Coppens	southern Ethiopia, west of the Omo River	1967
Australopithecus afarensis ("Lucy")	Donald Johanson	Hadar, Ethiopia	1974
Australopithecus africanus ("Mrs. Ples")	Robert Broom and John Robinson	Sterkfontein, South Africa	1947
Australopithecus boisei ("Nutcracker Man")*	Mary Leakey	Olduvai Gorge, Tanzania	1959
Homo erectus ("Peking Man")	Various	Zhoukoudian (Chou K'ou-tien) near Beijing, China	1923-27
Homo habilis ("handy man")	discovered by Kamoya Kimeu, described by Richard Leakey	Koobi Fora, Kenya	1973
Homo heidelbergensis ("Rhodesian Man")	discovered by Tom Zwigelaar (miner), described by Arthur Woodward	Kabwe, Zambia (formerly Rhodesia)	1921
Homo neanderthalensis ("La Ferrassie 1")	described by Louis Capitan and Denis Peyrony	France	1909
Homo sapiens (earliest)	Jean-Jacques Hublin and associates	Jebel Irhoud, Morocco	2004-2017
Sahelanthropus tchadensis ("Chad")	Michael Brunet	Chad	2001

Source: PBS, Evolution. http://www.pbs.org/wgbh/evolution/

** Some anthropologists use the genus "Paranthropus" instead of "Australopithecus" to describe these skulls.*

Handout #5: Measurement Worksheet

Upon taking your measurement, note the value you obtained in this worksheet.

Table 2. Measurement worksheet of relative bipedalism, prognathism, and cranial capacity.

	Bipedalism			Prognathism	Cranial capacity (CC)			
Name	**Opisthocranion-opisthion distance (cm) (A)**	**Opisthocranion-orale distance (cm) (B)**	**Opisthion index (A/B)*100**	**Maxillary angle (°)**	**Height (H)**	**Width (W)**	**Length (L)**	**CC (cm^3) (LxWxH)* .5236**
Ardipithecus ramidus								
Australopithecus aethiopicus								
Australopithecus afarensis								
Australopithecus africanus								
Australopithecus boisei								
Homo erectus								
Homo habilis								
Homo heidelbergensis								
Homo neanderthalensis								
Homo sapiens								
Sahelanthropus tchadensis								

Handout #5: Measurement Aid

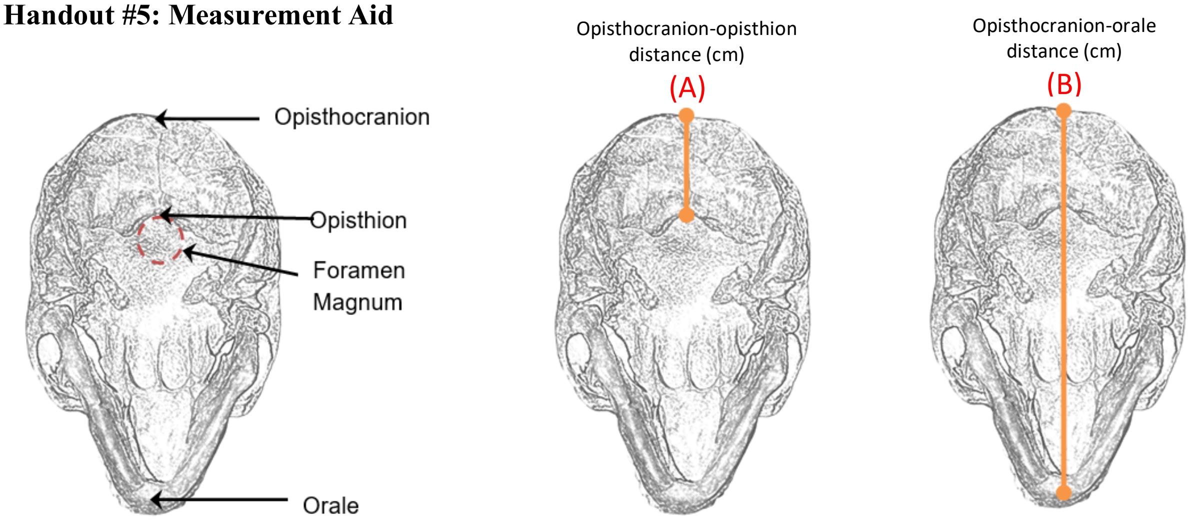

Figure 1. Foramen magnum measurement.

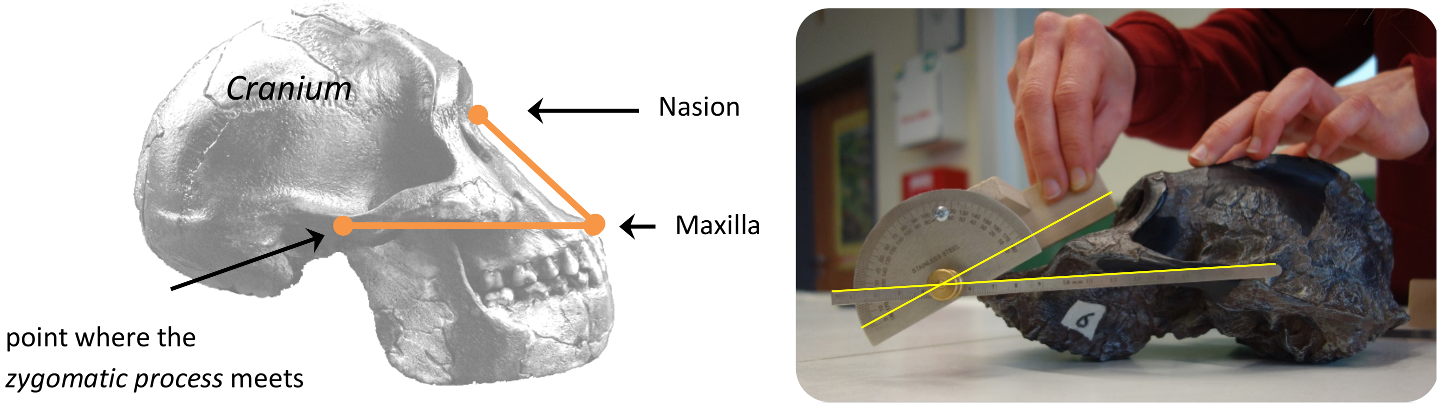

Figure 2. Maxillary prognathism measurement.

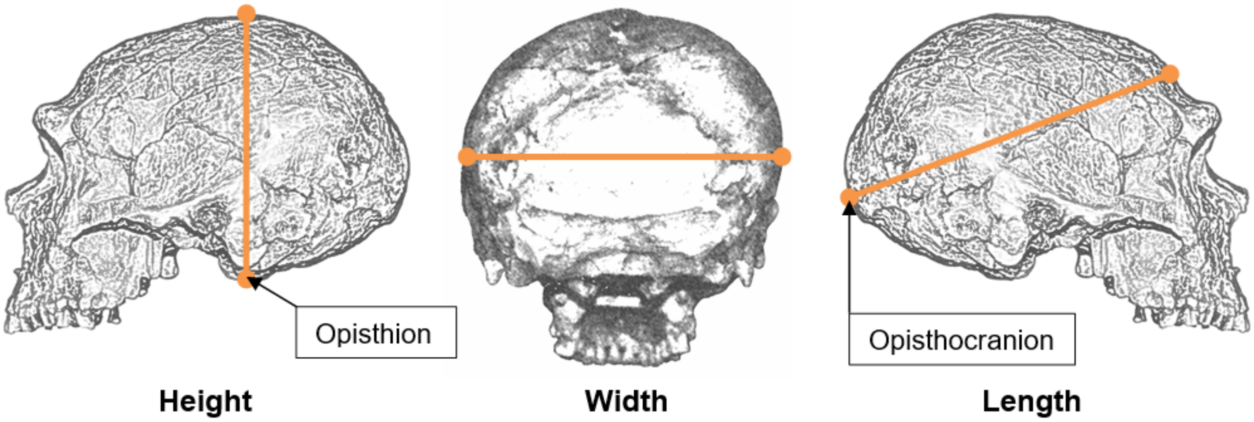

Figure 3. Cranial capacity measurement.

Handout #6: Operational Definitions of Key Terms

Table 3. Operational definitions of key terms.

Terms	***Operational Definitions***
Anterior	Situated before or toward the front
Arboreal	Living in trees
Argon-argon	Argon-argon (Ar/Ar) dating is a relative dating method which utilizes the half-life of argon isotopes
Bipedal	Walking on two legs
Caliper	An instrument used to measure the distance between two opposing sides of an object
Canine tooth	A deep-rooted tooth, lateral to the incisors, that is used by most animals for grasping and piercing food
Cc	cubic centimeters
Cm	Centimeters
Cranial capacity	The interior volume of the cranium, where the brain is housed
Cranium	The portion of the skull that does not include the mandible (lower jaw)
Encephalization	An increasing cranial capacity over generations
Evolution / Evolve	Change over generations in one or more inherited traits found in populations of organisms. There are chiefly four drivers behind evolution: (1) natural selection, (2) genetic drift, (3) mutation, and (4) gene flow.
Foramen magnum	A hole in the base of the skull through which the spinal cord exits
Gracile	Gracile, in general, connotes something slender, less robust. Gracile hominin skulls are characterized by orthognathism and less pronounced dentition and cranial features as robust hominins.
Hominid	A member of a group of primates that includes orangutans, gorillas, chimps, and humans (also referred to as the great apes)
Hominin	A member of the tribe Hominini and evolutionary trend that led to humans, including the animals most closely related to *Homo sapiens*, as opposed to chimpanzees and bonobos.
Hominini	The taxonomic tribe comprising the tree of hominids resulting in humans, evolving separately from chimpanzees
Index	A number (as a ratio) derived from a series of observations and used as a composite indicator
Mandible	A bone that forms the lower jaw
Mastication	The process of chewing
Maxilla	A paired bone that forms the upper jaw

Morphology	A branch of bioscience dealing with the study of the form and structure of organisms and their specific structural features
mtDNA	mitochondrial DNA
Orbit	The two hollow eye sockets in the cranium that house the eyeball and assist musculature
Orthognathic	Derived from the Greek words *orthos* (straight) and *gnathos* (jaw) to denote a jaw that does not project forward resulting in a (near) vertical face
Palate	The roof of the mouth
Physiology	The science of the function of living systems and their features
Phylogenetic tree	A branching diagram which shows relations between organisms based upon similarities and differences in their physical or genetic characteristics – an evolutionary tree of life
Posterior	Situated behind
Prognathism	Derived from the Greek words *pro* (forward) and *gnathos* (jaw) to denote a protruding upper jaw (Maxilla)
Protractor	An instrument used to measure an angle or a circle
Quadrupeds	An animal that walks on all fours
Radiocarbon dating	A leading dating technique measuring the decay of carbon isotopes used on fossils from 40,000 years ago to 1945
Robust	Robust hominins sport heftier, thicker skulls. A robust hominin skull is characterized by large grinding molars, widely flared zygomatic arches, and a large sagittal crest.
Sagittal crest	A protruding bone formation sitting above the sagittal suture which function is to anchor the temporalis muscle for mastication and to reinforce the cranium.
Skull	The bones that make up the head of an animal, including the cranium and mandible (lower jaw)
Stratigraphy	A branch of geology which studies rock layers and layering (stratification)
Superposition (Law of)	Sedimentary layers are deposited in a time sequence, with the oldest on the bottom and the youngest on the top.
Zygomatic process	The bone connecting the cheek bone and the cranium

Handout #7: Time Period Species Lived

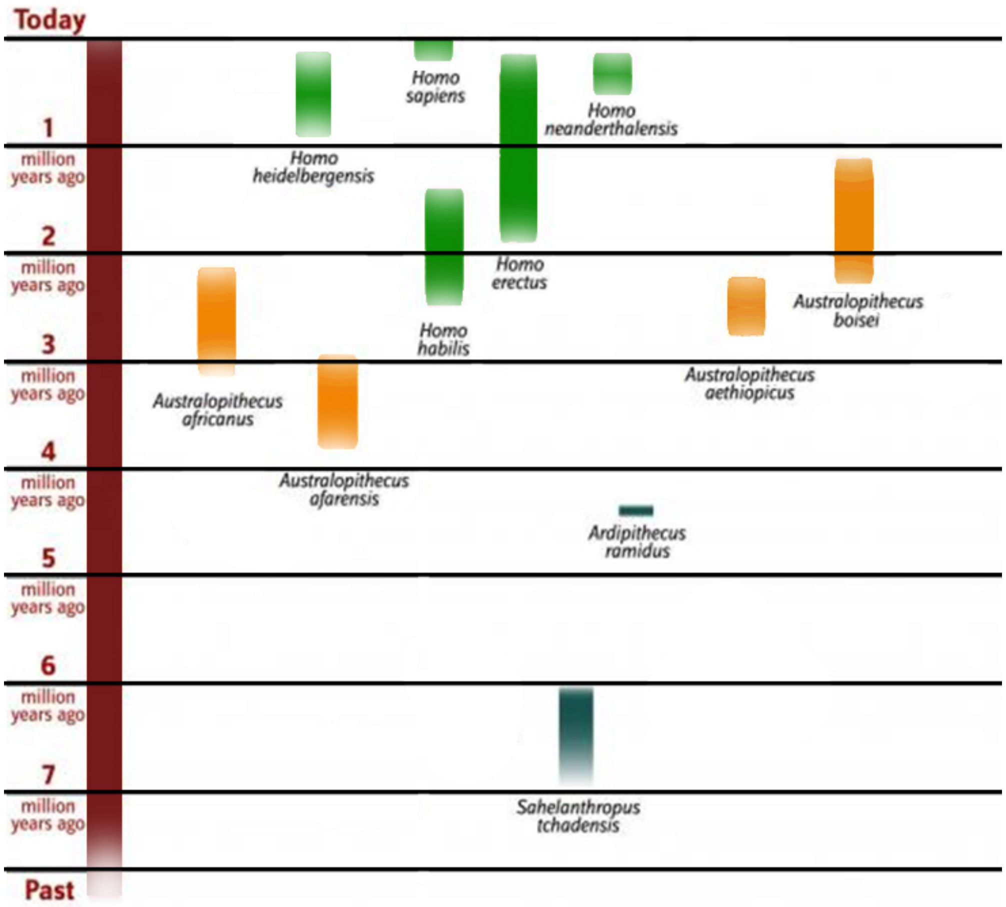

Figure 4. Hominin phylogenetic tree and ages.

Table 4. Time period species lived.

Age (million years)	**Hominin Species**
0.3 to present	*Homo sapiens*
0.6. to 0.3	*Homo neanderthalensis*
0.6 to 0.2	*Homo heidelbergensis*
1.8 to 0.3	*Homo erectus*
2.3 to 1.6	*Homo habilis*
2.3 to 1.4	*Australopithecus boisei*
2.7 to 2.3	*Australopithecus aethiopicus*
3 to 2	*Australopithecus africanus*
3.6 to 2.9	*Australopithecus afarensis*
4.4	*Ardipithecus ramidus*
7 to 6	*Sahelanthropus tchadensis*

Source: Smithsonian Institute

Materials

The following equipment is needed for the implementation of the lab:

1. *Measurement tools*: 11 protractors (bevel angle gauge, customized) and 11 calipers (long jaw).
2. *Set of 11 hominin skulls*: *Sahelanthropus tchadensis, Ardipithecus ramidus, Australopithecus afarensis, Australopithecus africanus, Australopithecus aethiopicus, Australopithecus boisei, Homo habilis, Homo erectus, Homo heidelbergensis, Homo neanderthalensis, Homo sapiens.*
3. *Google/Excel Spreadsheet:* The lab's *Google/Excel Spreadsheet* allows instant graphing of data collected by students and also compares the student data with the curriculum data. The *Google/Excel Spreadsheet* can be downloaded at: http://www.ancientancestors.org/.

Vendor information for lab materials is noted in Appendix A.

Notes for the Instructor

As we regularly update this lab's *Instructor Curriculum* based on the latest state of the literature and scientific discourse, we kindly request you to download, free of charge, the most up-to-date version at: http://www.ancientancestors.org/. Given that many biology teachers do not specifically have a physical anthropology or paleoanthropology background, the detailed *Instructor Curriculum* serves as a step-by-step guide for the lab's implementation. The *Instructor Curriculum* also includes student handouts. A basic, 10-step procedure is suggested:

1. Place a caliper and a protractor at each station (11);
2. Divide class into groups and assign station;
3. Introduce field of paleoanthropology and the skull replicas, and provide Handouts #1 – #6 to students (see Student Outline);
4. Demo measurement with *Homo sapiens*;
5. Have students measure skull replicas, record the measurement data, and perform the calculations on the worksheet;
6. Have students rotate until they have visited each station or until the time limit has been reached;
7. Collate the data and together analyze the graphed data;
8. Discuss morphological function of each main analyzed trait;
9. Have students propose a phylogenetic tree and only then reveal the actual dated order (pass out Handout #7 – see Student Outline);
10. Address the "how" questions by investigating the interplay between traits, behavior and the environment, e.g. how the brain in the genus *Homo* likely increased, and conclude lab.

For each of these steps, the *Instructor Curriculum* provides suggested discussion topics and material that the instructor may weave into the classroom dialectic.

The most salient topics meriting discussion in the course of the lab's implantation are structured in the following five sections.

1. Data Collection

The explanations of three principle skull-based measurements, i.e. their measurement and corresponding graphs, are replicated from the *Instructor Curriculum* in the following discussion. The *Instructor Curriculum* further pro-actively addresses common measurement issues relating to the laboratory's data collection stage.

Measurement 1: Foramen Magnum

Guiding question: How does one determine whether a species was bipedal?

A. Introduction

Bipedalism is a unique trait to hominins and clearly sets us apart from other modern-day mammals. It is certain that early hominins were walking upright as evidenced at the Laetoli site, a well-preserved series of footprints covered in volcanic ash that is well dated to 3.6 million years ago (White, 1980).

To compare skulls, scientists use measurements of certain features to calculate indexes. An *index* is a ratio of one measurement in relation to another. In this case, we will be measuring the distance from the foramen magnum to the opisthocranion, and then compare it to the total skull length. Students will see the trend of the foramen magnum centering on the skull – a clear adaptation for bipedalism.

The index for measuring hominin skulls' bipedality is known as the *opisthion index*. The opisthion is the rear most point of the foramen magnum. This index indicates the distance of the foramen magnum from the rearmost point of the cranium relative to the total length of the cranium (see *Figure 1* in the Student Outline).

An *opisthion index* value greater than 15 means that the *foramen magnum* is situated close to the center of the *cranium*. This position is found in species that stand upright and demonstrates bipedalism. An *opisthion index* less than 15 means the *foramen magnum* is situated more in the rear of the *cranium*. This position is found in species that walk on their knuckles or on all four legs (Russo, 2013).

B. Measurement

To determine the *opisthion index*, follow the steps below and record the value in Handout #5: Measurement Worksheet.

- Position the skull so the underside is facing up and the upper jaw line is parallel to the lab desk.
- Using a ruler, measure the distance from the opisthocranion to the opisthion, as shown on the middle skull on *Figure 1*. Record the opisthocranion-opisthion distance in Handout #5.
- Measure from the opisthocranion to the orale, as shown in the right skull of *Figure 1*. Record the opisthocranion-orale distance in Handout #5.
- To calculate the opisthion index, divide your first measurement by your second measurement, and multiply this number by 100 [**(A / B) x 100 = opisthion index**]. The answer should yield a value between 0 and 55.

Measurement 2: Maxillary Prognathism

Guiding Question: How do the jaws/mouths of the hominins compare?

A. Introduction

In this module, the degree of maxillary prognathism is measured using a custom protractor. The teeth and the bones around the mouth provide a great deal of information about both a species' diet and how it eats. This exercise concerns the maxilla*,* a two-bone fusion that forms the upper jaw. Take a moment to identify the maxilla and where the zygomatic process (cheekbone) meets the cranium. The *Australopithecus* genus is noted for having protruding faces (as in *A. aethiopicus*) and can be clearly contrasted with the relatively flat-faced *H. sapiens*.

Facial prognathism is the extent to which the face and jaws protrude forward when looking at the skull from the side. Orthognathic skulls protrude less while prognathic skulls protrude more. Prognathic skulls are marked by larger mandibles, and consequentially larger teeth. *Australopithecus boisei* is an excellent example with molars the size of cow's teeth (an appropriate hint when discussing the diet of *Australopiths* versus *Homo*).

B. Measurement

As shown in *Figure 2* in the Student Outline (and also illustrated in Figure 5), hold the skull sideways, align the upper end of the extension block with the nasion, the nasal depression between the orbital sockets, and the lower end with tip of the maxilla, right before the teeth emerge. The extension should be situated below the brow ridge and above the teeth.

Then, identify the socket point of the mandible and the cranium located right below the meeting point of the zygomatic process and the cranium. Rotate the protractor's arm such that it hovers over this point – the resulting angle (vertex) is the *maxillary angle*. Be sure that the students record the acute (smaller) angle for each skull in Handout #5.

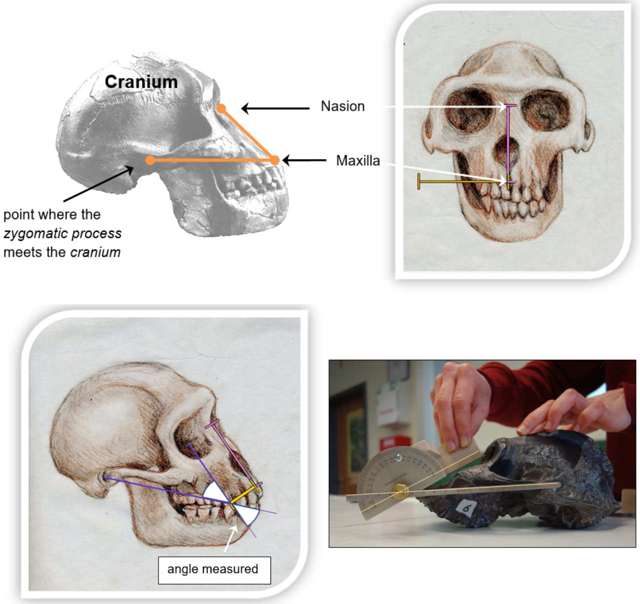

Figure 5. Maxillary angle measurement. Top left shows the side view, top right the frontal view. Bottom left indicates the angle being measured, which is identical to the inverse angle highlighted in white. Bottom right depicts how the protractor head is applied to the skull.

Measurement 3: Cranial Capacity

Guiding Question: How does the cranial capacity compare amongst hominins?

A. Introduction

The brain is housed inside the *cranium*. The interior volume of the cranium is called the *cranial capacity*. This module facilitates the measurement of the cranial capacity.

Brain size has a long history of analysis and measurement, sometimes washed with racism and sexism. Within the hominin lineage, brain expansion almost quadruples, from *S. tchadensis* to *H. neanderthalensis,* and this represents a very significant change. Students should be reminded that within *Homo sapiens,* cranial capacity varies widely: from 1200 cubic centimeters (cc) up to 2000cc.

B. Measurement

To estimate the cranial capacity of each skull, using the caliper measure the space of the part of the cranium that houses the brain, i.e. the neurocranium as illustrated in *Figure 3* of the Student Outline. Calculating the cranial capacity provides a rough numerical value for the size of the brain. Measure the maximum length by placing one end of a caliper on the most forward projecting point of the forehead (above the brow ridge) and the other end on the most posterior point at the back of the skull, i.e. the opisthocranion. The maximum **width** is determined with the calipers on the sides (temples) of the skull at the widest point (above the zygomatic process). The maximum **height** is measured by holding one arm of the caliper on the underside flush with the foramen magnum and the other arm at the top most point of the skull. Multiply these three measures and then multiply by 0.5236 [**(L x W x H) * 0.5236**].

2. Review of Measurements

Review the observed values in plenary with Handout #5 in hand, and present the graphs of the summarized results, pointing out differences between the data measured by the students and the data provided.

Another option is to have students type their data into a shared *Google/Excel Spreadsheet* (see Materials above), which allows the instant graphing of the student data collected and also a comparison between the student data with the curriculum data. A point concerning measurement accuracy can usually be made here.

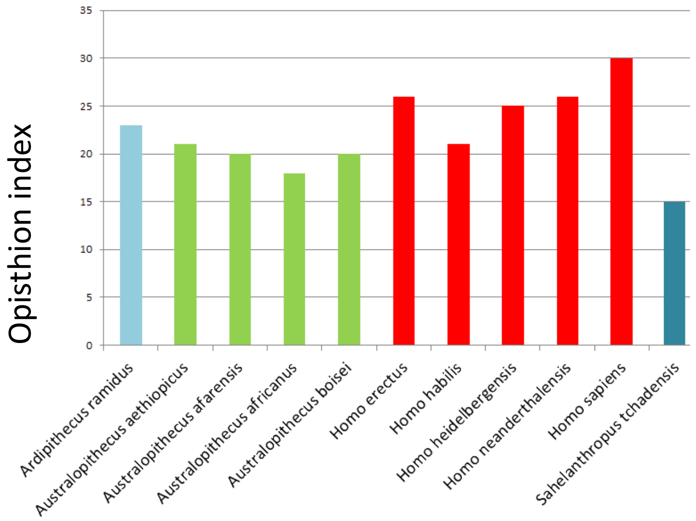

Figure 6. Opisthion index graph. The order of species in the graph is deliberately not chronological, merely grouped by genus. Data obainable through student measurements.

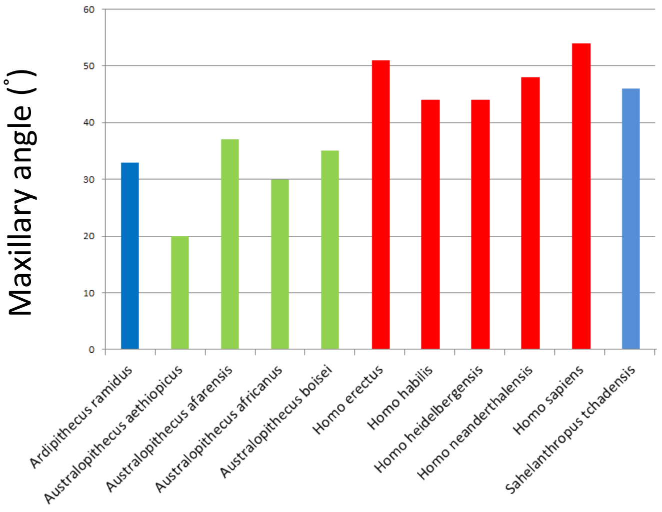

Figure 7. Maxillary angle graph. Data obainable through student measurements.

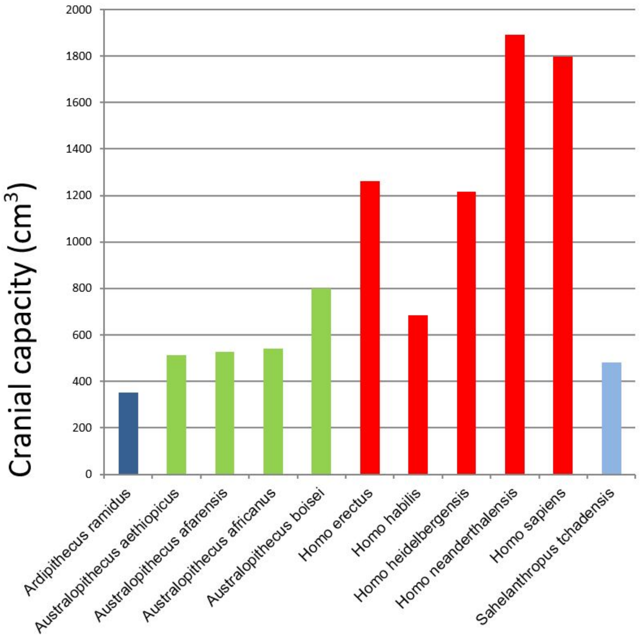

Figure 8. Cranial capacity graph. Data obainable through student measurements.

2. Morphological Function

Before advancing to the chronology-based discussions, it is helpful at this point to brainstorm with the students why these traits may hold evolutionary advantages or disadvantages. What are the advantages of upright posture, a smaller jaw, or a larger brain? An upright posture liberates the hands to experiment with tools and diets, and is more biomechanically efficient for long-distance marching and running. Orthognathism (smaller jaw) implies metabolic efficiency (less energy needed to build teeth and bones, as well as during active mastication). A larger brain means greater behavioral flexibility that aided our ancestors in establishing ecological niches in varied climate and landscape conditions, as well as the retention of complex tool traditions (to hunt prey and process food) were early distinctions. The investigation of fire and language was also critical, along with the ability to maintain a larger number of social relationships (*Dunbar's Number* is relevant here). To understand why the *Neanderthal* had a larger net brain, the encephalization quotient (EQ) is discussed. The lab's *Instructor Curriculum* provides further detail on all these points, drawing on the latest literature.

3. Fossil Dating Methods and DNA Evidence

Upon discussing the basic function of the measured features, an introduction of dating techniques is in order. A brief introduction to common dating methods (such as radiocarbon dating, argon-argon dating, etc.) conveys the point that there hard science behind these measurements. By extracting DNA from fossils – yes, under specific "storage" conditions it is possible to extract DNA from fossils – paleoanthropologists can genetically assess hominin lineages.

4. The Hominin Family Tree

A further inquiry-based activity involves the students working as a group around a central table. Ask the students to look at the collected data (Handout #5) and use the opisthion index, cranial capacity and the degree of maxillary prognathism to deduce the phylogenetic position and order of each fossil. Presented with all of the skulls, they are tasked with piecing together the tree, aided by a helpful suggestion or a question posed at the right time.

As students see the greater picture of the last 7 million years of hominin evolution, they can connect the data to our evolutionary history. Only after this exercise are students provided the phylogenetic tree and each fossil's age (Handout #7).

5. Chronology-based Discussion

A final discussion concludes the lab involving questions that require an understanding of the species' order:

- Which evolved first in hominins: bipedalism or large brains?
- Which evolved first in hominins: encephalization (big brains) or orthognathism (flat faces)?
- Why may the cranial capacity be getting larger in the *Homo* species?
- Why might a more pronounced facial prognathism give way to species with less prognathism?
- Which features distinguish *Homo*?
- Which hominin model won the evolutionary competition?

The curriculum answers these questions, in particular honing in on encephalization in the *Homo* genus. The first to make the leap above 600 cm^3 was "the toolmaker" *Homo habilis*. It walked more upright than the *australopiths*, each individual had more "friends," and behavior innovation included harvested animal bone marrow among other things.

Lastly, "how" questions may also be broached by investigating the interplay between traits, behavior and the environment. Brain size growth in *Homo* was notably driven by a positive feedback with factors featuring cooperative behavior, diet quality and access, as well as cognitive abilities (Antón et al., 2012). In sum, a smart, bipedal omnivore won Mother Nature's hominin survival contest – us.

Cited References

Anderson LW, Sosniak LA (1994). *Bloom's taxonomy: a forty-year retrospective*. Ninety-third yearbook of the National Society for the Study of Education, Pt.2., Chicago, IL., University of Chicago Press, 264 pages.

Antón SC, Snodgrass JJ (2012). *Origins and Evolution of Genus Homo New Perspectives*. Current Anthropology. Vol. 53, No. S6. Human Biology and the Origins of Homo. December 2012. The University of Chicago Press. http://www.jstor.org/stable/10.1086/667692

Bayer CN, Luberda M (2016). *Measure, Then Show: Grasping Human Evolution Through an Inquiry-Based, Data-driven Hominin Skulls Lab*. PLOS ONE. August 2016. https://doi.org/10.1371/journal.pone.0160054

Ruff C, Trinkaus E, Holliday T (1997). *Body mass and encephalization in Pleistocene Homo*. Nature. Vol. 387. May 1997. https://doi.org/10.1038/387173a0

Russo G, Kirk C (2013). *Foramen Magnum Position in Biped Mammals*. Journal of Human Evolution. Volume 65. Issue 6. November 2013. pp. 656-670. https://doi.org/10.1016/j.jhevol.2013.07.007

van der Merwel NJ, Masaoll FT, Bamford MK (2008). *Isotopic evidence for contrasting diets of early hominins Homo habilis and Australopithecus boisei of Tanzania*. South African Journal of Science. Vol.104 no.3-4. Pretoria, Mar/Apr 2008. http://www.scielo.org.za/pdf/sajs/v104n3-4/a1610404.pdf

White, T (1980). *Evolutionary Implications of Pliocene Hominid Footprints*. Science. Vol. 208 April 1980. pp 175-176. http://science.sciencemag.org/content/208/4440/175

Smithsonian Institute. *What does it mean to be Human?* Accessed June 2016. http://humanorigins.si.edu/evidence/human-fossils/species

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About the Author(s)

Dr. Chris Bayer spent 10 years of his early professional life working as a social scientist for Tulane University in Africa, which exposed him to many of the valuable sites and artifacts unearthed in the Great Rift Valley of East Africa. In 2013, he co-founded *Ancient Ancestors*, an initiative which develops inquiry-based educational labs and then study their impact on student's knowledge acquisition. Following the development of the *Be a Paleoanthropologist for a Day!* lab in the 2013/14 school year, he and anthropologist Michael Luberda piloted the lab in seven high schools located within the greater New Orleans area. Simultaneously, he studied the lab's effect on students, research which yielded a peer-reviewed paper. Dr. Bayer is currently developing a second human evolution lab and has partnered with the Leipzig University in Germany with the aim of conducting further scientific research on student impact.

Michael Luberda, Co-founder and Director of *Ancient Ancestors*, is a graduate of Tulane University in Anthropology with a focus in Archeology. Mr. Luberda's academic focus was in Human Prehistory and the rise of civilization which led to his field work through UCLA at the Chalcolithic site, Areni Cave, Armenia. In New Orleans he served as the Science Station Guy at the *Louisiana Arts and Science Museum.*

Appendix A
Vendor Information for Lab Materials

The following equipment is needed for the implementation of the lab.

Measurement Tools

a. 11 protractors (bevel angle gauge, customized):
The protractors are made bespoke to match each particular skull in the set (customizing this protractor: https://www.toolmarts.com/big-horn-19210-round-head-protractor-cum-depth-gauge). To assist schools in the fashioning of these protractors, we publicized a DIY guide.

b. 11 calipers (long jaw):
As for calipers, a regular x-ray caliper will do. Here, e.g., a vendor: http://www.shopmedvet.com/product/x-ray-measuring-caliper/x-ray-products-equipment-illuminators-filters-hangers

Set of 11 Hominin Skulls

Sahelanthropus tchadensis, Ardipithecus ramidus, Australopithecus afarensis, Australopithecus africanus, Australopithecus aethiopicus, Australopithecus boisei, Homo habilis, Homo erectus, Homo heidelbergensis, Homo neanderthalensis, Homo sapiens.

This lab is currently being updated to include *Homo naledi*, which will be integrated in the 2019 curriculum.

Bone Clones (https://boneclones.com/) and Skulls Unlimited (http://www.skullsunlimited.com/) are two vendors that manufacture resin skull replicas.

In the event a school is not able to procure the replica skulls and measurement tools, *Ancient Ancestors* has in select cases made available the full set of skulls and tools to high-school biology teachers – the so-called “Skulls on Tour.” Please contact us for more information.

Appendix B
Teacher Feedback

The following feedback was provided by high school teachers who either witnessed the *Be a Paleoanthropologist for a Day!* lab delivered to their biology class or themselves administered it.

"*This lab is fundamentally important for Biology. Evolution is the foundation of Biology and getting to have a hands on lab with these skulls helps to see the similarities for students. My students gained so much from this lab and truly enjoyed learning more about our past.*"

Anne Gill
AP Biology Teacher

"*Given the lack of exposure students have to the topic in school and the large amount of misinformation available, most of my AP Biology students have had little to no exposure to the topic of human evolution and come in with many misconceptions. I have now used these hands-on resources with my students for 2 years, and it has been transformational for them in their understanding of and excitement about human evolution. I am so grateful to this project for allowing me to introduce this to my students and I'm looking forward to their next steps.*"

Helen Snodgrass
Science Director, AP Biology Teacher

"Due to deeply embedded cultural ideas, holding the evidence in their hands helped a lot of them. The hands-on experience with fossil casts convinced them, and even those still in disagreement may eventually come around."

Jessica LeBlanc, M.Ed.
Biology I, Biology II, Anatomy & Physiology

"There is definitely a deeper and longer-lasting understanding observable with this class. They now understand for life! For those on the fence told themselves 'It must be real – I'm looking at these skulls.' Furthermore, the students saw how ideas can translate into research and a career."

Jessica LeBlanc, M.Ed.
Biology I, Biology II, Anatomy & Physiology

"One of the most invaluable things is having that complete set, not obviously entirely complete, but from a geological standpoint, you covered a really good piece of ground there, and being able to see that progression laid out in front of you in a spectrum is really powerful. It's not three, it's not seven, it's like 13 that really cover the diversity of hominid species that the students can look at. Being able to take their own data, and trust that someone else that they know collected similar datapoints on other skulls was probably part of that."

Michael Wytock
Biology Teacher, Teach For America

"If you survey a lot of the textbooks and look for their coverage of hominin evolution, you would find that it's poorly covered. They don't try to draw a particularly strong line between all of these different concurrently living species on earth. It's kind of like: 'They existed, here's a paragraph about it, and we fall here in this big classification/cladogram.' Your presentation shifted the focus to looking on ourselves and thinking about how we may have evolved, and applying fossil evidence for evolution to humans. It really changes that unit for a lot of students. We can now discuss this in terms of humans as animals, not just ecosystem-wide."

Michael Wytock
Biology Teacher, Teach For America

"I would say next to non-existent would be the degree to which my students in the past could have talked about human evolution. A lot of my current students would use this as a way of framing their thought around it."

Michael Wytock
Biology Teacher, Teach For America

"*It was a one-of-a-kind valuable experience that I don't think can be taught adequately any other way.*"

Michael Wytock
Biology Teacher, Teach For America

"The opportunity to, first of all, see and interact with the trajectory of human evolution was very powerful for many of the students who couldn't conceptualize the incremental change. Being able to see the plethora of skulls was very meaningful and really brought that to life. Secondly, and maybe the most impactful, was that the variety of skulls, in conjunction with the lesson really made it clear that this was not a single trajectory, and that it was not a quick one at that. For them to see that there were lots of dead ends, that there were lots of simultaneous relatives, gave them a much deeper understanding of evolution."

Alex Treiger
Biology Teacher

"There was a group of kids in the class who were like: 'Evolution isn't real because we weren't monkeys', and then they went through this and they had a much better appreciation: 'Oh, I see how it went!'"

Alex Treiger
Biology Teacher

"Seeing the skulls and measuring them, hearing where they came from, and what we look at and measure to compare and date them to piece together this timeline gave students one more example of evidence for evolution and that scientists are not just guessing, that we have empirical evidence that we use to support the claims that we make."

Casey McMann
Biology Teacher

"In terms of teaching human evolution, this was so much better. Students need visuals. A textbook really doesn't do that for them."

Jessica LeBlanc, M.Ed.
Biology I, Biology II, Anatomy & Physiology

"I've had kids from last semester this semester come up and ask: 'Oh, are you gonna do the skull thing again?' So in a semester, or in a year, or in 5 years, this will be something they will remember from biology class."

Katherine Adler
Biology Teacher

"*It takes a long time to go through the measurement phase. What a lot of teachers do, especially in settings where you are crunched for time, is you give them the data. But the actual measuring helped them appreciate how detail-oriented science can be, and maybe even how mundane sometimes it can be if you have to do this a thousand times, or replicate after replicate. It allowed them to appreciate a little bit what real science is, because they don't always get that. They think science is memorizing processes and terms and vocabs, and not actually doing the process. They got to do the process this time*."

Katherine Schilling, PhD
Biology I, Biology I Honors, and AP Biology, Science Department Chair

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