

Human Evolution Lab Suite (HELS): SHOW & TELL

Chris N. Bayer, PhD



claim

(disclaimer: hyperbole)

High school students who reject/deny evolution (or remain sceptical) do so because they have not been properly introduced to the evidence, and have not been helped to work out the *plausibility* and *veracity* of the theory.

What is needed at the high school level?

The most **compelling** – and most **accessible** – **evidence**,
delivered with inquiry-based **pedagogy**.

questions (to you teachers):

- How many of you have taught the subject of human evolution with a lab?
- How many of you have used hominid skull replicas as teaching aids? (3D-printed or resin)
- How many of you have had your students examine vestigial organs found in their own bodies?

types of compelling + accessible evidence for evolution

evidence:

fossil/anatomical

physiologic

behavioral

genetic

explanation:

... evidence, in the form of individual (mineralised) specimens, represents snapshots of (past) life – the record of which is vast and exploding.

... evidence considers functions and mechanisms in a living system (incl. vestigial organs).

... evidence, a phenotype subset, are traits that also influence evolution of a species.

... evidence concerns the genotype level, investigating e.g. mutations that lead to evolution in a species.

fields:

paleoanthropology
and anatomy

evolutionary physiology /
comparative physiology

primatology

molecular biology
and phylogenetics



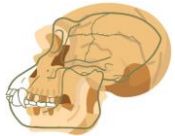
HELs:

6 interlocking labs to make a compelling case for (human) evolution



1. Human Origins (“Be a Paleoanthropologist for a Day!”)

- take skull-based measurements on 11 hominid skulls to determine their degree of cranial capacity, orthognathism, bipedalism



2. Dimorphism in Hominids

- investigate the interplay between behavioral traits (by conducting ethograms) and sexual dimorphism (by inspecting 3D-printed skulls) for bonobo, chimp, and human



3. “neanderthal ♥ sapiens”

- witness an ancient love-hate soap opera and model the ultimate conquest of the super cooperator species



4. “Encephalization in Homo”

- unpack the genotype-phenotype interaction driving brain development and enlargement



5. Human Evolution (“The Human Species in Transition”)

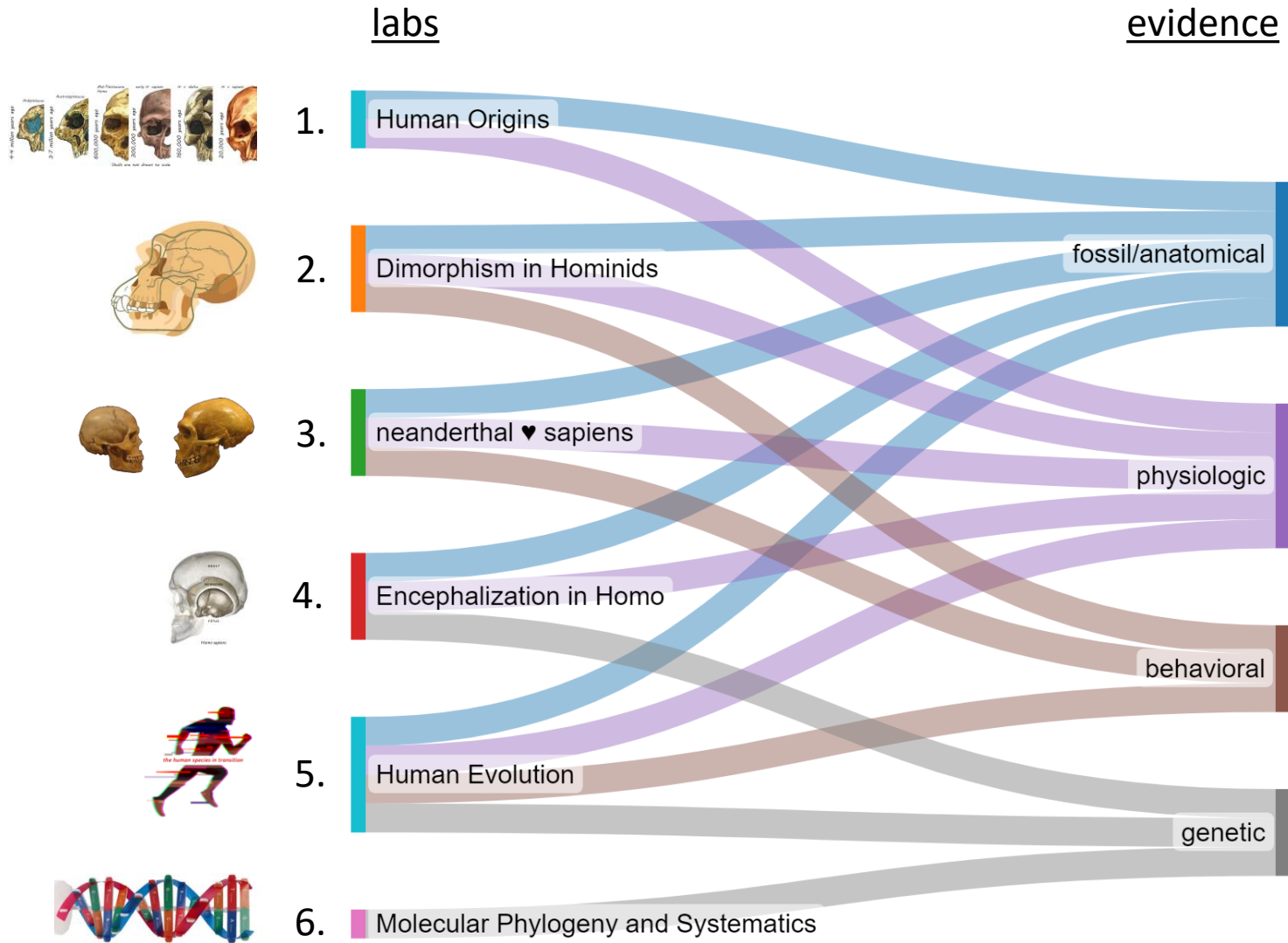
- carry out observations and measurements of 5 traits (incl. vestigial) emblematic of evolution (students examine traits on own bodies)



6. “Molecular Phylogeny and Systematics”

- analyze DNA sequences, protein sequences, and chromosomal maps to trace the ancestry of five species (homo, pan, gorilla, pongo, macaca)

interweaving evidence



inquiry-based pedagogy



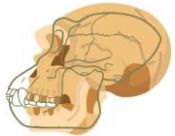
1. use of tactile teaching aids (e.g. hominid skulls, own bodies)
2. students are facilitated to:
 - collect data
 - analyse data
 - interpret results
 - wrestle with leading theories, and
 - draw own conclusions

introducing 3 labs



1. Human Origins (“Be a Paleoanthropologist for a Day!”)

- take skull-based measurements on 11 hominid skulls to determine their degree of cranial capacity, orthognathism, bipedalism



2. Dimorphism in Hominids

- investigate the interplay between behavioral traits (by conducting ethograms) and sexual dimorphism in bonobo/chimp/human (by measuring 3D-printed skulls)



3. “neanderthal ♥ sapiens”

- witness an ancient love-hate soap opera and model the ultimate success of the super cooperator species



4. “Encephalization in Homo”

- unpack the genotype-phenotype interaction on brain development and enlargement



5. Human Evolution (“The Human Species in Transition”)

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ANCIENT ANCESTORS.ORG

Discover
Human
Origins

Be a Paleoanthropologist for a Day!



Paleo - anthropo - logy:
Greek *palaio* "ancient" - *anthropos* "man" - *logia* "study"

Instructor Curriculum

Spring 2019

Authored by Michael Luberda and Chris Bayer, PhD
Reviewed by Larry Flammer and Trenton Holliday, PhD



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Validated by the
Association for Biology Laboratory Education
(ABLE)

lab objective

Granting high school students hands-on exposure to anthropological facts – in the form of cranium replicas of our early biological ancestors and relatives – has a **profound effect on their understanding of evolution** and the prehistory of humankind. Having in many cases survived for millions of years until they were found, **fossilized skulls provide irrefutable evidence for human evolution**. Through **guided observations and measurements of skull replicas**, high school biology students are challenged to become a paleoanthropologists who can derive **facts about human evolution** and **propose a cladogram**. In doing so, this course helps the student answer the questions: *“Where do we come from?”* and *“What methods are applied to generate knowledge about human evolution?”* This learning experience on the essential subject of human evolution places the young mind in the driver’s seat of discovery and knowledge.



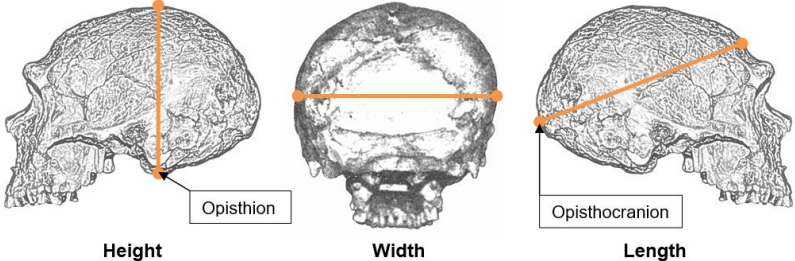
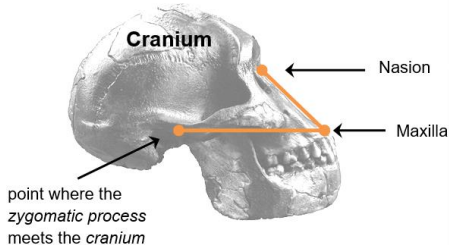
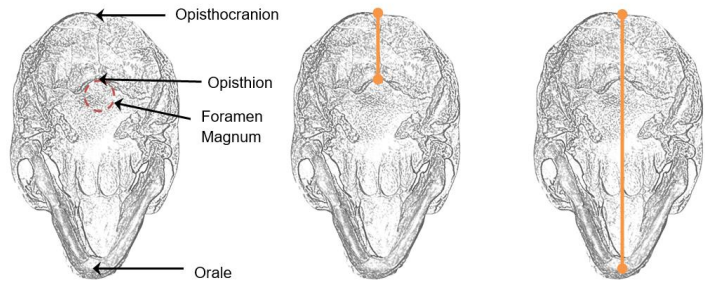
materials



The following equipment is needed for this lab:

1. Measurement tools: 11 protractors (bevel angle gauge, customized) and 11 calipers (long jaw)
2. Set of 11 hominid skulls:
Sahelanthropus tchadensis,
Ardipithecus ramidus,
Australopithecus afarensis,
Australopithecus africanus,
Australopithecus aethiopicus,
Australopithecus boisei, *Homo habilis*, *Homo erectus*, *Homo heidelbergensis*, *Homo neanderthalensis*, *Homo sapiens*

measuring three milestones of human evolution

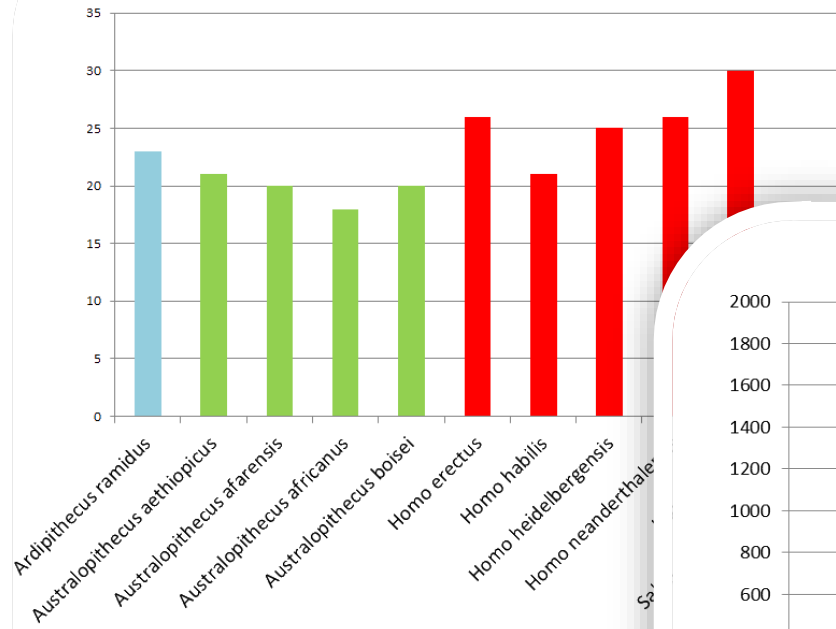
<p>encephalization (determined by the shape and volume of the neurocranium)</p>	<p>The cranial capacity is derived through a measure predictive volume measure.</p>	
<p>prognathism/orthognathism (determined by the slope of the maxilla)</p>	<p>The maxillary angle: angle of the upper jaw relative to the zygomatic process (“plan de Francfort”)</p>	
<p>bipedality (determined by the position of the foramen magnum)</p>	<p>The opisthion index is calculated from two measurements: the full length of skull and the distance of the foramen magnum to the rear of the skull.</p>	

data is collected by students

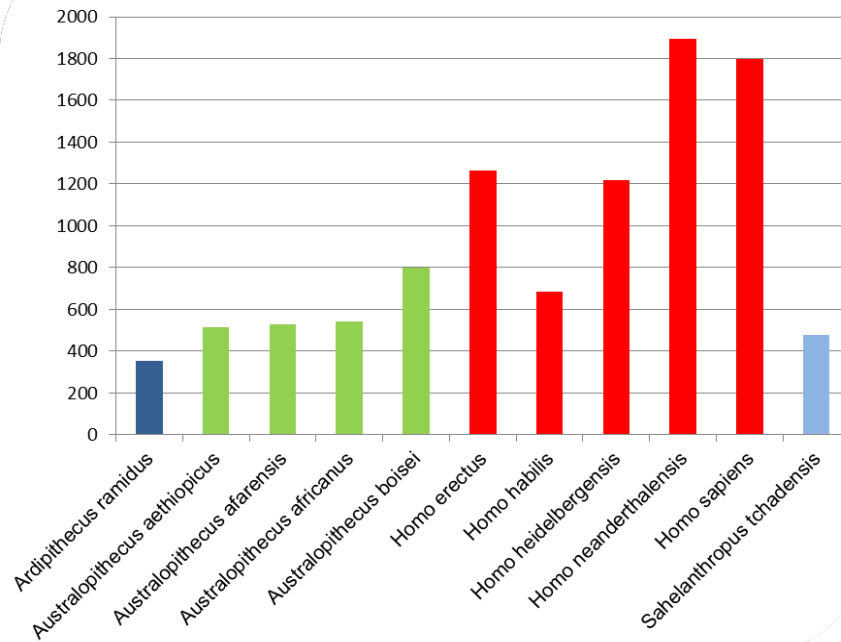
	Bipedalism			Prognathism	Cranial Capacity (CC)			
	Opisthocranium- opisthion distance (cm) (A)	Opisthocranium- orale distance (cm) (B)	Opisthion index (A/B)*100	Maxillary angle (°)	Height (H)	Width (W)	Length (L)	CC (cm ³) (LxWxH)* .5236
<i>Ardipithecus ramidus</i>	3.4	14.5	23	35	7.5	8.7	10.3	352
<i>Australopithecus aethiopicus</i>	4.5	21.6	21	27	6.9	10.4	13.7	514
<i>Australopithecus afarensis</i>	3.2	16	20	35	8.5	9.4	12.6	527
<i>Australopithecus africanus</i>	3	16.8	18	29	9.4	8.8	12.5	541
<i>Australopithecus boisei</i>	4	19.8	20	32	9	11.3	15	799
<i>Homo erectus</i>	5.2	20	23	51	10.5	13.2	17.4	1263
<i>Homo habilis</i>	3.3	15.4	24	44	10	10.2	12.8	683
<i>Homo heidelbergensis</i>	4.8	19.5	23	46	11	13.2	16	1216
<i>Homo neanderthalensis</i>	5.8	22.2	23	54	14	14.5	17.8	1892
<i>Homo sapiens</i>	5.5	18.6	30	54	14.5	14	16.9	1796
<i>Sahelanthropus tchadensis</i>	2.5	17.2	15	40	8.2	8.8	12.7	480

students plug in data

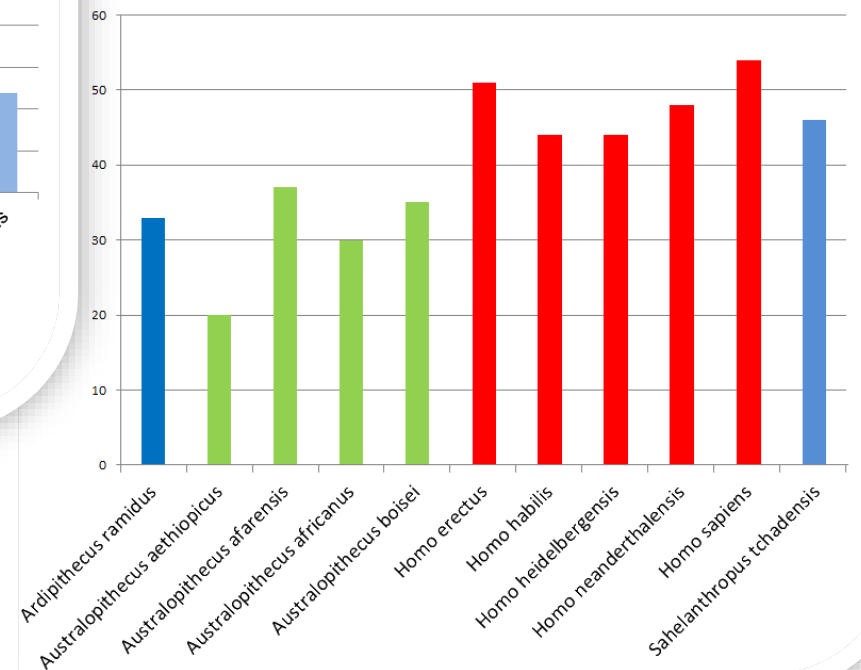
Opisthion index



Cranial Capacity (cm³)

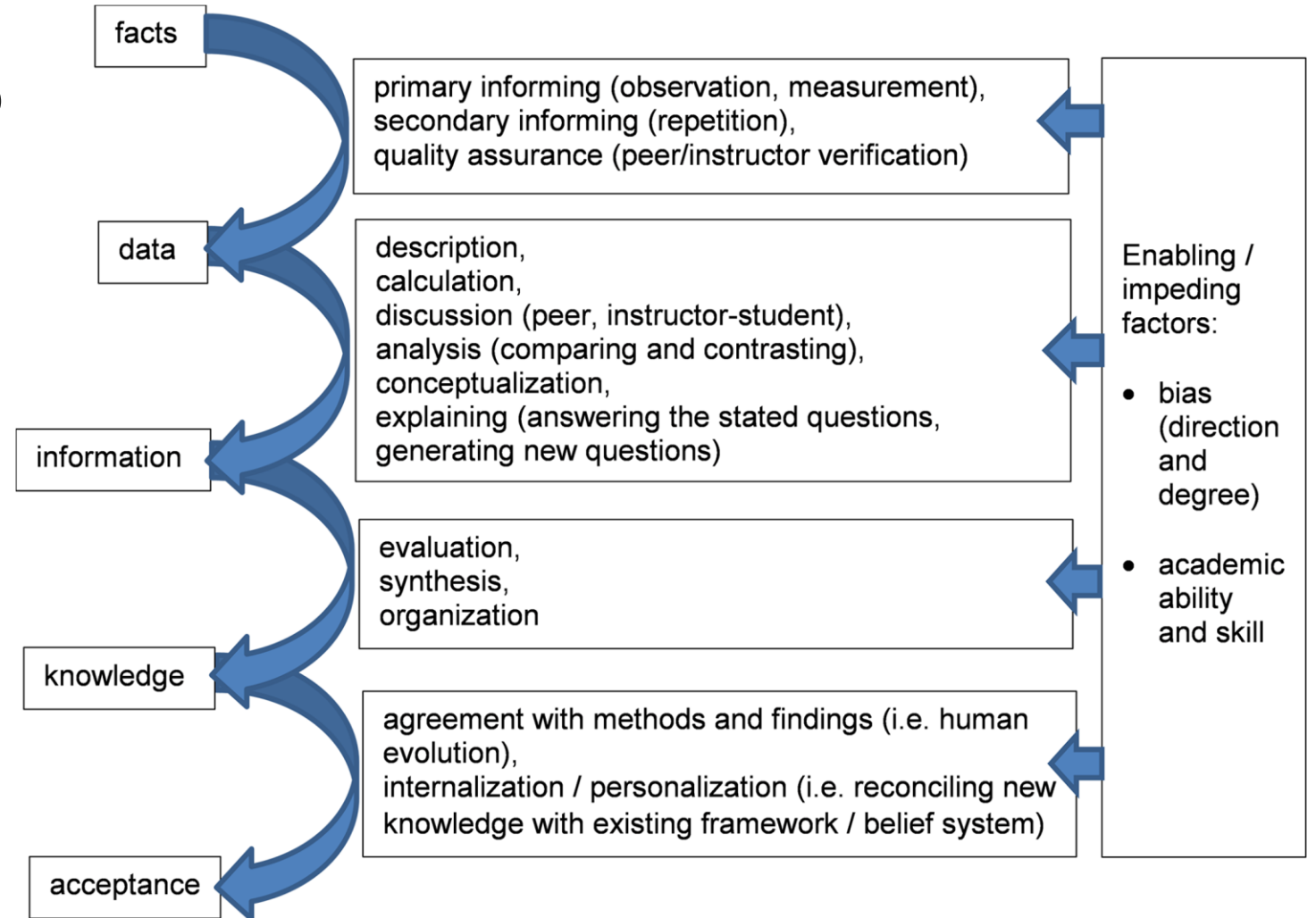


Maxillary angle (°)



“Be a Paleoanthropologist for a Day!”

- The lab’s learning path of facts to data, information 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 solid “grasp” of the subject, a high degree of retention and epistemic depth.



teacher quotes

"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



"There is definitely a deeper and longer-lasting understanding observable with this class. They now understand for life! Those on the fence told themselves 'It must be real – I'm looking at these skulls.'"

-- Jessica LeBlanc



Dimorphism in Hominids

Instructor Curriculum

By: Valentin

Reviewers: Dr. Dustin Eirdosh
Dr. Susan Hanisch
Dr. Molly Selba

under peer review – release: summer 2023

a river runs through it



lab objective

- Featuring hands-on observation and measurements of bonobo, chimp, and human 3D skulls, as well as conducting ethograms of their basic behavior, this lab allows students to take a deep dive into anatomical, physiological, genetic and cultural differences within and between the 3 most closely related ape species.
- By juxtaposing sexual dimorphism with their basic social behavior, within and across the species, students gain a nuanced understanding of the interplay between phenotype and genotype traits to drive morphology and evolution in each of the species.

materials

The following resources are needed for this lab:

1. Set of 3D-printed hominid skulls:

Homo sapiens female,

Homo sapiens male,

Pan troglodytes female

Pan troglodytes male,

Pan paniscus female,

Pan paniscus male,

2. Measuring devices (ruler/measuring tape, sliding calliper, mustard seeds);

3. Internet access (for open-access videos).



Well
hello
there!

ca. 2mya

ca. 5mya

Bonobo
(Pan Paniscus)

Chimpanzee
(Pan Troglodytes)

Human
(Homo Sapiens)

Male Bonobo

188 lbs / 45 kg
4.3 ft / 1.31 m tall

Female

Male

Male

Female

Male

Female

Female Bonobo

74 lbs / 33 kg
4.2 ft / 1.28 m tall

Male Chimp

132 lbs / 59 kg
4.4 ft / 1.34 m tall



Female Chimp

93 lbs / 49 kg
4.1 ft / 1.24 m tall

Female Human

148 lbs / 63.5 kg
5.2 ft / 1.58 m tall

Male Human

166 lbs / 75 kg
5.6 ft / 1.72 m tall

data collection / analysis

Step 1: data collection

Skull-based anatomical measurements:
Students identify the relative degree of sexual dimorphism within each specie

Step 2: between-specie analysis

Bonobo ↔ Chimp ↔ Human

Step 3: within-specie analysis

Bonobo male ↔ female
Chimp male ↔ female
Human male ↔ female

Step 4: data collection

Ethogram:
Students observe basic behavior within each of the 3 species (nature videos)

Step 5: between-specie analysis

Bonobo ↔ Chimp ↔ Human

Step 6: within-specie analysis

Bonobo male ↔ female
Chimp male ↔ female
Human male ↔ female

degree of sexual dimorphism within each specie

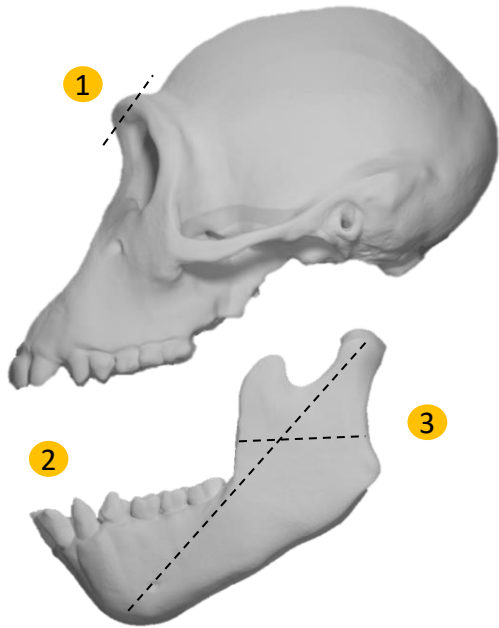
trait	description					
	Bonobo (Pan paniscus)		Chimpanzee (Pan troglodytes)		Human (Homo sapiens)	
	F	M	F	M	F	M
overall size and appearance	-2	-1	-2	+1	-1	+1
facial prognathism	+1	+1	+2	+2	-2	-2
zygomatic arches	0	+1	+1	+2	-1	0
brow ridge	+1	+1	+1	+2	-2	-1
nuchal area	-1	0	+1	+2	-2	0
mandible	0	+1	+1	+2	-1	0
mastoid	+1	+1	+1	+2	-1	+1
	measurement					
cranial capacity	350	350	300	400	1300	1400
maxillary canine	18 mm	19 mm	17 mm	27 mm	16 mm	16 mm
mandibular canine	14 mm	15 mm	13 mm	23 mm	11 mm	12 mm

Who has the smallest and largest cranial sexual dimorphism of the 3 species?

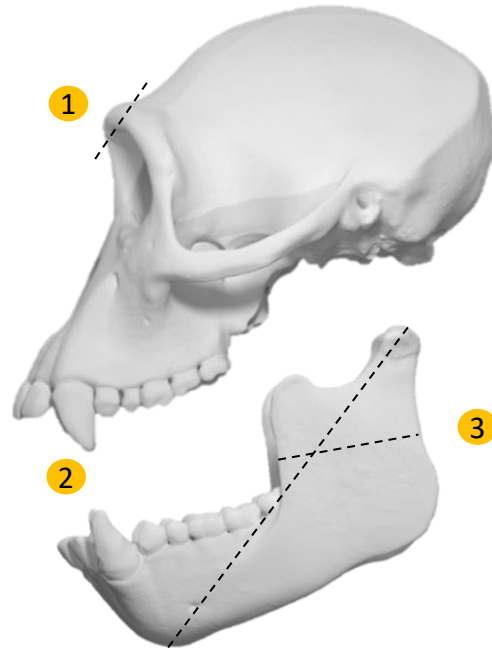
- **Compared to chimpanzees, the amount of sexual dimorphism in human and bonobo skulls is relatively modest.**
- When comparing canine teeth, those of male chimpanzees are often bigger and more prominent than females, but canine teeth in bonobos and humans are smaller and only mildly dimorphic.
 - Male chimpanzees tend to have larger and more robust skulls, with broader brow ridges, larger cranial vaults, and thicker jaw bones than females.
 - Bonobos males and females are known for having a similar cranial structure and shape, with only slight differences in size. The two more noticeable points of distinction are that males tend to have bigger zygomatic arches and in the back of the skull, the nuchal lines and occipital crest tend to be more marked, creating a bumpy surface to the touch.
 - In humans, the differences between males and females can be observed in the skull's overall size, as well as in specific features such as the brow ridge, mandible, mastoid process, nuchal area, and zygomatic arches.

between-species sexual dimorphism analysis

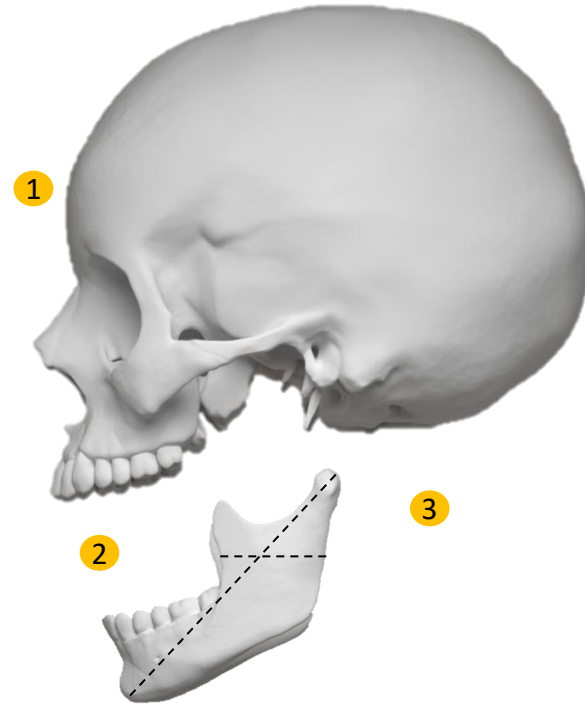
Male Bonobo



Male Chimpanzee



Male Human



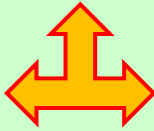
- ① Brow ridge or supraorbital torus
- ② Maxillary and mandibular canine
- ③ Mandible

ethogram (on basic behavior)

<i>behavior</i>	<i>description</i>					
	Bonobo (<i>Pan paniscus</i>)		Chimpanzee (<i>Pan troglodytes</i>)		Human (<i>Homo sapiens</i>)	
	female	male	female	male	female	male
<i>meeting an outsider</i>	territorial, but rarely aggressive		territorial and aggressive towards outsiders	territorial and aggressive towards outsiders	do not react aggressively but can show caution	
<i>sharing food</i>	females share food with females	males share food with females	reason for the majority of females fights	<ul style="list-style-type: none"> • hunters • share food (esp. with females) 	do not mind sharing	
<i>interaction with mother</i>	caregiver	no relation	caregiver	no relation	caregiver - nuclear family (mother, father and children)	
<i>within-group aggression</i>	only on rare occasion		<ul style="list-style-type: none"> • aggressive behavior is common • impulsive 	<ul style="list-style-type: none"> • show aggressive behavior, but also restraint • planned and deliberate 		
<i>sexual behavior</i>	<ul style="list-style-type: none"> • for pleasure and as a way to avoid conflict • females have an extended receptivity 		reproduction and "political" gain - only during estrus	reproduction	<ul style="list-style-type: none"> • multiple reasons for sex • females have an extended receptivity • not as often and freely as bonobos 	

relationship between sexual dimorphism and observed behavioral traits


Chimpanzees

Phenotype	food and mate competition	Genotype
higher levels of aggressive behavior		male-driven sexual selection / mate choice

higher levels of sexual dimorphism = gender roles

Chimpanzee groups are characterized by **male dominance**, where fully grown males are prominently dominant over females. They maintain supremacy through **aggression and violence**, and it is rare for a female to dominate a fully grown male. Males form strong bonds with each other to hunt and protect their shared territory.

Bonobos

Phenotype	selection against aggression	Genotype
lower levels of aggressive behavior		female-driven sexual selection / mate choice
	sex also as coping mechanism	

lower levels of sexual dimorphism = gender roles

Bonobo communities are generally **peaceful and egalitarian**. The strongest social bonds are formed among females, although they also bond with males. A male's social status depends on his mother's position, to whom he remains closely bonded for her entire life.

key lab lessons

Physical and behavioral traits are correlated.

- The chimp's more pronounced brow ridge, jaw, and canine teeth are correlated with the male-dominated social structures, where males compete for females and keep harems.
- Humans and bonobos exhibit less sexual dimorphism than chimps.
 - Like humans, bonobos may have undergone under a process of self-domestication.
 - When animals undergo self-domestication, they tend to show less sexual dimorphism. Specific physical traits may stop being a factor on mate choice (such as in chimpanzees) and individuals who are less aggressive and more cooperative may be more successful in reproducing and passing on their genes.
 - Bonobos may have evolved to select against aggression due to the advantages of heightened cooperation and social bonding in terms of survival and reproduction. By working together and avoiding conflicts, bonobos are successful in finding food, protecting themselves from predators, and attracting mates.
 - The social structure of bonobos is female-centered, and some observers would say female-dominated. Females form strong coalitions by exchanging sexual favors for food and defense, ensuring the survival of themselves and their offspring.



the human species in transition

a lesson plan for biology teachers

v. 1.4 – 07. December 2022

lab objective

- To illustrate, using particular physical traits of the human/hominin body as examples: (1) how the very physiology of specific traits varies across populations, and (2) how they are changing – over generations – due to certain evolutionary pressures.
 - In some cases – e.g. jaw vs. wisdom teeth, female pelvis vs. prenatal cranium, or hair follicles vs. sweat glands – traits “compete” over generations.
 - Other cases – e.g. the palmaris longus muscle in the forearm or the auricular muscles surrounding the ear – are vestigial organ candidates, as their primary function is no longer needed.

5 featured traits

- 1 **wisdom teeth**
- 2 **palmaris longus muscle**
- 3 **cranial capacity**
- 4 **auricular (ear) muscles**
- 5 **hair**

materials

trait		materials needed
1	<i>wisdom teeth</i>	<ul style="list-style-type: none">a. set of 6 hominin skulls (Homo habilis, Homo erectus, Homo sapiens, Homo neanderthalensis, Australopithecus afarensis, and optional: Ardipithecus ramidus)b. tape measure (soft tape measure)c. (panoramic) dental x-rays of impacted teeth (either example x-rays, those of the students, or print-outs of Figures 1-3)
2	<i>palmaris longus muscle</i>	students use their own forearms for this lab.
3	<i>cranial capacity</i>	set of 6 hominin skulls (Homo habilis, Homo erectus, Homo sapiens, Homo neanderthalensis, Australopithecus afarensis, and optional: Ardipithecus ramidus)
4	<i>auricular (ear) muscles</i>	students (attempt to) manipulate their own ear muscles
5	<i>hair</i>	students inspect (any) hair on their fingers

wisdom teeth

1. Measurement: arch circumference and maxillary angle

Species	lived (approximately)	arch circumference (in cm)	maxillary angle
<i>Homo sapiens</i>	300 k to present	13.2	54
<i>Homo neanderthalensis</i>	800 k to 40 k	13.5	54
<i>Homo erectus</i>	2 mya - 108 k	15.5	51
<i>Homo habilis</i>	2.3 – 1.65 mya	15.3	44
<i>Australopithecus afarensis</i>	3.9 – 2.9 mya	14.5	35
<i>Ardipithecus ramidus</i>	4.4 mya	14	35

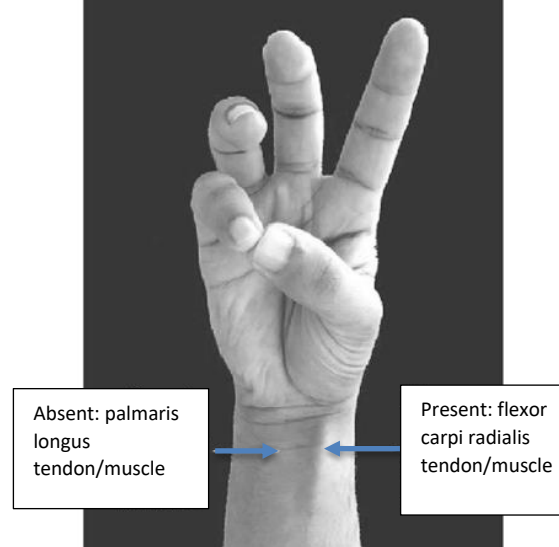
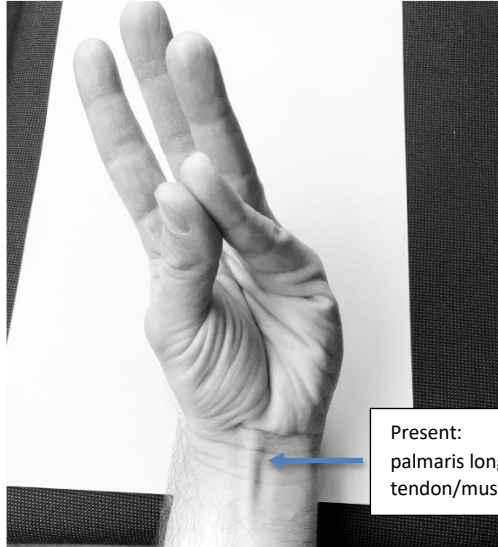


2. Analysis:

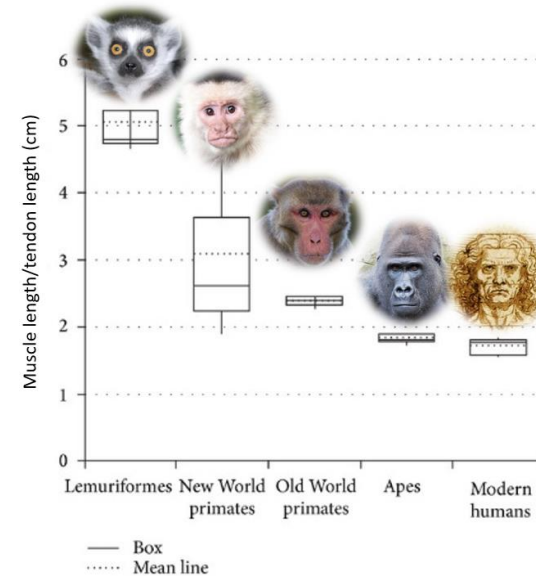
	<i>adaptation (over eons, also between species within a lineage)</i>	<i>competing traits</i>	<i>negative selection pressures (in concert with natural selection)</i>	<i>(potentially) vestigial organ?</i>
wisdom teeth	<ol style="list-style-type: none"> less mastication of robust foods reduced jaw size (orthognathism) potentiated by less mastication strength requirements due to technology (fire, cooking, and food processing) 	wisdom teeth (3 rd molars for better grinding) vs. orthognathism (linked to diet)	risk of impacted molar complications	partially; 3 rd molar impacted in 24% of the general population, missing in 22% of the population

palmaris longus

1. Measurement: palmaris longus



Palmaris longus muscle/tendon length in monkeys and apes



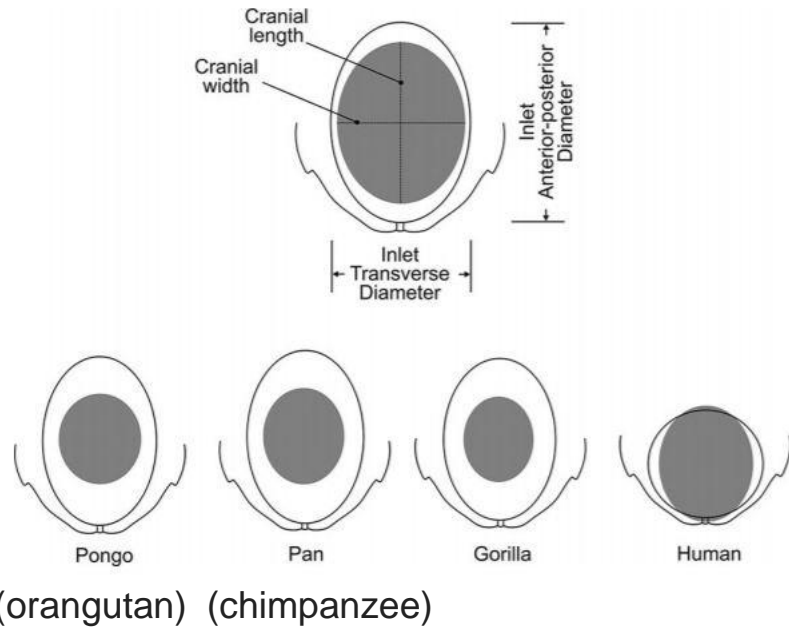
Source: Aversi-Ferreira et al., 2014

2. Analysis:

	<i>adaptation (over eons, also between species within a lineage)</i>	<i>competing traits</i>	<i>negative selection pressures (in concert with natural selection)</i>	<i>(potentially) vestigial organ?</i>
palmaris longus muscle	less tree swinging with arms	none	none	partially; missing in 14% of the world population on average

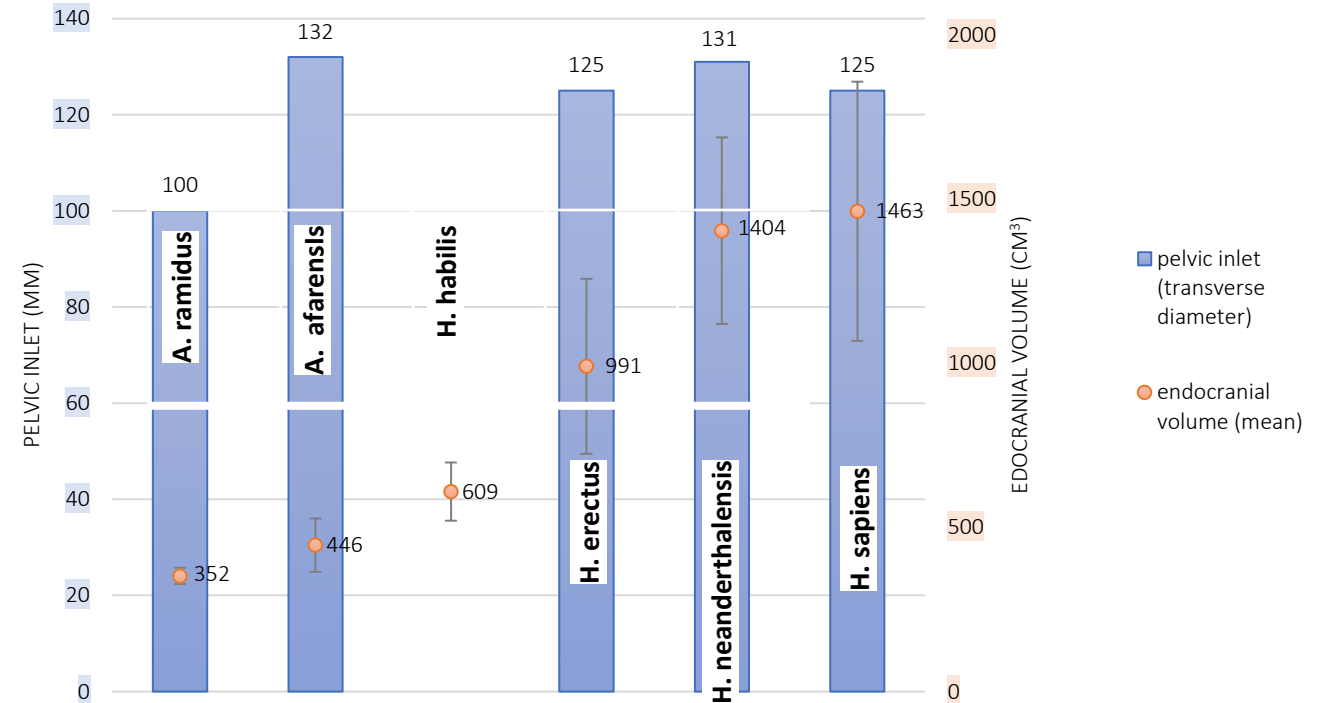
cranial capacity

Relationships between the fetal head and maternal pelvis in higher primates



Source: Wittman & Wall, 2007

Pelvic inlet vs. cranial capacity



2. Analysis:

	<i>adaptation (over eons, also between species within a lineage)</i>	<i>competing traits</i>	<i>negative selection pressures (in concert with natural selection)</i>	<i>(potentially) vestigial organ?</i>
cranial capacity	generally increasing cranial capacity	female locomotion and pelvic strength vs. size of the fetus' head (cranial capacity)	higher risk of complications at birth with large fetus' cranium	no; as both a certain pelvis and brain size are vital for survival

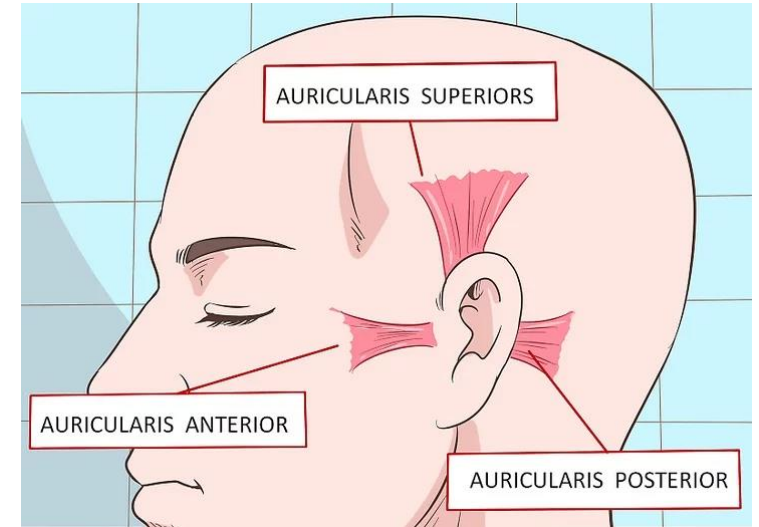
ear muscles

1. Measurement: ear wiggling/twitching

Ask the class:

- a) *Who of you can wiggle their ears?*
- b) *Have you ever noticed your ears twitch after hearing an unexpected sound or noise beside or behind you (especially observable in a quiet room)?*

Auricularis muscles



Source: WikiHow, 2020

2. Analysis:

	<i>adaptation (over eons, also between species within a lineage)</i>	<i>competing traits</i>	<i>negative selection pressures (in concert with natural selection)</i>	<i>(potentially) vestigial organ?</i>
auricular (ear) muscles	from pivoting to more stationary ears	none	none	potentially; little-to-no current physiological function

hair

1. **Measure:** examine your hands for dorsal phalangeal hair distribution applying the modified Bernstein (1949) classification, and note your results:

0: no hair on any of the phalanges.	5: hair present on the little finger.
1: hair present on the thumb.	45: hair present on the ring and little fingers.
2: hair present on the index finger.	345: hair present on the middle, ring and little fingers.
3: hair present on the middle finger.	234: hair present on the index, middle and ring fingers.
4: hair present on the ring finger.	etc.

Not how it happened!



2. **Analysis:**

	<i>adaptation (over eons, also between species within a lineage)</i>	<i>competing traits</i>	<i>negative selection pressures (in concert with natural selection)</i>	<i>(potentially) vestigial organ?</i>
hair	loss of fur/hair and more sweating	sweat glands (cooling) vs. fur (warmth)	1. need for sweat glands in African savanna (and Mexico) 2. sexual selection	yes and no: significant reduction of hair over the eons as sweating became more important than having fur, but current sexual selection preferences speak against going completely hair-free

key lab takeaway(s)

Students understand *how* evolution works:

- “... the randomness of mutations is akin to a ‘**mutation scattershot**’. And, if **natural selection** does not WEED OUT the mutations, they add to the general genetic diversity. Then some of those scattershot mutations get fixed in the population by **genetic drift** – meaning, sampling error due to small population size. This is the mechanism that best applies to the loss of the palmaris muscle, for example. Even though we do not need it, there is no specific advantage in losing it.”

-- Nathan Lents

- It gets lost only randomly in specific individuals, and then with nothing to maintain it, that loss could be eventually reflected in the entire population in the event of genetic drift. However, as genetic drift is an unlikely scenario in our modern, gene-flow enabled civilization, many populations will retain the trait for time to come.

Students should be able to say:

*“I don't believe in evolution!
I observe evolution,
I understand how evolution
works, and I not only accept
but I endorse modern
evolutionary theory.”*



Q&A / discussion



quiz

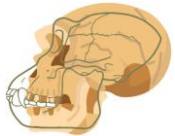
- Which U.S. president shares the same birthday as Charles Darwin?
- On a cranium, what is the supra-orbital torus?
- True-false: Humans have in their DNA instructions for their body to be covered in fur.
- When 3D printing, what are the types of support structures called?

lab curricula for download



1. Human Origins (“Be a Paleoanthropologist for a Day!”)

- take skull-based measurements on 11 hominid skulls to determine their degree of cranial capacity, orthognathism, bipedalism



2. Dimorphism in Hominids

- explore the internal structure (endocranial volume, brain organization) and sexual dimorphism in bonobo/chimp/human (by measuring 3D

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3. “neanderthal ♥ sapiens”

- witness an ancient love story: the ultimate success of the super cooperator species

under development



4. “Encephalization in Homo”

- unpack the genetic and developmental mechanisms of brain development and enlargement

under development



5. Human Evolution (“The Human Species in Transition”)

- carry out observations and measurements of 5 traits (incl. vestigial) emblematic of evolution (student examine traits on own bodies)



6. “Molecular Phylogeny and Systematics” + Supplemental Material 1 + Supplemental Material 2

- analyze DNA sequences, protein sequences, and chromosomal maps to trace the ancestry of five species (homo, pan, gorilla, pongo, macaca)