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Cornell Institute for Biology Teachers

Lab issue date: 5/27/2011, Rev. date: July, 2012

Title: **The Mystery of the Skulls: What Old Bones Can Tell Us About Hominins**

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Appropriate Level: *Advanced Placement Biology.*
Version for Regents and Honors: please download Hominin Skulls from http://cibt.bio.cornell.edu

NYS Standards: See page 23.

Abstract: In this laboratory activity students will examine 9 hominin skulls for specialized features and take measurements that will enable them to determine the relatedness of these species. They will identify the placement of each specimen on a phylogenetic tree that also reveals the geological time frame in which each species lived. Based on the data that they generate, and using similar scientific methods as paleoanthropologists to analyze them, students will be able to arrive at the same conclusions about hominin evolution as the ones currently accepted by the scientific community.

Time Required: This activity will take approximately 4 standard periods to complete depending on student level and class size.

Materials needed: CIBT Hominin Skulls kit, calculators, pencils with erasers. Additional metric rulers may be required, depending on class size.

Teacher Information

Background Information

Humans: Bipedal mammals with a large brain

Many specialized characteristics distinguish humans from other apes. Most obviously, humans stand upright and are bipedal. Humans also have a larger brain and are capable of language, symbolic thought, and the manufacture and use complex tools. Compared to other apes, humans also have reduced jawbones, along with a shorter digestive tract. All these features are evolutionarily derived, as opposed to traits shared among related living and ancestral species, such as stereoscopic vision, which is common to all primates.

Scientists have begun to compare the genomes of humans and chimpanzees. Although these 2 genomes are 99% identical, the difference of 1% translates into a large number of differences because each genome contains approximately 3 billion base pairs. Furthermore, changes in a small number of genes can have big effects: for example, regulatory genes that turn other genes on and off may account for many differences between the 2 species. Such genomic differences, and the derived phenotypic traits that they code for, separate humans from all other *living* apes. However, many of these characteristics first emerged in our ancestors long before our own species appeared.

Earliest hominins

The study of human origins is known as paleoanthropology. Paleoanthropologists have found about 20 extinct species that are more closely related to humans than to chimpanzees. These species are known as hominins (the older synonym hominid is still in use). The oldest of these hominins, *Sahelanthropus tchadensis*, lived about 6 to 7 million years ago (mya). *Sahelanthropus*, and other early hominins, showed some derived characteristics such as reduced canine teeth, and some had relatively flat faces. In these early hominins signs of being more upright than other apes include the position of the foramen magnum, the hole at the base of the skull through which the spinal cord exits. In chimpanzees, the foramen magnum is relatively far back on the skull, more similar to its position in the dog, a quadrupedal mammal. In early hominins and in humans, the foramen magnum is located underneath the skull, more towards the center of the skull. This position allows us to hold our head directly over our body while being upright.

Australopithecus anamensis, an early hominin that lived 4.5 to 4 mya, has a more forward positioned foramen magnum and more human-like leg bones, which together suggests that these early hominins were increasingly bipedal. While they were showing signs of bipedalism, their brains however, remained small, 400 to 450 cm^3, compared with an average 1300 to 1400 cm^3 for *Homo sapiens*. Early hominins were also relatively small, but had relatively large teeth and a lower jaw that projected forward. Humans, by contrast, have a relatively flat face.

There are two common misconceptions about early hominins that should be avoided. One is to think of them as chimpanzees, which are on a separate evolutionary branch. Chimpanzees acquired their own set of derived characteristics as they diverged from their common ancestor with humans, e.g., they developed extra-long arms for locomotion in the trees. Another common misconception is to think of an evolutionary ladder that leads directly from an ancestral ape to *Homo sapiens*. Instead, our own evolution is a series of branches, with many groups breaking away on their own evolutionary paths. During the past 6 million years, several hominin species coexisted. These species had different skull shapes, body sizes, and diets (as inferred from their teeth). Ultimately, all but one branch ended in extinction. *Homo sapiens* is the only surviving member of a highly branched evolutionary tree.

Australopiths

Between 3 and 2 mya, the fossil record indicates that hominin diversity increased dramatically. Many of the hominins from this period are collectively called australopiths. *Australopithecus africanus* was discovered in 1924 and given its scientific name that translates to "southern ape of Africa". These hominins lived between 3 and 2.4 mya, were fully bipedal and had human-like hands and teeth. However, the brain of *A. africanus* was only one-third the size of a present-day human. Then, in 1974 another *Australopethicus* species was discovered that was 3.2 million years old. This fossil was short, only about 1 m tall, and nicknamed "Lucy". This new species, *Australopithecus afaransis* ("from the Afar region") coexisted with *A. africanus* for at least 1 million years. Fossilized footprints in Laetoli, Tanzania, that date back at least 3.6 million years, provide further evidence that all these early hominins were bipedal.

Early Homo

Homo habilis is the oldest fossil (2.4 to 1.6 million years) that paleoanthropologists categorize as in the genus *Homo*. Compared to the australopiths, *H. habilis* had a shorter jaw and larger brain volume (about 600-750 cm^3). The fossils of *H. habilis* ("the handy man") were found along with sharp stones, indicating that this species made and used tools.

Around the same time period during which *H. habilis* lived (1.9 to 1.5 mya), a distinct species, *Homo ergaster* (Greek for "workman"), emerged. *H. ergaster* had a substantially larger brain (900 cm^3), and was well adapted for long-distance walking with its longer, slender legs. *H. ergaster* marks an important change in the relative size of the sexes. In primates, varying degrees of sexual dimorphism (the difference in size and/or appearance between the sexes) appear to have a major impact on their social structure. Extreme sexual dimorphism is associated with a male-dominated social structure in which males compete for multiple females (for example, a silverback gorilla and his "harem" of females). By contrast, gibbons (which are also known as lesser apes because they are relatively small) show no sexual dimorphism and their social structure is monogamous (pair bonding between one male and one female). In chimpanzees and bonobos, sexual dimorphism is moderate, i.e., males are less than 1.5 times bigger than females. Their social structure is described as multi-male/multi-female and translates to all members of the group capable of mating with any other group members. Within this type of social structure, the paternity of a newborn is unknown. In early *Homo* species, the sexual dimorphism became reduced, with this trend beginning in *H. ergaster* and continuing through our own species. Human males average about 1.2 times the size of females. This reduction in sexual dimorphism provides insight into the social structure of these extinct hominins. Because *H. ergaster* shows a less dramatic sexual dimorphism than earlier hominin species, trending towards the situation found in gibbons, it is conceivable that members of this species also engaged in more pair bonding than their ancestors. Long-term care of the young by both parents may have impacted the need for pair bonding, since they depend on their parents for food and protection for much longer than do offspring of other apes.

Homo erectus

Homo erectus was likely the first hominin to migrate out of Africa. The oldest fossils of hominins outside Africa, dating back 1.8 million years, were discovered in 2000 in the former Soviet Republic of Georgia. *H. erectus* eventually migrated as far as the Indonesian archipelago. This highly successful hominin species lived until about 200,000 years ago, when it was replaced by the Neanderthal in Europe and the modern *H. sapiens* in the rest of the world.

Neanderthals

Neanderthals were living in Europe and the Near East starting around 200,000 years ago, but never populated other regions. They had a brain as large or larger as that of present-day humans. They buried their dead, and made tools from stone and wood. However, despite their adaptations to the cold climate in Europe (e.g., a huge nose for humidifying and warming cold, dry air, shorter and stockier body than ours) and culture, Neanderthals apparently became extinct about 28,000 years ago. They were gradually displaced by modern humans likely because of the climate warming up in Europe. Neanderthal and human nuclear DNA appear to be consistent with limited gene flow between the two species. The latest genetic studies indicate that about 1 to 4% of the Neanderthal genome is present in modern-day humans.

Also see: http://www.npr.org/2010/12/28/132243863/2010-a-good-year-for-neanderthals-and-dna

Homo sapiens

The fossil record indicates that human ancestry originated in Africa. Older species, such as *H. ergaster* or *H. erectus*, gave rise to later species, ultimately including *H. sapiens*. The oldest fossils of *H. sapiens* were found in Ethiopia and are 195,000 and 160,000 years old. Unlike *H. erectus* and Neanderthal, early *H. sapiens* lacked the heavy brow ridges, and were also more slender than other hominins.

Outside of Africa, the earliest fossils of *H. sapiens* are from the Middle East and date back to about 115,000 years. Humans left Africa in one or more waves: first to Asia, then to Europe and Australia. The date of humans arriving in the New World is uncertain, but is generally thought to be sometime before 15,000 years ago.

Also see: http://www.npr.org/2011/01/28/133271273/tools-suggest-humans-left-africa-earlier-via-arabia

Setting Up Your Classroom

As part of the kit, you will receive 9 skulls that are labeled on the underside (usually near the foramen magnum) with a single letter. Lay them out in 3 groups of 3 skulls each on separate tables/workstations as follows (also see Table 1 teacher version for chronological order):

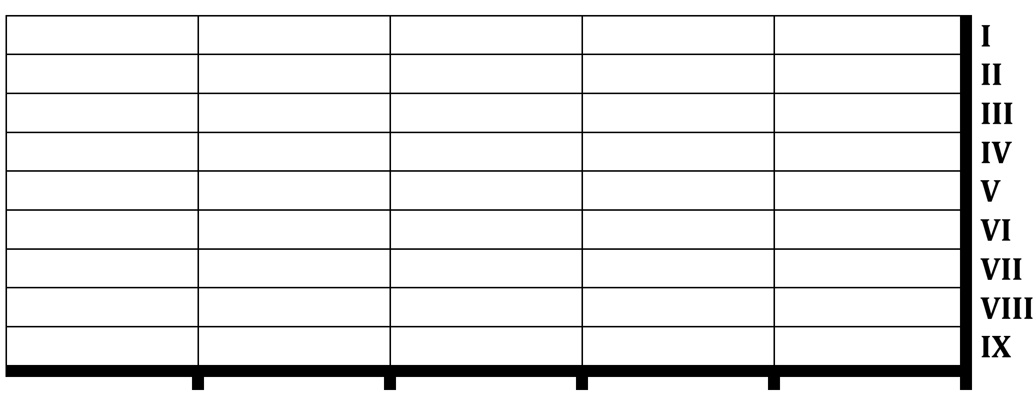
Station 1	**Station 2**	**Station 3**
S = *H. sapiens*	**G** = *H. ergaster*	**B** = *Paranthropus boisei*
N = *H. neanderthalensis*	**H** = *H. habilis*	**K** = *Kenyanthropus platyops*
E = *H. erectus*	**A** = *A. africanus*	**L** = *A. afarensis* (**L**ucy)

The accompanying CD contains a short PowerPoint presentation that introduces the workstations. Divide your class into 4 groups. Each group will rotate between the 3 workstations and spend about 10 minutes at each station, where they will determine the characteristics of the skulls and fill out the Table 1. A 4th workstation will be dedicated to students creating a geological time scale modeled after the graph below, where 0 years (present time) is set far to the right on the x-axis and each tick mark represents one million years ago (think of those as negative years from the present, i.e., 2 mya = - 2 million years from the present, hence further to the left on the x-axis). Students in this 4th group will be working with the graph found on page 4 in the Student Section.

Have the students mark/shade the following time periods starting with the top one

- (I) 160,000 years ago to present
- (II) 200,000 to 30,000 years ago
- (III) 1.8 to 0.2 mya
- (IV) 1.9 to 1.5 mya
- (V) 2.4 to 1.6 mya
- (VI) 3.0 to 2.4 mya
- (VII) 2.2 to 1.0 mya
- (VIII) 3.5 to 3.3 mya
- (IX) 4.0 to 2.7 mya

Each Roman numeral represents the time period for one of the 9 skulls in the kit.



Geological Time Scale (mya)

The following items of Table 1 are to be addressed by the students (items not mentioned here will be addressed in a second class period):

FL - Forehead Length: Look at the front of the skull and determine if the forehead is Long (L) or Short (S). The forehead is roughly the area from the top of the eye socket to the part of the skull that begins to flatten. Visualize your own forehead and imagine the part between your eyebrows to where your hairline begins. This is the forehead. If this length is at least the length of the average thumb, we consider it to be Long (L).

SC - Sagittal Crest: Look at the top of the skull and determine if a sagittal crest is present (+) or absent (-). A sagittal crest is a ridge of bone that protrudes from the skull and runs on top of the skull from front to back.

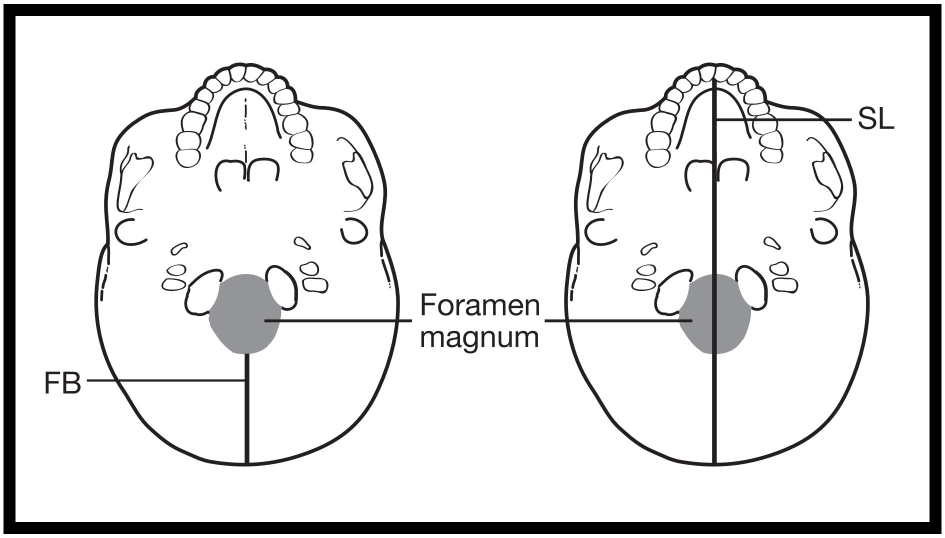
BR - Brow Ridge: Look at the front of the skull and determine if a brow ridge is present (+) or absent (-). A brow ridge is a bone that runs the entire width of the skull just above the eyes.

P/S - Prognathism/Snout: Look at the front of the skull and determine if it exhibits prognathism (+) or not (-). Prognathism refers to the protrusion of the mouth from the front of the skull. Animals with prognathism are thought of as having a 'snout'. To determine if a skull exhibits prognathism, press your fingers along the base of the nose opening (Anterior Nasal Spine) and rest it on the top of the maxilla (where the top teeth attach). If this area is greater than 1 index finger in width, then we consider the skull to exhibit prognathism.

CL - Canines Long (and sharp): Look at the teeth in the top of skull and determine if the canines are long and sharp (+) or (-). The canines are sometimes referred to as 'fangs'. They are the third pair of teeth from the front – in your mouth, your 2 front teeth and the next one in each direction are called 'incisors'. The next tooth on either side is slightly pointy and called 'canine', but in many animals, like dogs and cats, these canines are very long and sharp. If the canines are not present in the skull, the cell in the table has been blackened out. If you notice that the canines are 'fang-like', we consider them to be long and sharp (+).

FB - Foramen Magnum Distance to Back (mm): Look at the underside of the skull and determine the distance between the foramen magnum and the back of the skull, measured in mm). The foramen magnum is the hole in the skull through which the spinal cord attaches to the brain. To determine this distance, place a ruler on the base of the skull, starting at the back most edge of the foramen magnum and measure the distance to the end of the skull (see diagram below). Be sure to demonstrate this measurement to your students.

SL - Skull Length (mm): Look at the underside of the skull and determine the length of the skull (measured in mm). Place a ruler on the base of the skull (see diagram below) and measure the distance from the back of the skull to the end of the palate (roof of the mouth). Be sure to demonstrate this measurement to your students.



FMI - Foramen Magnum Index: Calculate the ratio using the Foramen Magnum Distance to Back (FB) and the Skull Length (SL). To do this for each skull, divide the value that you recorded for FB by the value that you recorded for SL, and fill in the corresponding box to the 3rd digit after the decimal point.

***Note:** since the foramen magnum of K (*Kenyanthropus*) is quite difficult to locate, the measurements of FB, SL and the calculated FMI (showing 3 digits after the decimal point) are prefilled in the student version of Table 1.

CC - Cranial Capacity: Look at the skull from the top and sides and estimate the number of average fists that would fit inside the cranium (the area of the skull where the brain is located). For these skulls, limit your estimate to 2, 3 or 4.

This task should take approximately 1 class period to complete.

Data provided in the teacher version of Table 1 are based on the authors' measurements and calculations on the skulls. They should be considered estimates of what to expect from student-generated values and should not necessarily be viewed as the true or absolute measurements.

Definitions for items of Table 2:

L - Length of the braincase: Position three rulers as shown on the left side of the photograph (see student section). Ruler 1 should stand perpendicular to the table, and rest at the back of the skull. Ruler 2 should also stand perpendicular to the table, but rest on top of the skull, just behind the brow ridge. If a brow ridge is not present, align the ruler against the forehead in the same perpendicular orientation (imagine it flat against your forehead). Ruler 3 should rest on the highest point of the cranium, making sure that it is parallel with the table. Once all 3 rulers are in place, read the distance on ruler 3 between the 2 upright rulers in mm (see the right side of the photograph). Record your data in the first column labeled "L".

H - Height of the braincase: Without moving the 3 rulers from your measurement of Length, read the height of the skull off ruler 1 (at the back of the skull) in mm (also see photographs in student section). Record your data in the first column labeled "H".

W - Width of the braincase: Position 3 rulers as shown in the photographs (see student section). Rulers 1 and 2 should stand perpendicular to the table and flat against the skull (imagine 2 rulers flat against where the ears would be positioned). Position ruler 3 so that it rests on the top of the skull, making sure that it is parallel with the table. Read the distance between rulers 1 and 2 in mm. Record your data in the first column labeled “W”.

Cranium Shape - Look at each skull from the top. Specifically, look at the shape of the cranium (the part of the skull where the brain is located). If the shape is boxy, we consider it to be Cuboid (C). In other words, it more closely resembles that of a box than that of a ball. If the shape is rounded, then we consider it to be Spheroid (S). In other words, it more closely resembles that of a ball than that of a box.

ASV - Approximate Skull Volume: calculate the product of AVG L, AVG H, and AVG W, and divide your answer by 1000.

ESV - Estimated Skull Volume: the measurements that you took of the skull will overestimate the cranial capacity because skulls are not cubes. To correct this, you should divide the number that you calculated in the previous column (ASV) by 2 for species S, N, E, G and H, and by 3 for all other species (A, B, K and L). You use a different correction factor for each group of skulls because the skull shapes vary between the two groups.

Table 1 (Teacher version)

Skull Letter Code	FL (S, L)	SC (+,-)	BR (+,-)	P/S (+,-)	CL (+,-)	FB (mm)	Class AVG FB	SL (mm)	Class AVG SL	FMI (FB/ SL)	Class FMI (AVG FB/ AVG SL)	CC (2, 3, 4 "fists")	CCC (CC x 300 cm^3)	ESV (cm^3)	ACC (cm^3)	Age
S	L	–	–	–	–	55		180		0.286		4	1200		1300-1400	160,000 to present
N	L	–	+	–		55		210		0.262		4	1200		1400-1500	200,000 to 30,000 years ago
E	S	–	+	+	–	48		190		0.253		3	900		850-1200	1.8 to 0.2 mya
G	S	–	+	+	–	45		190		0.237		3	900		700-1100	1.9 to 1.5 mya
H	S	–	+	+	–	34		154		0.221		2	600		600-700	2.4. to 1.6 mya
A	S	–	+	+		38		175		0.217		2	600		400-500	3 to 2.4 mya
B	S	+	+	+	–	43		207		0.208		2	600		400-500	2.2 to 1.0 mya
K	S	–	+	+		34		165		0.206		2	600		300-500	3.5 to 3.3 mya
L	S	–	+	+	–	30		158		0.190		2	600		375-550	4 to 2.7 mya

Table 2 (Teacher version)

Skull Letter Code	L (mm)	Class AVG L	W (mm)	Class AVG W	H (mm)	Class AVG H	ASV (LxWxH/1000) (cm^3)	ESV (cm^3)	Cranium Shape (C/S)
S	160		130		140		2912	1456	C
N	196		144		126		3556	1778	C
E	161		137		117		2581	1290	C
G	138		128		123		2173	1086	C
H	120		92		107		1081	591	C
A	135		90		111		1349	450	S
B	135		110		120		1782	594	S
K	128		116		105		1559	520	S
L	130		98		105		1338	446	S

All of the measurements in this table should be made with the top of the skull facing upwards (natural resting position) with the lower jaw removed.

During the second class period, students will gather the data of all 4 groups to calculate the Class AVG FB, Class AVG SL and Class FMI (AVG FB/AVG SL). These data should be recorded in Table 3 and then transferred to the gray shaded columns in Table 1. This can be done in various ways depending on your preference: using a blackboard or an overhead projector each group of students can have a 'reporter' provide their data for an in-class calculation. Or each group could communicate with the other groups and collect the 4 data points per skull measurement individually and then calculate the class averages. A brief discussion about repeated measurements and averages could be included here. Students will also convert their fist estimates for cranial capacity (CC) into an approximate metric by using the formula for CCC = CC x 300 cm^3, where 300 cm^3 is an estimate of the volume of an average teenage human fist.

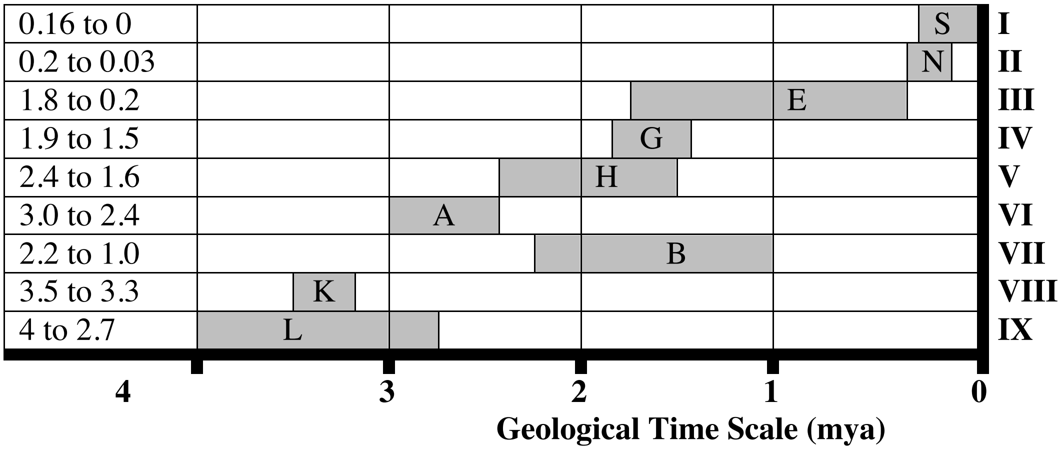
Table 3

Skull Letter Code	FB (mm)	FB (mm)	FB (mm)	FB (mm)	Class AVG FB	SL (mm)	SL (mm)	SL (mm)	SL (mm)	Class AVG SL	Class FMI AVG FB/ AVG SL
S											
N											
E											
G											
H											
A											
B											
K											
L											

The Geological Time Scale graph should be completed by the students at this stage after they are provided with the single letter code for each time period (the various Roman numerals) – see the completed graph below.

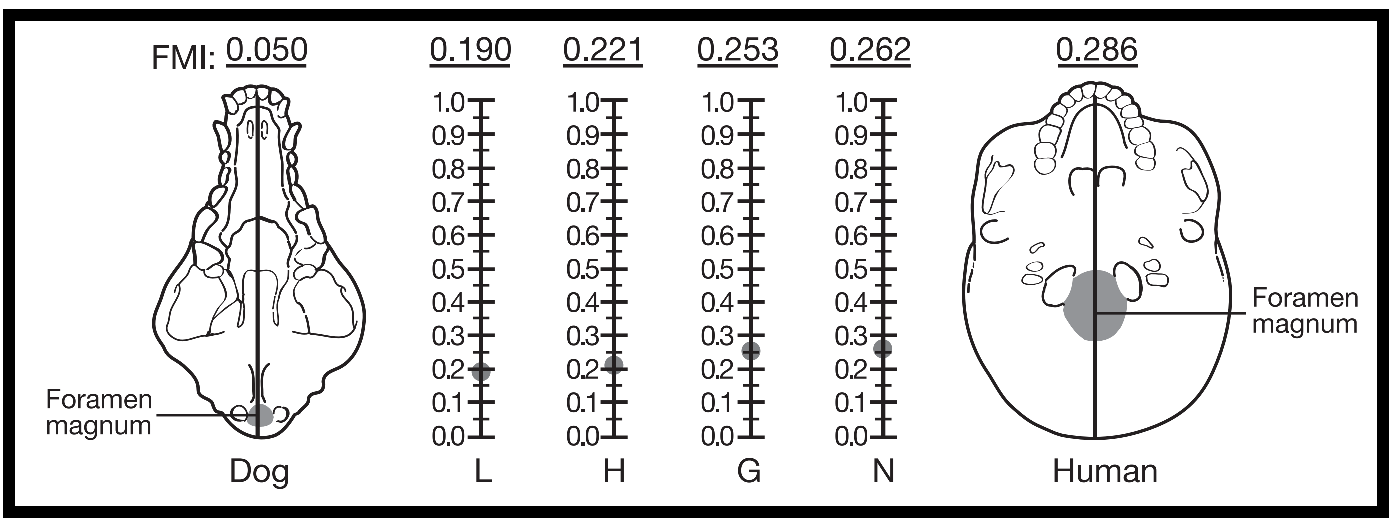
The students should write the single letter codes in their graph and then transfer those now identified ages into the appropriate places in the last column of Table 1.

Each Roman numeral represents the time period for one of the 9 skulls in the kit.



In Table 1, the second to last column titled ACC (Actual Cranial Capacity) can now also be completed by the students – simply convey the corresponding data of your teacher version of Table 1 to your students. Please hold off with providing those actual figures until the students have completed their cranial capacity measurements (Tables 2 and 3). A brief discussion on estimates (how accurate were they using the fist method) and on various ways of measuring things using different tools and methods could be included here.

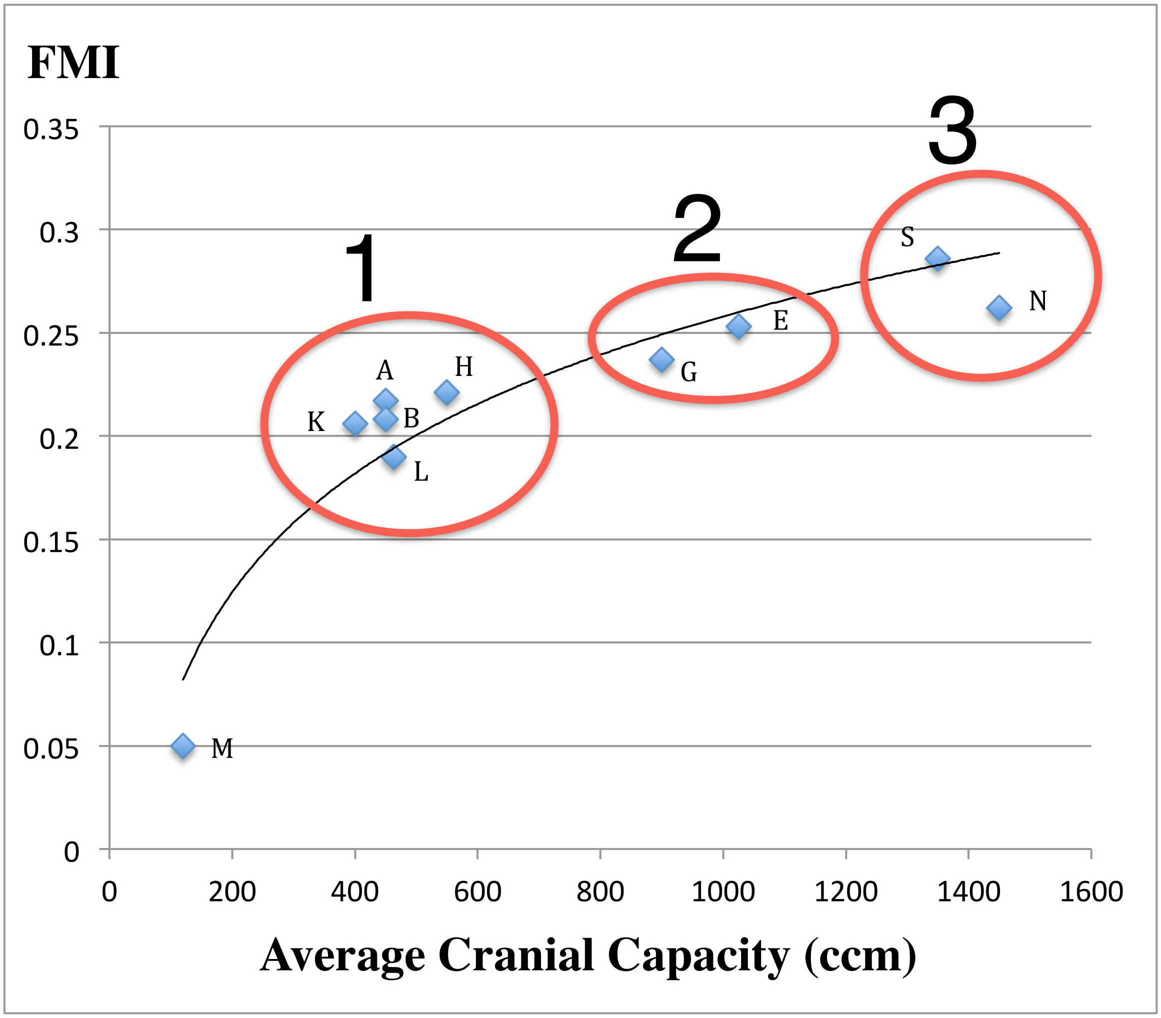
The final part of this period should be devoted to the students completing the Foramen Magnum Index graph, which illustrates the evolution of upright walking in hominins. On each of the 4 single letter coded scales representing a hominin species, the students will mark with a round dot the Foramen Magnum Index (Class FMI) they calculated earlier in Table 1. Discuss the progression of the index from left to right as an indication of how well adapted each species is/was to bipedal locomotion.



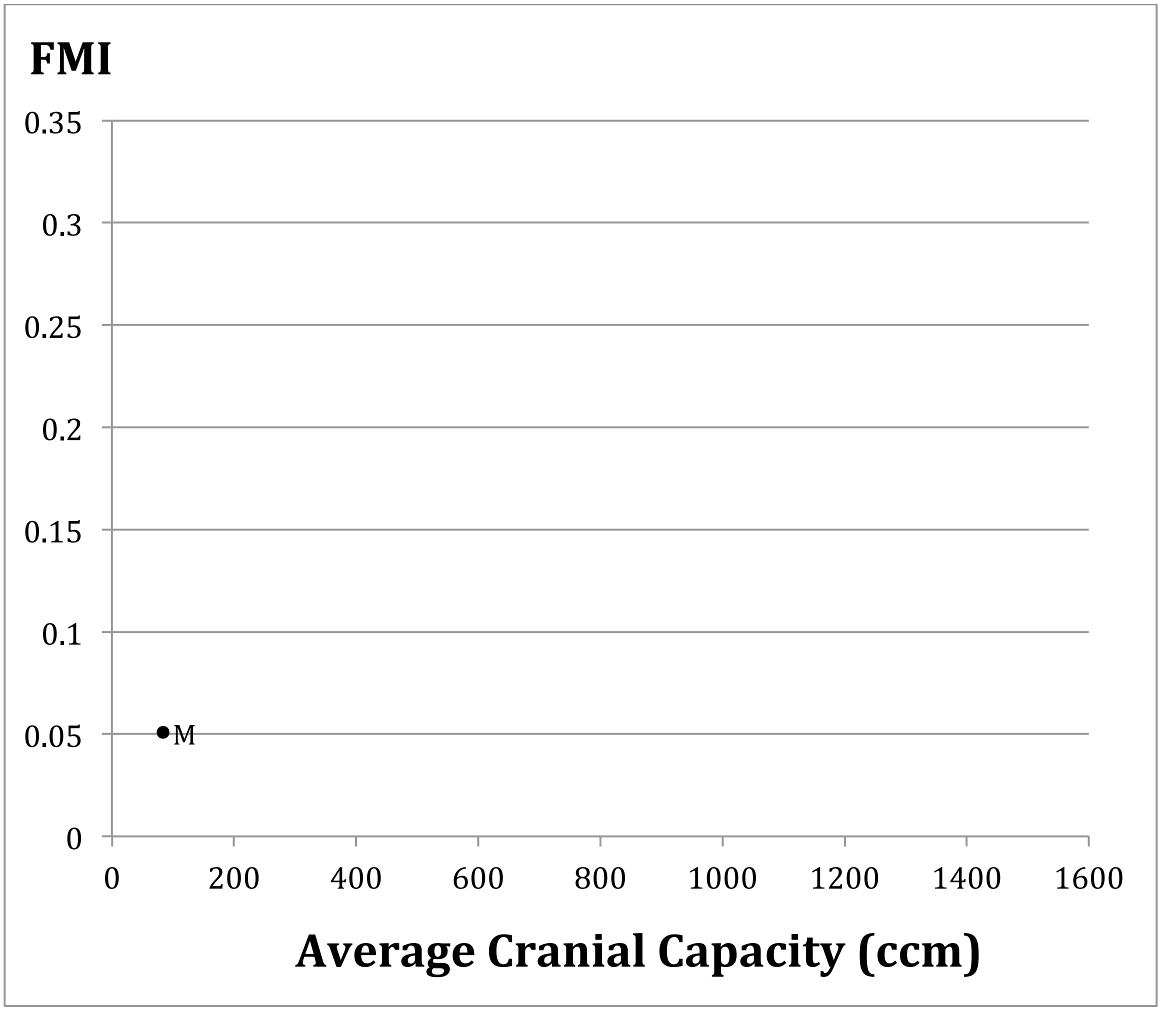
Foramen Magnum Index graph *(Teacher version)*

Above Foramen Magnum Indices are based on the FMI (FB/SL) column of the Table 1 (teacher version). Students will use their own data (Class FMI in Table 1).

During the third class period, the students will create a new graph that illustrates how cranial capacity and the central location of the foramen magnum evolved in hominins. For this exercise the student version includes a graph that is pre-populated with one data point M. M represents the macaque, an old-world monkey species that plays the role of a place holder for the dog we used for the Foramen Magnum Index graph (we do this mostly because dogs' cranial capacity varies enormously between different breeds). Macaques are very much quadrupedal and also spend a lot of their time on the ground, thus their foramen magnum is far to the back of their skull, similar to that of a dog. Students should by now have all the data in their Table 1 and will use the Class FMI and Average Cranial Capacity (Table 3) data to fill in the data points in the graph. Make sure they label each dot with the corresponding single letter code. Students may need help to come up with the best-fit curve (see teacher version of the graph below).



FMI-Cranial Capacity graph *(Teacher version)*



FMI-Cranial Capacity graph *(Student version)*

Please note that the data for M (macaque) are not included in the student version of Table 5. Students are asked to extrapolate those numbers from the point on the graph. This row is shaded in the table below to emphasize this detail.

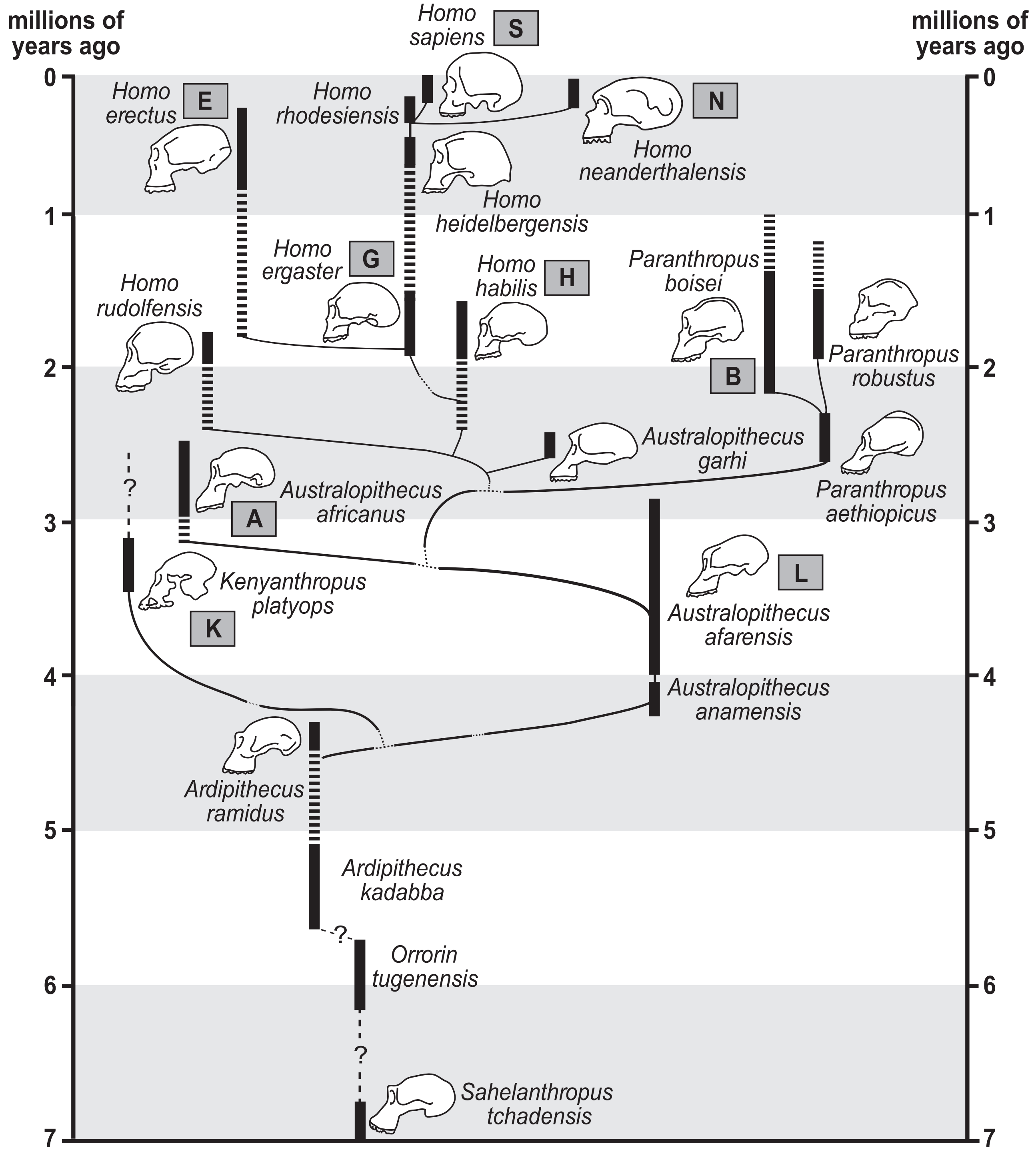
Table 5 (Teacher version)

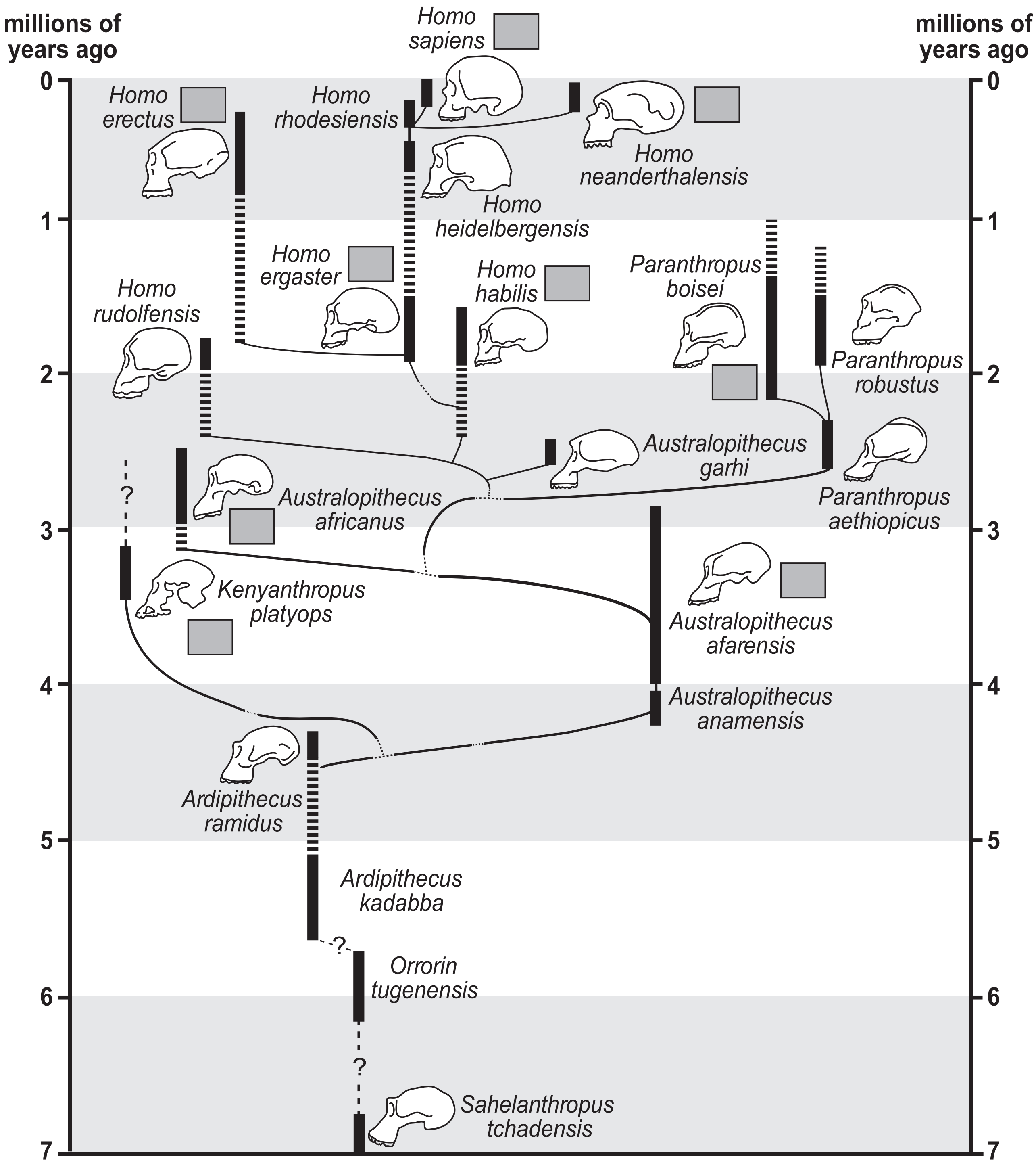
Skull Letter Code	Average Cranial Capacity (ccm)	Class FMI (from Table 1)
S	1350	0.286
N	1450	0.262
E	1025	0.253
G	900	0.237
H	550	0.221
A	450	0.217
B	450	0.208
K	400	0.206
L	463	0.190
M	90	0.050

The next task for this third period will be to complete the Phylogenetic Tree to reveal the complete picture of hominin evolution we have as of today. There are quite a few more species in the fossil record than what we worked with in this activity. To keep it relatively simple, only the species that the students are now familiar with from this activity have a little gray square next to them. The students' task is to assign the correct single letter codes to these species based on what they learned with regard to age (mya) of the fossils and characteristics of the skulls (compare the real skulls with the little pictures in the tree). The solid bars in the tree indicate a solid fossil record whereas the stippled bars designate less abundant fossil finds. An example that sticks out a bit is *Homo erectus*. This species is thought to have emerged from a group of hominins that included *H. ergaster* sometime between 1 and 2 mya, hence the connecting line in the tree. This tree nicely shows that during most of human evolution there were more than one hominin species living at the same time (see, e.g., the australopiths) until one single species, *Homo sapiens sapiens*, the modern human of today became the last and only survivor.

A nice way to conclude this activity would be to go back to the skull replicas and have the students create a tree by laying them out in rough chronological order and on a scale where 1 meter represents 1 million years. The entire class may participate and engage in discussions as to how the tree of skulls should look, thereby revisiting what they learned in this activity. This would also be the time for a teacher-guided discussion on evolution of hominins or primates in general.

This would also be the time for a teacher-guided discussion on hominin evolution or indeed primate evolution. CIBT offers a second skull kit that expands on the present activity with skulls dating back up to 35 mya. It also includes non-human primate skulls for comparison and for more in-depth discussion of human origins.


millions of years ago
0
1
2
3
4
5
6
7
Homo sapiens
S
Homo erectus
E
Homo rhodesiensis
N
Homo neanderthalensis
Homo heidelbergensis
Homo ergaster
G
Homo habilis
H
Paranthropus boisei
Homo rudolfensis
B
Paranthropus robustus
Australopithecus garhi
Paranthropus aethiopicus
?
Australopithecus africanus
A
Kenyanthropus platyops
K
L
Australopithecus afarensis
Australopithecus anamensis
Ardipithecus ramidus
Ardipithecus kadabba
?
Orrorin tugenensis
?
Sahelanthropus tchadensis



(Student version of ***Phylogenetic Tree****)*

Required Time

This activity will take approximately 4 standard periods to complete depending on student level and class size. **Part I (Collecting Your Data)** can be completed in 2 periods. **Part II (Organizing Your Data)** can be completed during the third period and students will need calculators to complete this task. **Part III (Analyzing Your Data)**, as well as analysis questions, should be finished during the fourth and last period. However, if class time is limited, only 2 standard class periods should be needed to complete the measurements of the skulls and exchange data. Calculations and graph construction can be assigned as independent homework. Analysis questions can also be completed independently.

Equipment and Supplies

Equipment and supplies included in the CIBT Hominin Skulls kit:

- 9 skulls
- 9 yellow CIBT metric-only rulers, (3 each for workstations 1-3)
- Special note for the AP extension: If your class size is larger than 18 or so, you might want to provide 3 additional rulers per workstation so that more than one skull's cranial capacity can be measured at a time
- 1 laminated Geological Time Scale Guide (not recommended for use with AP students)
- 6 laminated Skull Assessment Guides (2 pages each for workstations 1-3)

Notes/Recommendations

- We recommend that students use pencils to complete the tables and graphs so that errors can be easily corrected with an eraser.
- Laminated guides are provided for each workstation. For workstations 1-3 the 2-page guides are identical and include instructions for the skull assessments. Please note that the skulls used in the photos are different from those in the kit. For workstation 4 a single-page guide includes instructions for the Geological Time Scale graph, also showing an example for how to complete that task. We recommend that you do not set out that laminated guide for workstation 4 for the AP version of this lab.
- Since individual students vary in size, it may be helpful to pick a "model fist" in each group for estimating cranial capacity. In general, we consider the "average fist of a teenager" to be approximately 80 mm wide when measured with the hand flat on the table, from pinky to index finger across the knuckles. Also assign the role of a "model index finger" and "model thumb" in each group for estimating prognathism and forehead length – this choice is less critical since this assessment is less quantitative, simply make sure you don't pick an extreme within a group.
- It is critical to ensure that the students are looking at the ACTUAL foramen magnum and not at an artifact/hole in the skull further towards the front. Inexperienced students will need some guidance or might otherwise miss the foramen magnum because it is sometimes filled in.

- A value of 0.15 or greater for the FMI is commonly considered to be indicative of progressed bipedalism.
- All hominin species in this activity have canines that are **not** long or sharp. We included this feature in the activity mainly as a preparation for the comparison between hominins and non-human primates that is part of the extension kit.

Answers to Student Questions

Answers to Pre-Lab Questions

1. What is the difference between bipedal and quadrupedal?

    Bipeds walk on 2 legs, while quadrupeds walk on 4 legs.

2. Where is the foramen magnum located?

    The foramen magnum is located on the underside of the skull.

3. What is the function of the foramen magnum?

    The foramen magnum is the hole in the skull through which the spinal cord attaches to the brain.

4. How many species of extinct hominins have been described by paleoanthropologists?

    About 20.

5. Why is the task to classify fossil organisms more difficult than the task to classify living organisms?

    Classification of fossil organisms is especially difficult because it is very rare to find an entire skeleton. Instead, usually only a skull, a skull fragment or some other body part is found. Only recently fossil DNA has been shown to be useful for classification purposes.

Answers to Peri-Lab Questions

Compare your data for FMI to the class FMI, which is based on average class data.

1. Why is the class FMI usually a better indicator of the location of the foramen magnum than your individual calculation?

    Increased sample size provides more reliable data.

Compare the data that you calculated for cranial capacity (CCC) to the Actual Cranial Capacity (ACC), which has been determined by scientists, in Table 1.

2. Which of your calculations have overestimated the cranial capacity?

    A, B, K, L

3. Which of your calculations have underestimated the cranial capacity?

S, N

4. Which of your calculations are within the range of the Actual Cranial Capacity?

   E, G, H

5. What could you do to get your Calculated Cranial Capacity value closer to the actual value?

   Use better/more accurate measuring tools than your fist.

6.a Imagine using ping pong balls instead of fists as your unit of measure for cranial capacity, do you think that your calculated value would be closer to or further from the actual value?

Probably closer provided there is a good estimate available for the volume of a ping-pong ball.

6.b Why?

Better resolution with smaller unit of measure.

7.a What about using an even smaller unit of measure, such as grains of rice or sand? Do you think that your calculated value would be closer to or further from the actual value?

The answer could go both ways considering the better resolution of the small unit of measure, but also taking into account the difficulty to accurately count the grains and then multiplying that number with a given volume per grain of rice.

7.b Why?

See answer for 7a)

7.c What new problems might you encounter when using such small units of measure?

Difficulty of counting small units.

7.d How could you overcome those problems? What tools could you use?

Use an appropriate tool to measure volume such as a graduated cylinder to determine the total volume of the grains of rice.

8.a After measuring the skull volume using rulers, you applied a correction factor to arrive at your ESV. Why was a correction factor necessary?

LxHxW measures a cube-like volume. Hominin skulls are not cubes and the measurement therefore would overestimate cranial capacity. By using the rulers in the prescribed way, non-braincase volume is included in the measurement, whereas the fist estimates are approximating the cranium only. Another, smaller component would be the thickness of the skull bones themselves, which are included in the ruler measurements, but are not part of the cranial capacity.

8.b Why was a different correction factor used for different groups of species?

Different species have differently shaped craniums.

8.c What was the shape of the cranium of the skulls for which you applied a correction factor 2?

C.

8.d What was the shape of the cranium of the skulls for which you applied a correction factor 3?

S.

9. Which time interval has the greatest number of hominin species coexisting?

1.6 to 1.8 mya.

10. What is the time period during which species S has been the only surviving hominin?

30,000 years ago to present

11. Examine the Foramen Magnum Index graph. Do you notice any trend in the FMI as you look from left (dog) to right (human) among the hominin skulls? And if so, describe it.

Trend is increasing towards 0.3.

12. Determine which of the skulls in this graph is the oldest by looking at the Geological Time Scale graph. Now, compare the FMI of this oldest species to that of the dog and human. Do you think that this species was bipedal or quadrupedal? Why?

L (Lucy) is bipedal, or bipedal but not in the same perfectly upright manner that today's humans walk. Reason: the FMI is lower than in Homo sapiens, but much higher than that of the dog.

13. Which of the 4 species (L, H, G, N) is best adapted to upright walking? Why?

N since the FMI is 0.262, which is close to the modern human.

14. Do any of the Class FMI in Table 1 closely match the one provided for the human in your graph? If so, which one(s)?

Yes, S.

15.a Excluding the macaque M, group the 9 species into 3 clusters of two or more points that are near each other. Draw a circle around each cluster and list the letters for each of these clusters.

See circles in teacher version of FMI-Average Cranial Capacity graph.

15.b Comparing cluster 1 (with 5 data points) to M (macaque), which variable accounts for the major difference between them, FMI or Cranial Capacity?

FMI.

15.c Comparing cluster 2 (with 2 data points to the right of cluster 1) to cluster 1, which variable accounts for the major difference between them, FMI or Cranial Capacity?

Cranial Capacity.

15.d Comparing cluster 3 to cluster 2, which variable accounts for the major difference between them, FMI or Cranial Capacity?

Cranial Capacity.

15.e Using the Geological Time Scale graph as a reference, list the three clusters in order of their relative age:

*cluster #_1_ is older than cluster #_2_ is older than cluster #_3_*

15.f As you go from oldest to most recent cluster of hominin species, which factor (FMI or Cranial Capacity) changed more?

Cranial Capacity.

Answers to Post-Lab Questions

1.a Concluding from the Phylogenetic Tree, what is the greatest number of hominins that coexisted?

5.

1.b List the names of these species (your answer may include species that were not represented by skull specimens in this activity).

Homo rudolfensis, Homo ergaster, Homo habilis, Paranthropus boisei, Paranthropus robustus.

1.c What is the approximate time period during which these multiple species coexisted?

1.9 - 1.8 mya, but anything between 2.0 and 1.7 mya will do.

2.a Based on your answers for question 15, what was the driving force in early hominin evolution?

FMI or more specifically, the movement of the foramen magnum towards a more forward position in favor of bipedalism.

2.b What was the driving force in later hominin evolution?

The increase in cranial capacity.

3.a What trend do you notice in the shape of the cranium as hominin evolution progresses?

Trend from Spheroid (S) to Cuboid (C).

3.b. Why do you think this trend occurred?

Since the volume of a cube is bigger than the volume of a sphere with the same diameter, one way of increasing cranial capacity is to develop a more box-shaped (cuboid) than ball-shaped (spheroid) cranium.

4.a Looking at the oldest fossil in the tree, *Sahelanthropus tchadensis*, and based on the evidence you collected during this investigation, which of the 9 species that you studied would you predict is most similar to this old hominin with regard to cranial capacity?

Kenyanthropus platyops.

4.b And with regard to FMI?

Australopithecus afarensis.

4.c Does the Phylogenetic Tree support your hypotheses for 4.a and b?

Yes. Note: Both species are very old and low on the hominin evolution tree, so they are to be expected to have a rather low FMI and cranial capacity according to the trends discussed in question 15.

A. afarensis is the oldest species studied in this activity and its FMI is also the lowest, as expected. The cranial capacity is a little bigger than that of K. platyops even though the latter appeared later in hominin evolution. However, K. platyops seems to be a branch that resulted in a dead end while A. afarensis seems to have existed longer and given rise to more modern hominins.

4.d Go back to the FMI-Average Cranial Capacity graph that you completed earlier. Place a mark (use a big X) on the best-fit curve for *Sahelanthropus tchadensis*. Explain your reasoning for the placement of your X in the graph.

The X should be placed anywhere on the best-fit curve between the datapoint M (macaque) and Cluster 1, but closer to Cluster 1 than to M as Sahelanthropus is considered a hominin (or close to the last common ancestor of humans and chimpanzees) with a cranial capacity of 350 ccm and an FMI of 0.17 (measured by the authors in the described way using skull TM 266).

Other Resources

Videos:

- NOVA: Becoming Human. 2009. A 3-part series that explores the origins of humans.
- Secrets of the Dead: The Search of the First Human. Explores bipedalism in an early hominin, *Orrorin tugenensis*, using forensic techniques.

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Hominin Skulls

New York State Learning Standards

Standard 1: Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

Key Idea 1:

The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing and creative process.

Performance indicator 1.1: Elaborate on basic scientific and personal explanations of natural phenomena, and develop extended visual models and mathematical formulations to represent one's thinking.

Major Understandings

1.1a Scientific explanations are built by combining evidence that can be observed with what people already know about the world.

1.1b Learning about the historical development of scientific concepts or about individuals who have contributed to scientific knowledge provides a better understanding of scientific inquiry and the relationship between science and society.

Performance indicator 1.3: Work toward reconciling competing explanations; clarify points of agreement and disagreement.

Major Understandings

1.3a Scientific explanations are accepted when they are consistent with experimental and observational evidence and when they lead to accurate predictions.

1.3b All scientific explanations are tentative and subject to change or improvement. Each new bit of evidence can create more questions than it answers. This leads to increasingly better understanding of how things work in the living world.

Key Idea 3:

The observations made while testing proposed explanations, when analyzed using conventional and invented methods, provide new insights into natural phenomena.

Performance indicator 3.1: Use various methods of representing and organizing observations (e.g., diagrams, tables, charts, graphs, equations, matrices) and insightfully interpret the organized data.

Major Understandings

3.1a Interpretation of data leads to development of additional hypotheses, the formulation of generalizations, or explanations of natural phenomena.

Standard 4: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

Key Idea 3:

Individual organisms and species change over time.

Performance indicator 3.1: Explain the mechanisms and patterns of evolution.

Major Understandings

3.1a The basic theory of biological evolution states that the Earth's present-day species developed from earlier, distinctly different species.

3.1e Natural selection and its evolutionary consequences provide a scientific explanation for the fossil record of ancient life-forms, as well as for the molecular and structural similarities observed among the diverse species of living organisms.

3.1f Species evolve over time. Evolution is the consequence of the interactions of (1) the potential for a species to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, and (4) the ensuing selection by the environment of those offspring better able to survive and leave offspring.

3.1g Some characteristics give individuals an advantage over others in surviving and reproducing, and the advantaged offspring, in turn, are more likely than others to survive and reproduce. The proportion of individuals that have advantageous characteristics will increase.

3.1h The variation of organisms within a species increases the likelihood that at least some members of the species will survive under changed environmental conditions.

3.1i Behaviors have evolved through natural selection. The broad patterns of behavior exhibited by organisms are those that have resulted in greater reproductive success.

3.1k Evolution does not necessitate long-term progress in some set direction. Evolutionary changes appear to be like the growth of a bush: Some branches survive from the beginning with little or no change, many die out altogether, and others branch repeatedly, sometimes giving rise to more complex organisms.

3.1l Extinction of a species occurs when the environment changes and the adaptive characteristics of a species are insufficient to allow its survival. Fossils indicate that many organisms that lived long ago are extinct. Extinction of species is common; most of the species that have lived on Earth no longer exist.

Laboratory Checklist

- Uses metric ruler to measure length
- Collects, organizes, and analyzes data, using a computer and/or other laboratory equipment
- Organizes data through the use of data tables and graphs
- Analyzes results from observations/expressed data
- Formulates an appropriate conclusion or generalization from the results of an experiment

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The Mystery of the Skulls: What Old Bones Can Tell Us About Hominins

Name:____

In this laboratory activity, you and your investigative team will examine 9 skulls to expose the secrets of how these species lived. In a CSI-type analysis, your team will collect and compare data that will enable you to unlock the mystery of the relatedness of these species.

Introduction

When scientists discover an organism, whether it is a fossil or a living species, they set out to determine whether this organism is a new species or one that has already been described. With living, or recently dead specimens, this task is reasonably easy because usually an entire body is found, or because DNA analysis can be used to compare the specimen to other known species. With fossils, the task is much more difficult because most of the time only a skull, a fragment of a skull, or some other part of the body is found. Scientists must then determine how similar or different it is to species that are already described. In some cases, the differences are so significant that they cannot be explained as individual differences or differences between the sexes. In these cases, scientists decide that they have found a new species. From here, again they make comparisons to other described species to decide how to classify their new discovery. Organisms that are similar to those already described would be placed in the same genus, while those that are very different would be classified in a different genus, or even a different family within the accepted classification system.

The study of human origins is known as paleoanthropology. Paleoanthropologists have found about 20 extinct species that are closer to humans than to other primates such as chimpanzees, gorillas, baboons, and macaques. These species are known as hominins (the older synonym hominid is still used in some textbooks). Among hominins, skulls of different species have specialized features that are used to classify them. These features include, among others, the presence or absence of a brow ridge, cranial capacity (the volume of the braincase), and the placement of the foramen magnum (the hole in the underside of the skull through which the spinal cord attaches to the brain). You will examine the same features that scientists do in the skulls that you will be working with. These features will help you to determine how closely related the skulls are to each other.

One of the most exciting aspects of examining old bones, however, is that they can reveal information about how the organism lived. Just from information gathered from the bones, scientists can determine whether the species walked on 2 legs (bipedal) or 4 legs (quadrupedal).

Pre-Lab Questions

1. What is the difference between bipedal and quadrupedal?

2. Where is the foramen magnum located?

3. What is the function of the foramen magnum?

4. How many species of extinct hominins have been described by paleoanthropologists?

5. Why is the task of classifying fossil organisms more difficult than the task of classifying living organisms?

Procedure Part I: *Collecting Your Data*

Your classroom will be set up with 4 workstations through which you and your team will rotate. Three of these stations include 3 skulls, and you will make observations and measurements that you will record and use later to determine the identity and relatedness of these specimens. At the fourth station, you will be asked to graphically represent the time during which each of the hominins lived. You will have approximately 10 minutes at each station during which to make your observations and measurements OR to make your graph.

Look for the letter codes written on the underside of each skull. Your investigative team's mission is to identify each skull with its proper scientific name and figure out how it is related to the other skulls.

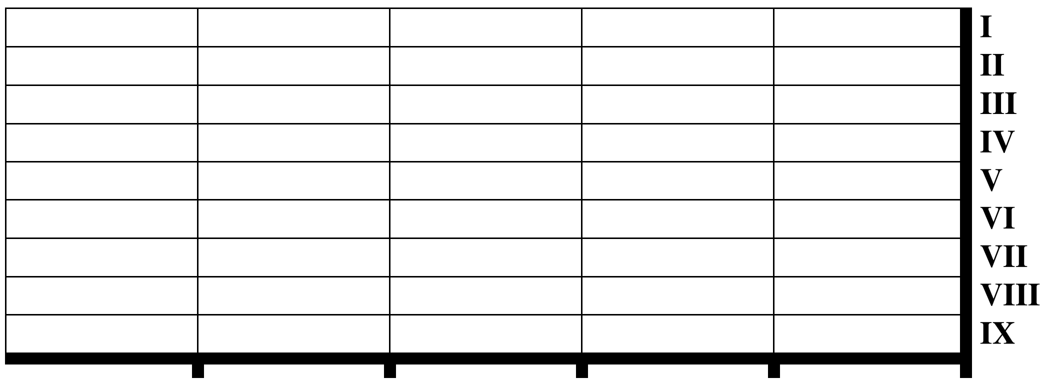
Skulls found at 3 workstations:

Station 1	Station 2	Station 3
S	G	B
N	H	K
E	A	L

At **Station 4** you will create a geological time scale. First you should label the Geological Time Scale graph so that 0 years (= present time) is set far to the right on the x-axis, and each tick mark represents one million years ago (mya). Remember that we are going BACKWARDS in time, so it might help to think of the years as "negative" years from the present, i.e., 2 mya = - 2 million years from the present, hence further to the left on the x-axis.

You should mark/shade the following time periods on each bar of the graph starting with the top one:

(I) 160,000 years ago to present
(II) 200,000 to 30,000 years ago
(III) 1.8 to 0.2 mya
(IV) 1.9 to 1.5 mya
(V) 2.4 to 1.6 mya
(VI) 3.0 to 2.4 mya
(VII) 2.2 to 1.0 mya
(VIII) 3.5 to 3.3 mya
(IX) 4.0 to 2.7 mya



Geological Time Scale (mya)

Each Roman numeral represents the time period for one of the 9 skulls. Think of each time period as a fossil layer in which a skull was discovered. From a collaborating lab that performs radiometric dating of fossils, you received the age of each of the fossil layers (I through IX), and will later pair these ages up with the identity of the skulls found in these layers (your teacher will provide you with the corresponding letter codes at a later time). As an investigator, you will want to establish the relationship between these layers and the corresponding skulls – see the column labeled "Age" in Table 1. Once you have filled in the graph above, you will later be able to determine the time intervals during which each species lived, and possibly coexisted with others. Remember, not all fossils were found in the same location, or even the same continent. You will eventually place this information in a phylogenetic tree that shows the relatedness of these and other hominin species.

At **Stations 1 – 3**, you will be presented with 3 skulls at a time and should fill out the table below by looking at 1 feature at a time. When you are examining the skulls, you should collect the data to complete the following: FL, SC, BR, P/S, CL, FB, SL, CC. If you have time left before you have to rotate to the next workstation, you may calculate the FMI (Foramen Magnum Index, see directions below), otherwise leave this calculation for a later time. The gray shaded columns (Class AVG FB, Class AVG SL, and CLASS FMI) and the last three columns (CCC, ESV, ACC, and Age) should be left blank for now – you will return to them later. **Make sure that you record your data in the row (Skull Letter Code in the leftmost column) that corresponds to the particular skull that you are examining.**

FL - Forehead Length: Look at the front of the skull and determine if the forehead is Long (L) or Short (S). The forehead is roughly the area from the top of the eye socket to the part of the skull that begins to flatten. Visualize your own forehead and imagine the part between your eyebrows to where your hairline begins. This is the forehead. If this length is at least the length of the average thumb, we consider it to be Long (L).

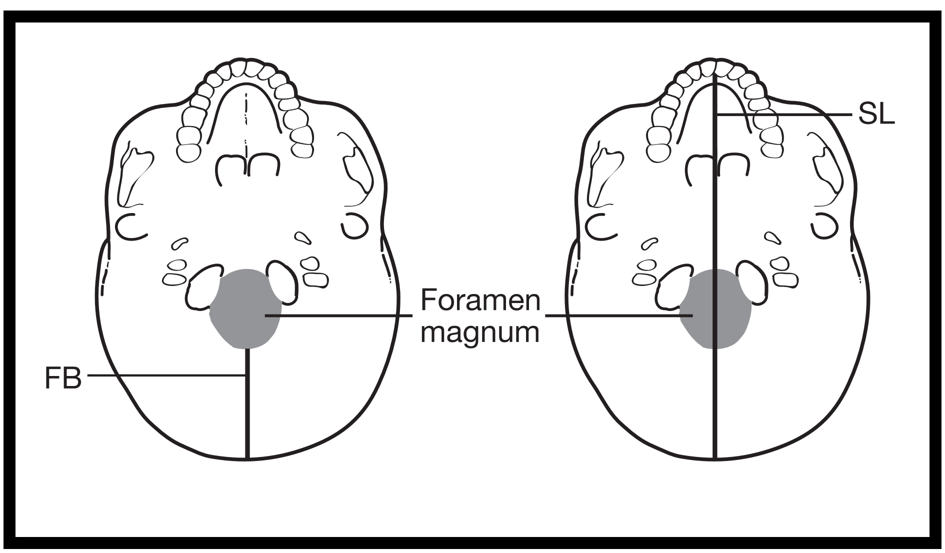
SC - Sagittal Crest: Look at the top of the skull and determine if a sagittal crest is present (+) or absent (-). A sagittal crest is a ridge of bone that protrudes from the skull and runs on top of the skull from front to back.

BR - Brow Ridge: Look at the front of the skull and determine if a brow ridge is present (+) or absent (-). A brow ridge is a bone that runs the entire width of the skull just above the eyes.

P/S - Prognathism/Snout: Look at the front of the skull and determine if it exhibits prognathism (+) or not (-). Prognathism refers to the protrusion of the mouth from the front of the skull. Animals with prognathism are thought of as having a ‘snout’. To determine if a skull exhibits prognathism, press your fingers along the base of the nose opening (Anterior Nasal Spine) and rest it on the top of the maxilla (where the top teeth attach). If this area is greater than 1 index finger in width, then we consider the skull to exhibit prognathism.

CL - Canines Long (and sharp): Look at the teeth in the top of skull and determine if the canines are long and sharp (+) or (-). The canines are sometimes referred to as ‘fangs’. They are the third pair of teeth from the front – in your mouth, your 2 front teeth and the next one in each direction are called ‘incisors’. The next tooth on either side is slightly pointy and called ‘canine’, but in many animals, like dogs and cats, these canines are very long and sharp. If the canines are not present in the skull, the cell in the table has been blackened out. If you notice that the canines are ‘fang-like’, we consider them to be long and sharp (+).

FB - Foramen Magnum Distance to Back (mm): Look at the underside of the skull and determine the distance between the foramen magnum and the back of the skull, measured in mm). The foramen magnum is the hole in the skull through which the spinal cord attaches to the brain. To determine this distance, place a ruler on the base of the skull, starting at the back most edge of the foramen magnum and measure the distance to the end of the skull (see diagram below). Be sure to follow the directions that were demonstrated by your teacher.



SL - Skull Length (mm): Look at the underside of the skull and determine the length of the skull (measured in mm). Place a ruler on the base of the skull (see diagram above) and measure the distance from the back of the skull to the end of the palate (roof of the mouth). Be sure to follow the directions that were demonstrated by your teacher.

FMI - Foramen Magnum Index: Calculate the ratio using the Foramen Magnum Distance to Back (FB) and the Skull Length (SL). To do this for each skull, divide the value that you recorded for FB by the value that you recorded for SL, and fill in the corresponding box to the 3rd digit after the decimal point.

CC - Cranial Capacity: Look at the skull from the top and sides and estimate the number of average fists that would fit inside the cranium (the area of the skull where the brain is located). For these skulls, limit your estimate to 2, 3 or 4.

Table 1

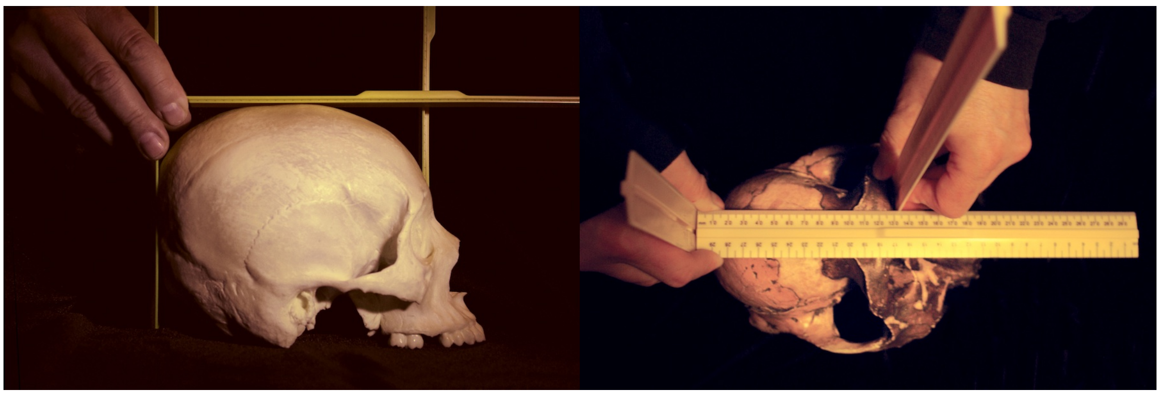
Skull Letter Code	FL (S, L)	SC (+,-)	BR (+,-)	P/S (+,-)	CL (+,-)	FB (mm)	Class AVG FB	SL (mm)	Class AVG SL	FMI (FB/ SL)	Class FMI (AVG FB/ AVG SL)	CC (2, 3, 4 "fists")	CCC (CC x 300 cm^3)	ESV (cm^3)	ACC (cm^3)	Age
S																
N																
E																
G																
H																
A																
B																
K						34		165		0.206						
L																

Next you will take additional measurements of the skulls and eventually compare these measurements to the ones that you made previously using your fists to estimate cranial capacity.

You and your team will rotate through the sets of skulls again, this time taking measurements to estimate the volume of the skulls. Once again, you will be presented with

3 skulls at a time. You should collect the data to complete the columns L, W, and H of **Table 2**. **DO NOT calculate ASV (Approximate Skull Volume) at this time** because you will be using the class data to make these calculations. The gray shaded columns Class AVG L, Class AVG W, Class AVG H, and ESV (Estimated Skull Volume) should be left blank for now – you will return to them later.

L – Length of the braincase: Position three rulers as shown on the left side of the photograph below. Ruler 1 should stand perpendicular to the table, and rest at the back of the skull. Ruler 2 should also stand perpendicular to the table, but rest on top of the skull, just behind the brow ridge. If a brow ridge is not present, align the ruler against the forehead in the same perpendicular orientation (imagine it flat against your forehead). Ruler 3 should rest on the highest point of the cranium, making sure that it is parallel with the table. Once all 3 rulers are in place, read the distance on ruler 3 between the 2 upright rulers in mm (see the right side of the photograph below). Record your data in the first column labeled "L".



Skull length measurements for two different species: View from the side (left), view from the top (right).

H – Height of the braincase: Without moving the 3 rulers from your measurement of Length, read the height of the skull off ruler 1 (at the back of the skull) in mm (also see photographs below). Record your data in the first column labeled "H".

Skull height measurement: view from the side for two different species. Note: upright ruler in the front of skull is removed.

W – Width of the braincase: Position 3 rulers as shown in the photographs below. Rulers 1 and 2 should stand perpendicular to the table and flat against the skull (imagine 2 rulers flat against where the ears would be positioned). Position ruler 3 resting on the top of the skull, making sure that it is parallel with the table. Read the distance between rulers 1 and 2 in mm. Record your data in the first column labeled "W".

Skull width measurement for two different species with the three rulers perpendicular to each other. Note the placement of the upright rulers on the sides: for the species on the right photograph, the rulers are not at the widest point of the skull (the 'zygomatic arch' or cheek bone), but at the widest point of the braincase further back.

Next you will assess the approximate shape of each cranium:

Cranium Shape – Look at each skull from the top. Specifically, look at the shape of the cranium (the part of the skull where the brain is located). If the shape is boxy, we consider it to be Cuboid (C). In other words, it more closely resembles that of a box than that of a ball. If the shape is rounded, then we consider it to be Spheroid (S). In other words, it more closely resembles that of a ball than that of a box.

Table 2

Skull Letter Code	L (mm)	Class AVG L	W (mm)	Class AVG W	H (mm)	Class AVG H	ASV (LxWxH/1000) (cm^3)	ESV (cm^3)	Cranium Shape (C/S)
S									
N									
E									
G									
H									
A									
B									
K									
L									

All of the measurements in this table should be taken with the top of the skull facing upwards (natural resting position) with the lower jaw removed.

Procedure Part II: *Organizing Your Data*

Once you have collected all the data for Tables 1 and 2 in Part I of the lab, you can begin organizing your data (if you have not already calculated FMI, you should do so now). You also will begin calculations for comparative analysis so that you can draw conclusions about relatedness of these 9 hominins. To do so, fill in the Table 3 below following your teacher's guidance. Once you and your team have gathered all of the data for Table 1, you will need to compile the data from all other teams for FB and SL into Table 3. When you have compiled the class data, you can then calculate the class average for FB (Class AVG FB) and SL (Class AVG SL); and from these data you can calculate the Class FMI (AVG FB/AVG SL). These calculated averages can then be transferred into the corresponding gray shaded columns in Table 1.

Table 3

Skull Letter Code	FB (mm)	FB (mm)	FB (mm)	FB (mm)	Class AVG FB	SL (mm)	SL (mm)	SL (mm)	SL (mm)	Class AVG SL	Class FMI AVG FB/ AVG SL
S											
N											
E											
G											
H											
A											
B											
K											
L											

To complete Table 4, copy your L, W and H data from Table 2 into the first columns with the corresponding labels in Table 4. Collect the data from the other teams in your class and complete Table 4 by calculating the average for L, W and H (Class AVG L, Class AVG W, Class AVG H) **and record these averages in the corresponding gray shaded columns of Table 4, and then Table 2 as well.** Now you can complete your calculations for ASV and ESV in Table 2, which are defined as follows:

ASV - Approximate Skull Volume: calculate the product of AVG L, AVG H, and AVG W, and divide your answer by 1000.

ESV - Estimated Skull Volume: the measurements that you took of the skull will overestimate the cranial capacity because skulls are not cubes. To correct this, you should divide the number that you calculated in the previous column (ASV) by 2 for species S, N, E, G and H, and by 3 for all other species (A, B, K and L). You use a different correction factor for each group of skulls because the skull shapes vary between the two groups.

Table 4

Skull Letter Code	L (mm)	L (mm)	L (mm)	L (mm)	Class AVG L	W (mm)	W (mm)	W (mm)	W (mm)	Class AVG W	H (mm)	H (mm)	H (mm)	H (mm)	Class AVG H
S															
N															
E															
G															
H															
A															
B															
K															
L															

Next, convert your fist estimates for Cranial Capacity (CC) into an approximate measurement (CCC) by using the formula CC x 300 cm^3 - the estimated volume of an average human fist is 300 cm^3. These calculations can be added to Table 1.

At this point in time, your teacher will provide you with the Actual Cranial Capacity (ACC) for each skull based on scientists' measurements. Use these data to complete the appropriate column in Table 1.

Compare your data for FMI to the class FMI, which is based on average class data.

1. Why is the class FMI usually a better indicator of the location of the foramen magnum than your individual calculation?

Compare the data that you calculated for cranial capacity (CCC) to the Actual Cranial Capacity (ACC), which has been determined by scientists in Table 1.

2. Which of your calculations have overestimated the cranial capacity?

3. Which of your calculations have underestimated the cranial capacity?

4. Which of your calculations are within the range of the Actual Cranial Capacity?

5. What could you do to get your Calculated Cranial Capacity value closer to the actual value?

6.a Imagine using ping pong balls instead of fists as your unit of measure for cranial capacity, do you think that your calculated value would be closer to or further from the actual value?

b. Why?

7.a What about using an even smaller unit of measure, such as grains of rice or sand? Do you think that your calculated value would be closer to or further from the actual value?

b. Why?

c. What new problems might you encounter when using such small units of measure?

d. How could you overcome those problems? What tools could you use?

8.a After measuring the skull volume using rulers, you applied a correction factor to arrive at your ESV. Why was a correction factor necessary?

b. Why was a different correction factor used for different groups of species?

c. What was the shape of the cranium of the skulls for which you applied a correction factor 2?

d. What was the shape of the cranium of the skulls for which you applied a correction factor 3?

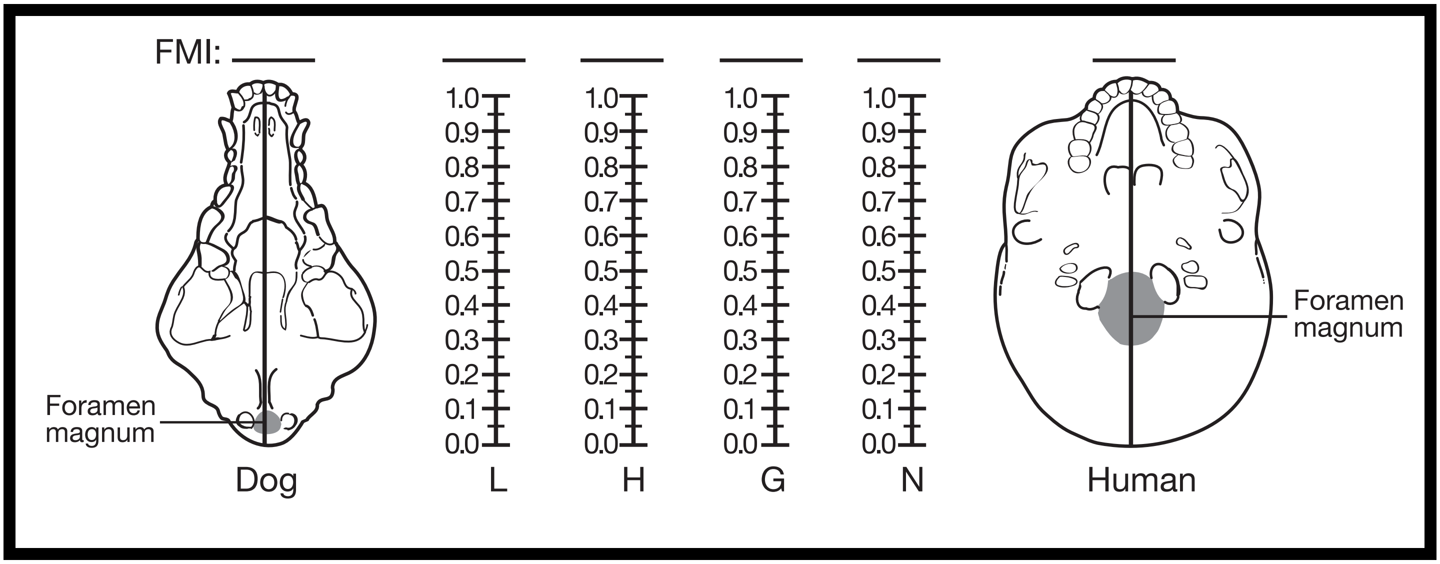
Your teacher will now also provide you with the Skull Letter Codes that correspond to each time period in your Geological Time Scale graph. Once your teacher has identified the time period that corresponds to each skull, write the single letter code for each skull in the area that you shaded within the Geological Time Scale graph. Once you have added the single letter codes into this graph, you can then transfer these identified ages into the appropriate places in the last column (Age) of Table 1.

9. Which time interval has the greatest number of hominin species coexisting?

10. What is the time period during which species S has been the only surviving hominin?

As scientific investigators, your team will now begin to compare the data that you have collected from different skulls. Specifically, you will put some of your Class FMI data onto a graph in order to compare them to each other.

The location of the foramen magnum in the skulls will reveal some interesting information about the way that the hominins lived. The FMI is an indicator of the location of the foramen magnum on the underside of the skull. The closer to 0.3 the FMI of a species is, the better adapted this hominin is to upright/bipedal walking. In order to visualize any trends in the location of the foramen magnum among the hominin skulls, you will enter the Class FMI for the 4 skulls (L, H, G, N) on the Foramen Magnum Index graph (see below). Determine the FMI for dog (a quadruped) and human (a biped) using the scales provided. Focus on the bottom end of the foramen magnum, which is labeled for these two species and write this number on the line above the diagrams of these 2 skulls. Next in Table 1, locate the Class FMI values for the 4 other hominin species (L, H, G, N). Write these values on the lines above each corresponding scale. Now you can plot your numbers on the provided scales with round dots approximately the same size of the illustrated foramen magnum of the dog.



Foramen Magnum Index graph

11. Examine the Foramen Magnum Index graph. Do you notice any trend in the FMI as you look from left (dog) to right (human) among the hominin skulls? And if so, describe it.

12. Determine which of the skulls in this graph is the oldest by looking at the Geological Time Scale graph. Now, compare the FMI of this oldest species to that of the dog and human. Do you think that this species was bipedal or quadrupedal? Why?

13. Which of the 4 species (L, H, G, N) is best adapted to upright walking? Why?

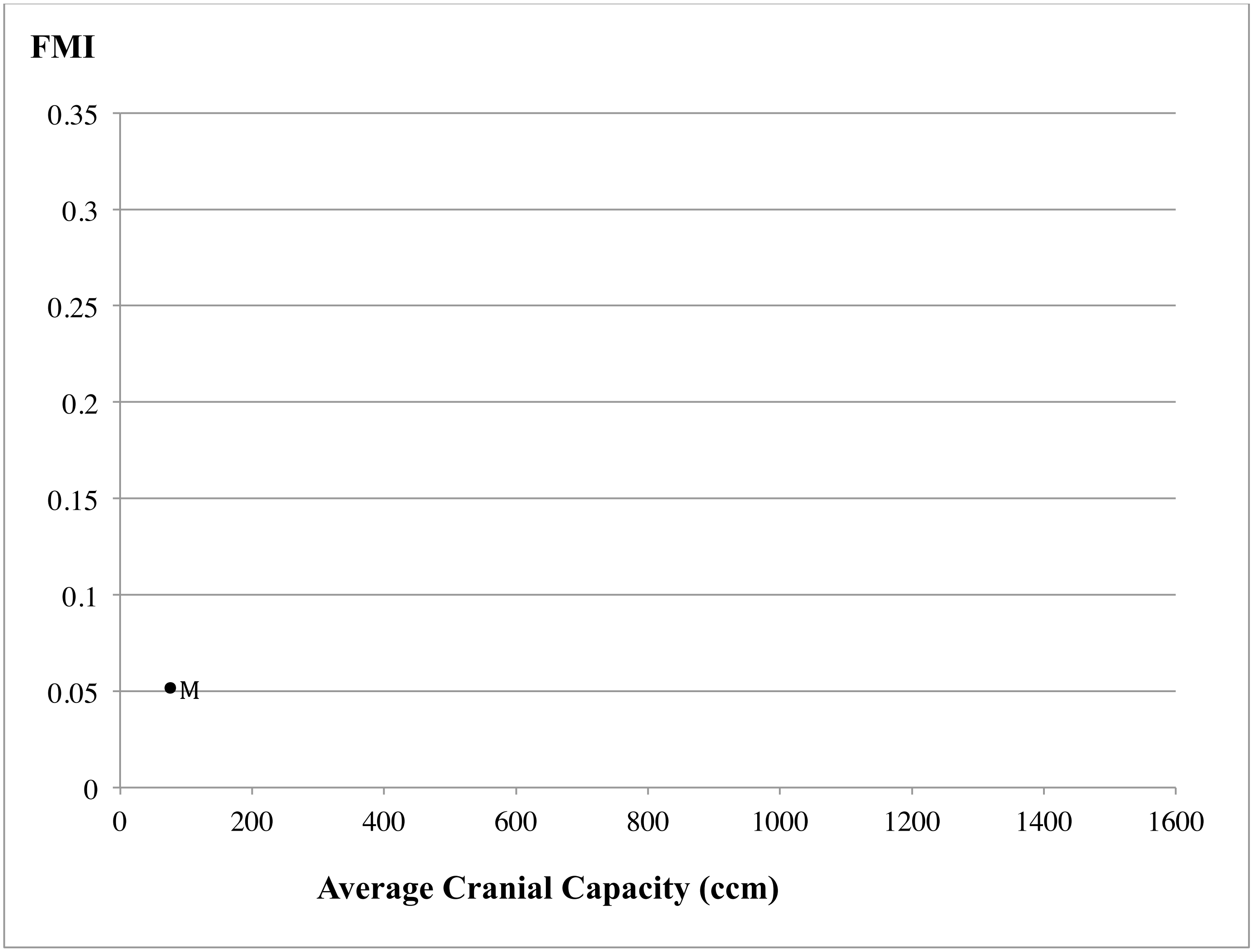
14. Do any of the Class FMI in Table 1 closely match the one provided for the human in your graph? If so, which one(s)?

Procedure Part III: *Analyzing Your Data*

In order to determine whether a relationship exists between the Foramen Magnum Index and Cranial Capacity, you will plot these two parameters for each species in the provided FMI-Cranial Capacity graph below. For this you need to first complete Table 5 using your Class FMI from Table 1. The provided Average Cranial Capacity is based on the Actual Cranial Capacity (ACC), also from Table 1. You will notice that there is a new Skull Letter Code "M" in Table 5. This "M" is also the only data point already filled in on the FMI-Cranial Capacity graph and represents the macaque, an old-world monkey species that is quadrupedal. From this data point "M" you can determine the macaque's Average Cranial Capacity and FMI and add them to Table 5. With Table 5 now completed, plot the values in the graph and write the Skull Letter Code next to each data point. **Do not connect the dots with lines.** Instead, once you have plotted the points for all of the skulls, you should draw a "best-fit curve". While there is a way to mathematically determine the location of such a curve, you can estimate it by visualizing the sum of the distances from each point above and below the curve. These 2 sums should be approximately the same. If you are having trouble finding the best-fit curve, your teacher will assist you.

Table 5

Skull Letter Code	*Average Cranial Capacity (ccm)*	*Class FMI (from Table 1)*
S	1350	
N	1450	
E	1025	
G	900	
H	550	
A	450	
B	450	
K	400	
L	463	
M		



FMI-Cranial Capacity graph

15.a Excluding the macaque M, group the 9 species into 3 clusters of two or more points that are near each other. Draw a circle around each cluster and list the letters for each of these clusters.

b. Comparing cluster 1 (with 5 data points) to M (macaque), which variable accounts for the major difference between them, FMI or Cranial Capacity?

c. Comparing cluster 2 (with 2 data points to the right of cluster 1) to cluster 1, which variable accounts for the major difference between them, FMI or Cranial Capacity?

d. Comparing cluster 3 to cluster 2, which variable accounts for the major difference between them, FMI or Cranial Capacity?

e. Using the Geological Time Scale graph as a reference, list the three clusters in order of their relative age:

cluster #___ is older than cluster #___ is older than cluster #___

f. As you go from oldest to most recent cluster of hominin species, which factor (FMI or Cranial Capacity) changed more?

Part IV: *Putting It All Together*

In this final part of the investigation you will combine your results with data that other scientists have already collected. Specifically your goal is to complete a phylogenetic tree that shows how all these hominins are related to each other and how paleanthropologists concluded that they have evolved. This phylogenetic tree contains many more species than the 9 that you have been studying. In this phylogenetic tree all the hominins are already correctly placed regarding their ages, and they are labeled with their scientific names. Your task is to fill in the Skull Letter Codes from your 9 skulls into the correct gray squares that are drawn next to some of the hominins - use the information that you gathered in Table 1 and the Geological Time Scale graph. Tip: the biggest help for this undertaking is most likely the age of the fossil species (see time axis on each side of the tree). Both the solid and stippled parts of the bars next to the skull sketches indicate the time period during which the species lived.

Other characteristics, especially skull shape, should also be taken into account when making your final determination. Once you have completed filling in the gray squares, you should write the names of the 9 skulls in Table 1. Use the space in the Skull Letter Code column.

Check with your teacher to see if you have correctly named the skulls! If so, congratulations – you solved the mystery!

Post-Lab Questions

1.a Concluding from the Phylogenetic Tree, what is the greatest number of hominins that coexisted?

b. List the names of these species (your answer may include species that were not represented by skull specimens in this investigation).

c. What is the approximate time period during which these multiple species coexisted?

2.a Based on your answers for question 15, what was the driving force in early hominin evolution?

b. What was the driving force in later hominin evolution?

3.a What trend do you notice in the shape of the cranium as hominin evolution progress?

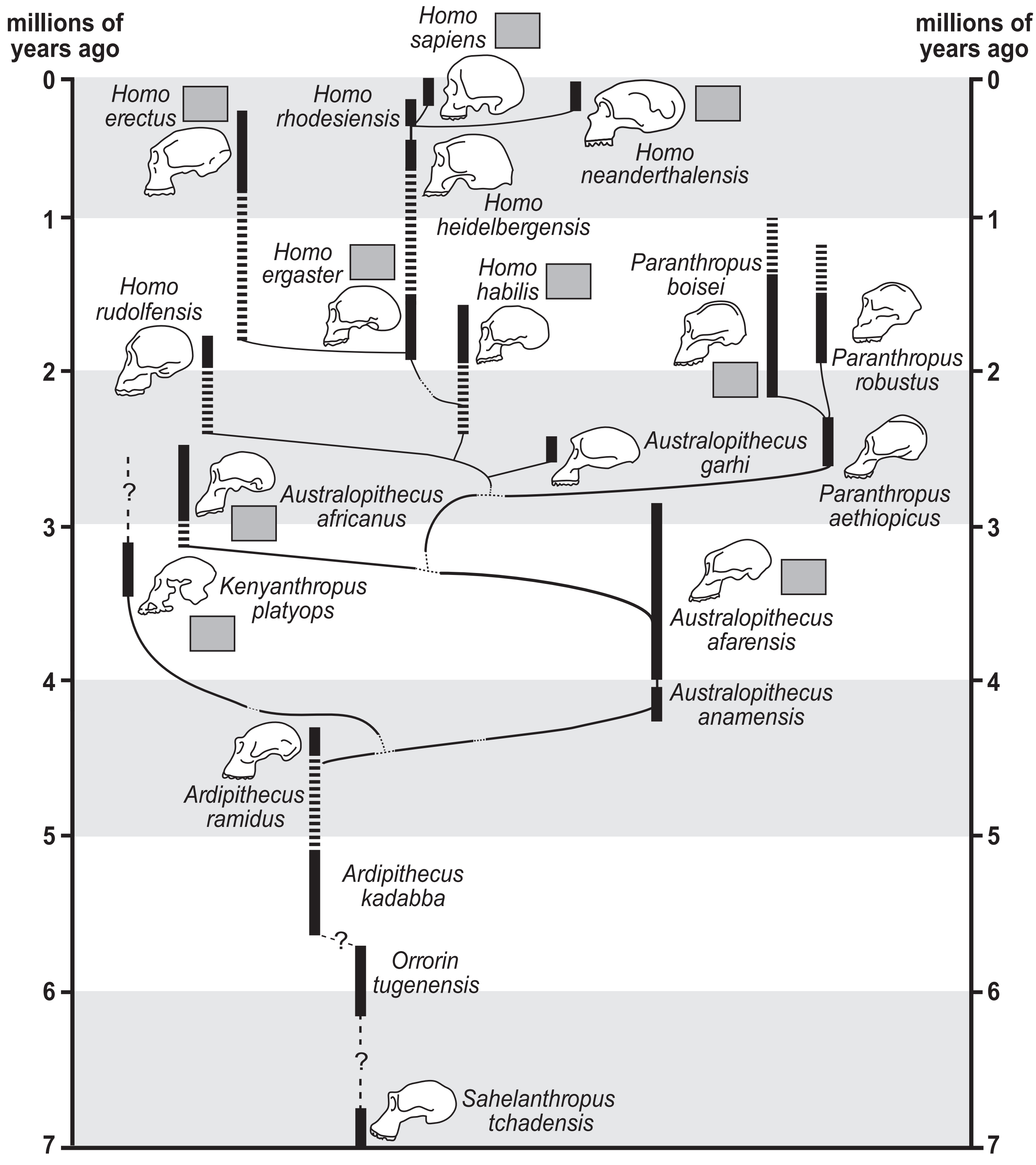
b. Why do you think this trend occurred?

4.a Looking at the oldest fossil in the tree, *Sahelanthropus tchadensis*, and based on the evidence you collected during this investigation, to which of your 9 investigated species is that old hominin most similar with regard to cranial capacity?

b. And with regard to FMI?

c. Does the Phylogenetic Tree support your hypotheses for 4.a and b?

d. Go back to the FMI-Average Cranial Capacity graph that you completed earlier. Place a mark (use a big X) on the best-fit curve for *Sahelanthropus tchadensis*. Explain your reasoning for the placement of your X in the graph.



Phylogenetic Tree