INTERPRETING EVIDENCE:

An Approach to Teaching HUMAN EVOLUTION in the Classroom

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Perhaps the best topic teachers can use to exemplify the nature of science is paleoanthropology, the study of human evolution through the fossil record. Science educators have an opportunity to tackle "How do we know?" questions by examining evidences of our past and accurately defining the terms "hypothesis," "fact," "theory," and "belief." They can use recent discoveries to demonstrate that science is a self-correcting mechanism of understanding the world. By examining different hypotheses, they can encourage the skepticism, debate, and challenge to authority on which science thrives.

Often, teaching human evolution is a struggle. Teachers can be derailed into philosophical discussions inappropriate in a science class. They can fall victim to a curriculum design that leaves evolution to the end of the year, forcing them to squeeze four billion years of life into the last two weeks of June. Even schools addressing biological evolution may fail to teach the evolutionary history of the mammals sitting in front of them.

In this article, we present an updated approach to teaching human evolution, and a model for explaining what science is and how it is done.

What Is the Problem?

There may be no other scientific exploration that elicits more passion, skepticism, and debate than human origins. Paleoanthropologist Meave Leakey writes, "All people are innately curious and seek to know why and how they came to be." (Leakey, 2003).

Since Charles Darwin published *On the Origin of Species* in 1859, paleoanthropologists have been

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searching for fossil evidence of our past, and fiercely debating hypotheses for human ancestry. Many popular ideas have come and gone, and some of the most enthusiastically endorsed hypotheses have withered in light of new evidence. Just in the last two years, newly discovered fossil hominids have forced paleoanthropologists to reanalyze the evolution of bipedalism in our ancestors (Shipman, 2002), and to reevaluate the morphology and timing of the last common ancestor with chimpanzees (Brunet, 2002; Wood, 2002).

But, textbooks often do not communicate the excitement and debate generated by new discoveries. The typical, linear representations of our evolutionary history are not only incorrect, they are boring. Alles and Stevenson have recently remarked on this problem in a phenomenal article "Teaching human evolution" found in the May, 2003 issue of *The American Biology Teacher*. Using the model we propose in this paper, students will have an opportunity to explore a science with more questions than answers, without having to memorize oversimplified versions of human ancestry.

Unfortunately, confusion over the discoveries themselves prevents many teachers from ever reaching this point with their students. To start, the names assigned to new fossils are often confusing to teachers and misunderstood by students.

Lumpers & Splitters

Currently, there are two modes of thought in categorizing human ancestors: the "lumpers," who tend to group fossils into relatively few species, and the "splitters," who use measurable differences as evidence for prolific speciation in our past. Each uses the same measurements, and the same fossils, but interpret the results differently.

Tim White, Professor of Integrative Biology at the University of California, Berkeley, uses the variation that exists within a species today to understand the fossil record (Figure 1). This strategy has landed him within the "lumper" category.

"Right now, there is oversplitting going on by modern people inferring too many fossil species based on the differences they see between fossils, when the same differences are seen among skulls from a single modern species, for example, chimpanzees, or gorillas, or humans," says Dr. White. "This is a good indication that naming many of the newer fossils as different species is not warranted." (White, 2003a)

Regarded now as a "splitter," Ian Tattersall, Curator of the Anthropology Division of the American Museum of Natural History in New York, is influenced by his first research interest, lemurs. Fifty species of lemur reside on the island of Madagascar, and by looking only at their skeletons, one may be hard pressed to find enough measurable differences to distinguish all 50 species. Fur color, ovulatory cycles, behavior patterns, communication methods, and genetics do not fossilize. Therefore, even the slightest difference in skeletal morphology might constitute evidence for a new species. Tattersall studied lemur taxonomy for many years and now sees the same diversity in the human fossil record (Figure 2).

"The lemurs had told me a tale of diversity; and looking at the human fossil record, which [has] been steadily expanding ... taught me the same thing about hominids," Tattersall wrote in *Monkey in the Mirror* (2002).

Tim White, a lumper, looks at the fossil record and sees variation within a few species. Ian Tattersall, a splitter, sees diversity and recognizes many different species. To highlight the difference, consider the following example. One million years from now, would a future paleontologist be able to tell that a 7'2" basketball player like Shaquille O'Neal was a member of the same species as a 5'2" actor like Danny DeVito? This is the challenge to a paleoanthropologist; trying to decide whether a new fossil discovery represents a new species, or a variant of an already recognized animal.

Abbreviation Key

for Figures 1-3

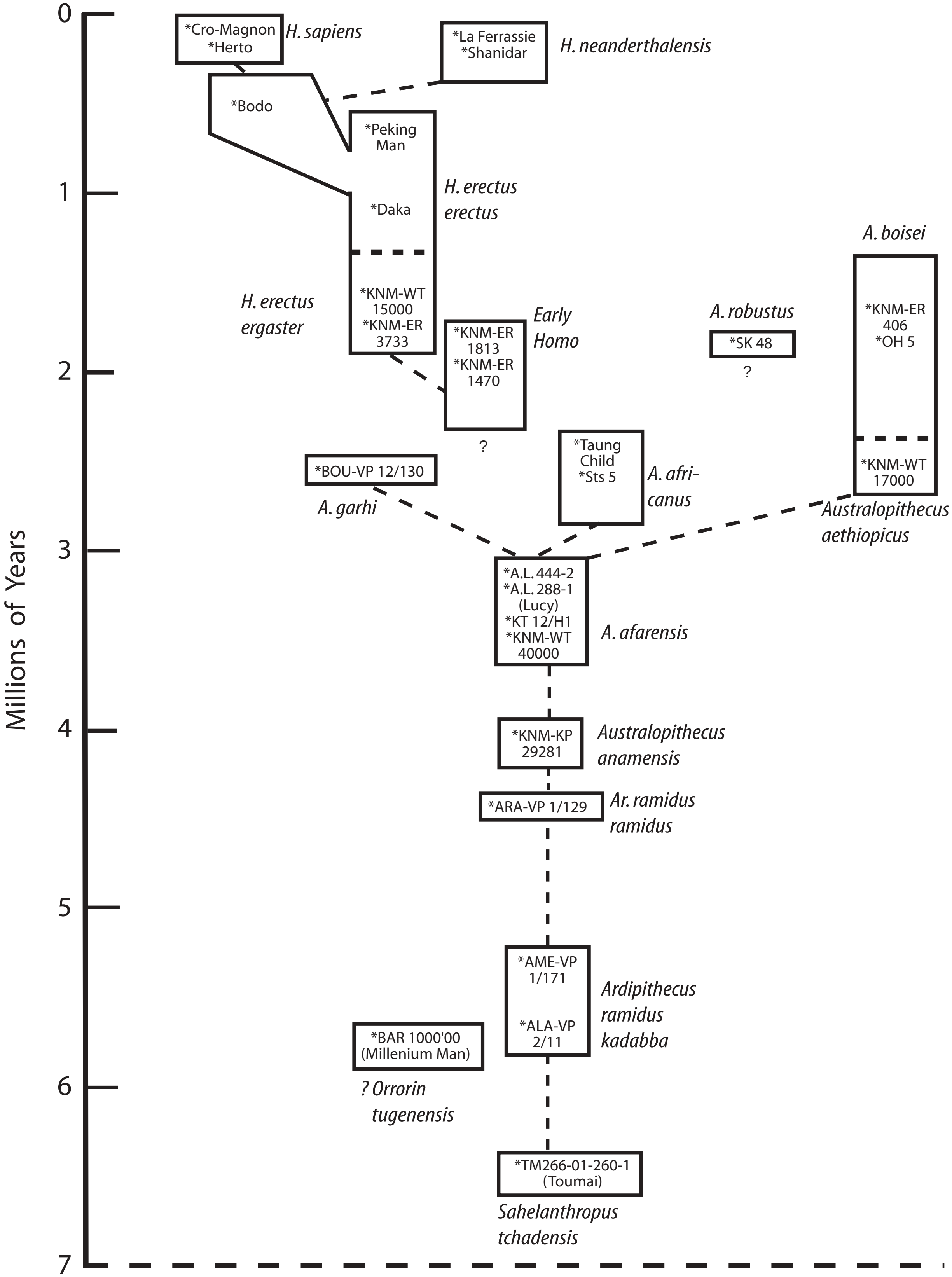
The **letters** indicate where the fossil was found:

- **AL** – Afar Locality, Ethiopia
- **BAR** – Baringo district, Kenya
- **BOU-VP** – Bouri Vertebrate Paleontology, Ethiopia
- **ER** – East (Lake) Rudolf, Kenya
- **KNM** – Kenya National Museum (where fossil is on display)
- **KP** – Kanapoi, Kenya
- **KT** – Koro Toro, Chad
- **OH** – Olduvai Hominid, Tanzania
- **SK** – Swartkrans, South Africa
- **Sts** – Sterkfontein type site, South Africa
- **TM** – Toros-Menalla, Chad
- **WT** – West (Lake) Turkana, Kenya

The **number** of the fossil found at that site follows:

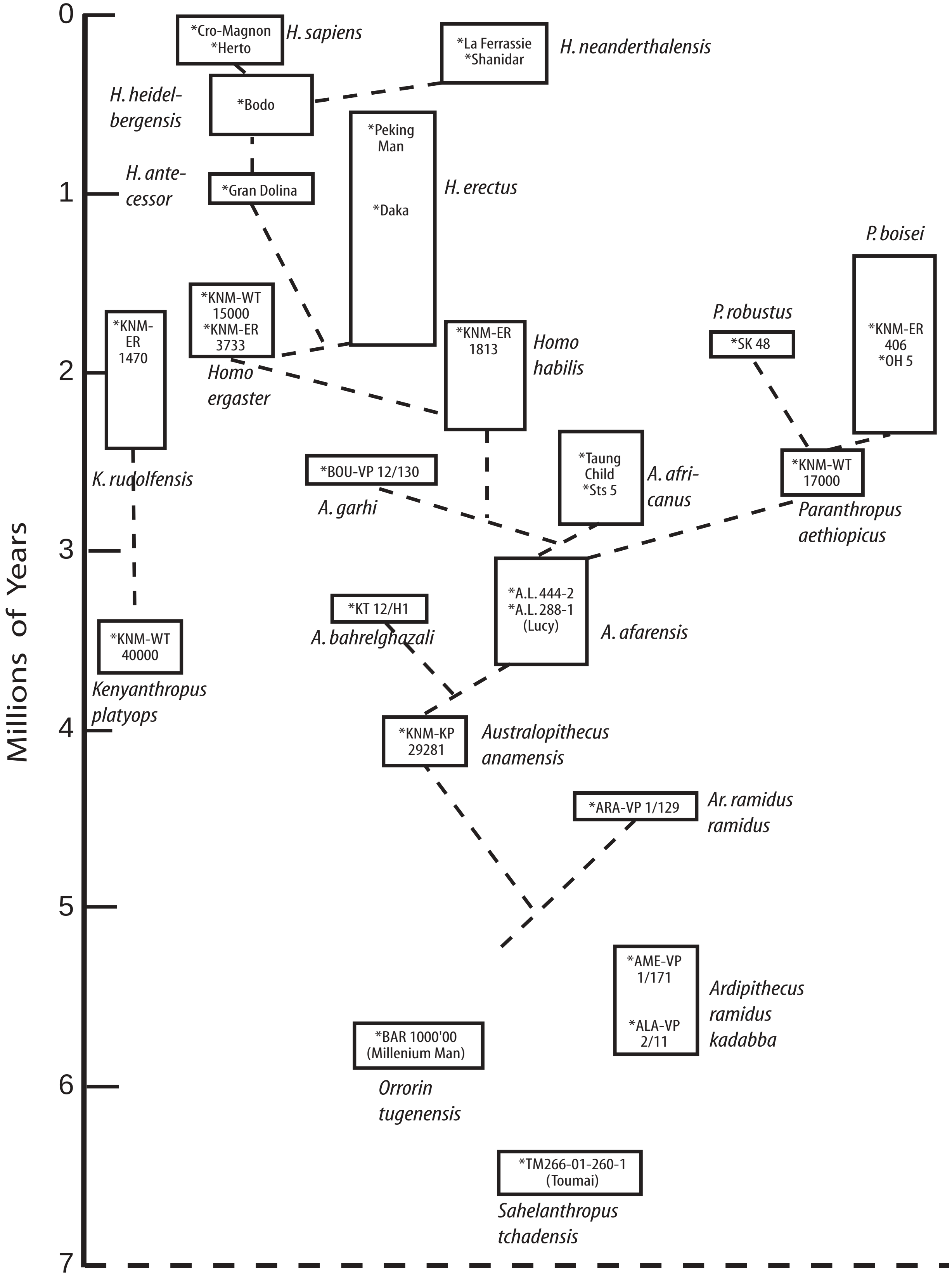
For instance, KNM-ER 3733 was the 3,733 specimen found in East Rudolf. It is at the Kenya National Museum.

Figure 1.



Tim White's Family Tree. Dr. Tim White is a professor of Integrative Biology at the University of California at Berkeley. His discoveries in Ethiopia include fossils of Ardipithecus ramidus, Australopithecus afarensis, Australopithecus garhi, Homo erectus, and Homo sapiens. Note that Dr. White groups the same fossil hominids into fewer species and has a much more linear relationship than Dr. Tattersall.

Figure 2.



Ian Tattersall's Family Tree. Dr. Ian Tattersall is Curator of the Division of Anthropology at the American Museum of Natural History. His research interes ts include Hominid evolution, and the biology and evolution of the Lemurs of Madagascar. In this tree, note the many recognized species and genera and the suggestion of as of yet undiscovered species.

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For a teacher, it is significantly more valuable to explain to students *why* scientists disagree over the species designation of a particular fossil, than to confuse them with the names themselves. Take for example the following situation.

Skull 1470

In August of 1972, Kenyan fossil hunter Bernard Ngeneo unearthed a 1.9 million-year-old skull, known technically as KNM-ER 1470, from the eastern shore of Lake Turkana (Schwartz & Tattersall, 2003). Paleontologist Richard Leakey published his analysis of this find in *Nature* (Leakey, 1973) and after much debate, Skull 1470 was assigned to the already known species, *Homo habilis*. Citing differences in cranial capacity (1470's cranial capacity is 775 cc, while other *H. habilis* skulls are in the 550 cc range) and dental pattern, Russian anthropologist Valerii Alexeev pulled 1470 from *H. habilis* and renamed it *Homo rudolfensis* (Johanson, 1996). In 2001, Meave Leakey discovered a 3.5 million-year-old skull in Kenya that she has designated *Kenyanthropus platyops* (flat-faced man of Kenya). Similarities in face morphology suggest that 1470's species (*H. rudolfensis*) may be a distant descendant of the newly named *K. platyops* (Figure 3) (Lieberman, 2001). This has led some paleontologists to rename 1470, *Kenyanthropus rudolfensis*. Others even suggest that Skull 1470 retains enough primitive characteristics to be considered *Australopithecus rudolfensis* (Wood, 2002).

So, what is 1470? Some still say it is a *Homo habilis*. Some say it is a *Homo rudolfensis*. And now, some call it a *Kenyanthropus rudolfensis,* or even *Australopithecus rudolfensis*. This can be confusing to teachers and students alike. Ultimately though, the names do not matter. The creature that died and left what we call 1470 lived approximately 1.9 million years ago. No one argues that fact. Whether 1470 was a *habilis* or a *rudolfensis* should not be the focus in a classroom. As Tim White suggests, "Why confuse your students with this? Get them onto *relationships,* not names." (White, 2003a)

Understanding Hominid Relationships

Many hominid species once existed. But, today, only one remains–us. How did this happen? Again, it depends on whom you ask.

Tim White, Ian Tattersall, and Meave Leakey's phylogenies, or family trees, all differ, even though their interpretations are based on the same measurements, using the same equipment, the same units, and the same well-aged fossils. These phylogenies are working hypotheses, designed to be tested and scrutinized, while flexible enough to be changed when new evidence is found. For students, the lesson from these family trees should not be the lines themselves, but *why* scientists draw the relationships they do, and *why* they disagree.

Too often, the public and our students think that conflicting hypotheses undermine the validity of a scientific principle. Too often, we fail to educate our students that science is rooted in doubt–that challenge, skepticism, and debate are exciting cornerstones of scientific thought. We fail to educate our students that science is driven by questions, not answers. The scientific arguments surrounding human evolution are intellectually stimulating and demonstrate how scientists develop hypotheses from available evidence. Next, we will outline a number of activities that teachers can employ in teaching human evolution to their students. Most of the information needed to execute these activities is available at the Boston Museum of Science Web site: www.mos.org/evolution.

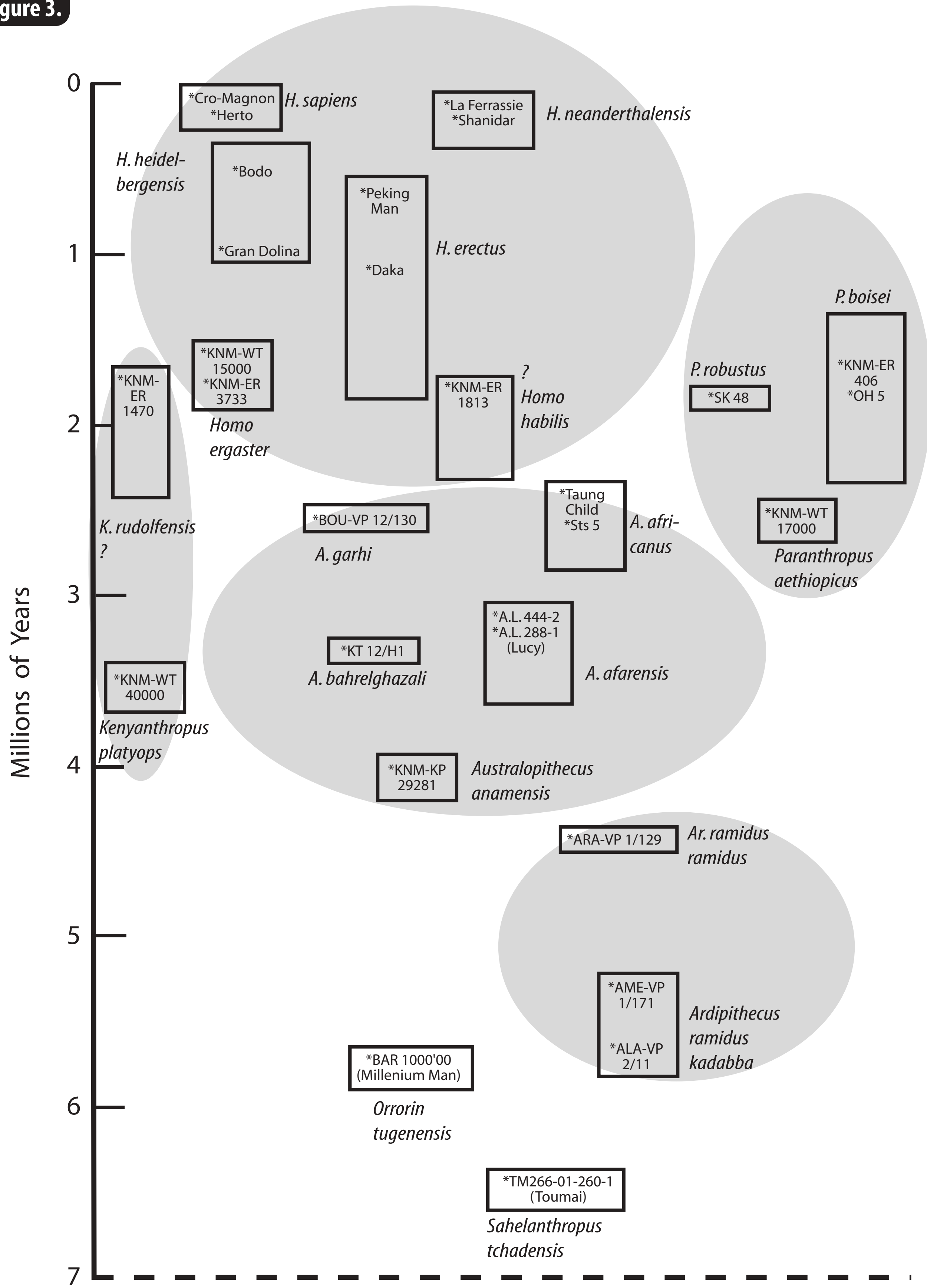
Activity 1. Where Do You Draw the Lines?

Print the three family trees presented in this paper or go to the Museum of Science Web site and download the family trees there. Print them (on transparency film if possible) and present them as handouts to your students. Now, examine each in detail. Of the thousands of fossils that have been unearthed, 29 were chosen to represent early humans. These are the "greatest hits." What differences do you notice about these interpretations of the fossil record? Compare the family trees (overlay them if using transparency film), paying careful attention to where Tattersall, Leakey, and White differ, and where they agree.

These phylogenies are up-to-date as of July, 2003 (see the www.mos.org/evolution Web site for the most current phylogenetic trees) and are considerably more accurate and interesting than the traditional textbook model. They illustrate alternative interpretations of the human fossil record, a teaching method conspicuously absent from most science textbooks.

Examine the White model versus the Tattersall model. White deals strictly with the known fossil record and does not speculate the existence of undiscovered hominid species. He also dismisses recent suggestions that the human family tree is shaped more like a bush.

Figure 3.



Meave Leakey's Family Tree. Dr. Meave Leakey is a Research Associate in the Paleontology Department of the National Museum of Kenya. Her work in Kenya has revealed fossils of Australopithecus anamensis, Kenyanthropus platyops (KNM-WT 40000), and early fossils of Homo. Note in this family tree that Dr. Leakey does not draw lines at all and instead tentatively suggests relationships with ellipses.

Observations regarding the "bushy" nature of the earliest hominid family tree fall into the category of "X-files paleontology" (pure speculation–based on preconception–but unchecked by fossil data). Present data indicate that the hominid family tree was never particularly "bushy," or speciose in the normal mammalian sense, despite recent claims to the contrary.

(T. White, *The Primate Fossil Record,* 2003.)

Tattersall's tree, however, is particularly "bushy." He recognizes five additional species, and two genera, *Kenyanthropus,* and *Paranthropus,* which White incorporates into *Australopithecus.* Also, Tattersall suggests a more indirect relationship between currently recognized hominids.

"No hominid fossil species that we know are likely to be the direct ancestors of any other known species," Tattersall explains. "In fact, recognizing ancestors is a problem since they have to be primitive in all respects relative to their descendents." (Tattersall, 2003).

Recognizing the uncertainly of their interpretations, both Ian Tattersall and Tim White use dotted lines, instead of solid lines, in their family trees.

Meave Leakey takes this caution a step further, and does not even use lines. She draws circles around related species.

"The species enclosed in the ellipses are those that share features that appear to link them. I do suggest relationships, but I do not give such detailed relationships as those who draw lines because I believe the lines imply that we know more about how things are related than we actually do." She continues, "We will never know exactly how any species relates to another unless, by some amazing good fortune, we are ever able to extract DNA from these fossils." (Leakey, 2003)

Activity 2. Why Do You Draw the Line?

Now, encourage your students to examine these phylogenies using real, measured evidence. They will learn the skills of inquiry, skepticism, and evidence-based understanding of a scientific concept.

Scientific supply companies like Carolina and Bone Clones have model hominid skulls–reproductions of actual finds. But, if you do not have the resources to purchase these skulls, you can print life-sized pictures from the Internet (see reference section for URLs), or purchase *From Lucy to Language* (Johanson, 1996), which has hundreds of life-sized photographs of fossil hominids. Referenced information about particular fossils is also available on the Boston Museum of Science Web site.

Students examining their fossilized ancestors may consider which criteria they would use to hypothesize relatedness. Perhaps they could look at the changing size of the skull diameter over time, or the angle of the face, molar size, browridge, or presence or absence of a sagittal crest (see Web site for guidance in taking these measurements). They may begin to understand that all traits do not necessarily evolve in step, or at a constant rate. Students may also recognize that certain characteristics may be informative when hypothesizing relationships and may use these data to construct their own phylogenetic trees. Compare their different phylogenies to those of White, Tattersall, and Leakey; encourage debate and "How do you know?" questions. There is no answer key to this activity. Rather, the objective of this exercise is to empower students to know that their hypotheses, if supported by evidence, are legitimate. Students may even leave your class with an understanding that challenge is healthy and necessary to science.

Activity 3. "How Do We Know What We Know?" Questions

Using models of hominid discoveries, or the photographs suggested in the previous activity, encourage the students to explore the specimens in more detail. Perhaps the students could work in groups researching one of these questions and present their findings to the class. Activities 3 and 4 are also excellent opportunities to integrate science writing into your curriculum. We suggest six different questions that can be addressed by your students.

- *Did more than one kind of hominid live at the same time?* We are currently the only type of human on the planet, but has it always been this way? Careful examination of the dates and morphologies of skulls KNM-ER 406 and KNM-ER 3733 provide insight into this question.
- *Can we tell whether a hominid is male or female?* Scientists apply what they know about animals today to those that no longer exist. Have your students examine the famous Lucy skeleton (A.L. 288-1), or the Black Skull (KNM-WT 17000). What evidence helps scientists hypothesize the sex of these individuals?
- *How do scientists know how old these individuals were when they died?* How do we know that the Taung Child was, in fact, a child and not a chimpanzee? How do we know that KNM-ER 1813 is an adult? How do we know Kabwe lived to be an old individual?
- *When did the last common ancestor between humans and the African apes live? What did it look like?* Discoveries in just the last few years of *Sahelanthropus, Orrorin,* and *Ardipithecus* show a fascinating morphological amalgamation of ape and hominid-like traits. Students will recognize that because we share a common ancestor with the African apes, when dealing with fossils from this time period (the late Miocene), it becomes exceedingly difficult to distinguish between a gorilla ancestor, chimpanzee ancestor, and a hominid. Students can also investigate how genetic comparisons and paleontological discoveries inform this multidisciplinary investigation of human origins.
- *Where did our genus evolve?* Encourage the students to examine all finds dated 1.8 million years and older. Where were they all discovered? Students can then hypothesize when hominids first left Africa and perhaps even engage in the "Out of Africa versus Multiregional Evolution" debate. How would we test whether humans evolved in Africa and spread worldwide, left Africa in one migration or many, or whether we evolved independently in different parts of Africa, Asia, and Europe?
- *Who were the Neanderthals?* Compare a Neanderthal skull to an anatomically modern human skull. What differences do you notice? Competing hypotheses argue whether our species may have interbred with Neanderthals or not. How might DNA help inform us about the relationship between modern humans and Neanderthals?

Activity 4. Incorporating New Discoveries

In the last three years, fossils that represent *Sahelanthropus, Orrorin, Kenyanthropus,* and *Ardipithecus* were added to the human family tree. The oldest *Homo sapiens* was unearthed in Ethiopia (White, 2003c). A remarkable set of skulls, possibly representing a new species of early *Homo,* was discovered in the former Soviet Republic of Georgia (Vekua, 2002). And a fossil from Olduvai Gorge in Tanzania may shed light on the 1470 puzzle mentioned earlier in this article (Blumenschine, 2003). Teachers have a wonderful opportunity to teach their students the very nature of science by presenting the latest fossil discoveries and following the scientific debate that ensues. You might obtain the primary journal articles of recent discoveries, found often in *Nature* or *Science,* and have your students compare these peer-reviewed papers to newspaper or science magazine accounts of new fossils. Understand that the interpretation of new discoveries is always controversial and informed skepticism is necessary to the scientific process. Consider the following example:

> New to Leakey's phylogeny in 2001 was KNM-WT 40000, the defining fossil, or type specimen, of *Kenyanthropus platyops*. An ellipse connecting 40000 with 1470 implies the relationship between those two skulls mentioned earlier in the article. Tattersall's phylogeny reflects an agreement with this interpretation. Tim White's does not.
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>> *I have now seen the original "platyops" and I find that it is most probably a crushed afarensis cranium and neither a new species nor a new genus,* White said. *I am looking forward to the recovery of additional undistorted fossils of this age from Kenya that might allow us to determine whether Dr. Leakey is right or wrong in her interpretation.*
>>
>> (T. White, Personal correspondence, 2003)
>
> Leakey adds
>
>> *... I appreciate that science advances by testing previous theories and that the more outrageous and "unscientific" theories often generate more intensive research by others to prove or disprove these theories. They are thus useful in generating and stimulating further research. In a sense, by making Kenyanthropus a new genus, we were doing just that and presenting an interpretation of our observations that was perhaps reading more into the evidence than the evidence justified.*
>>
>> (M. Leakey, Personal correspondence, 2003)

We have presented three distinct family trees from three well-respected scientists studying human origins. There is little disagreement about the ages of these fossils and whether they belong in the hominid family, but interpretations of species designation are varied and questions regarding which, if any, species are ancestral to modern humans remain. These questions can only be answered with more evidence. Failure to impress upon students the method by which we understand our past and the uncertainties that still remain undermines the science itself.

There is an exciting argument in paleoanthropology right now, one that allows informed students to get to the very heart of science. Every year this argument evolves, with new fossil discoveries provoking more questions than answers. As of the submission of this paper, reports of a partial skeleton of *Ardipithecus;* another skull from Dmanisi, Georgia; 22 additional fossils from *Orrorin,* and several more unclassified fossils from South Africa all await publication and interpretation. With these discoveries nearing publication, the phylogenies presented in this paper may be obsolete within the year. Such is the nature of science, so stay tuned, and keep those family trees updated.

Acknowledgments

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Web Site Addresses

www.mos.org/evolution

The activities suggested in this article are available online at the Boston Museum of Science Web site.

www.becominghuman.org

Multi-media site from Institute of Human Origins.

www.mc.maricopa.edu/anthropology/hominid_journey/index.html

Mesa Community College Department of Anthropology. Excellent photos.

www.mnh.si.edu/anthro/humanorigins/index.htm

American Museum of Natural History site.

www.talkorigins.org/faqs/homs/specimen.html

Analysis of individual fossils. Excellent photos.

www.msu.edu/~heslipst/contents/ANP440/index.htm

Michigan State University site. Well organized with useful photographs and fossil descriptions.

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BREAKING NEWS

In March 2004, Tim White's team of paleoanthropologists announced the discovery of 5.8 million-year-old hominid teeth in Ethiopia. As a result, it argues that *Ardipithecus ramidus kadabba* is its own separate species: *Ardipithecus kadabba*. Additionally, the authors suggest that the earliest known hominid fossils *Ardipithecus, Orrorin,* and *Sahelanthropus* may belong to a single genus: *Ardipithecus* (Haile-Selassie, 2004).