The Secrets in Skulls

Brief lesson Description: In this activity students will use modeling, 3D scanning and printing to communicate the ancestral and derived characters that illustrate the evolutionary history of humans.		
Grade Level: 9-12	**Preparation time:** 10-20 min/activity	**Activity time:** 6 periods, 50 min each
NGSS Topic(s): Structure and Function, Inheritance and Variation of Traits, Natural Selection and Evolution		
Performance expectation(s): **HS-LS4-1:** Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence. **HS-LS4-4:** Construct an explanation based on evidence for how natural selection leads to adaptation of populations. **HS-LS4-5:** Evaluate the evidence supporting claims that changes in environmental conditions may result in (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species. **HS-ETS1-4**: Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.		
Objectives: Students will be able to: - use modeling, 3D scanning and printing to communicate the ancestral and derived characters of human skulls - understand and generate an evolutionary tree (phylogeny) that shows relationships between different human lineages		
Disciplinary core ideas: **LS4.A: Evidence of Common Ancestry and Diversity:** Genetic information and anatomical evidence provide evidence of evolution. (HS-LS4-1) **ETS1.B: Developing Possible Solutions:** Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4) **ETS1.C: Optimizing the Design Solution:** Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)		
Crosscutting concepts: **Cause and Effect:** Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS4-4), (HS-LS4-5) **Patterns:** Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-LS4-1) **Systems and System Models:** Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions— including energy, matter, and information flows— within and between systems at different scales. (HS-ETS1-4)		
Tags: evolution, hominids, skull, 3D scanning and printing, phylogeny		

Introduction

The entire project focuses on the recreation of a museum exhibit featuring the skulls of early hominids. The exhibit shows an accurate phylogeny depicting the evolutionary relationships of the subject hominids with correctly identified skull models. The project is build in line with the 5-E instructional model.

<table>
<tr><td>Part I</td><td colspan="2">Engage</td><td>50 min</td></tr>
<tr><td colspan="4">This part will make connections between past and present learning experiences to ensure that students become engaged in the concept and skill to be learned.</td></tr>
<tr><td colspan="2">Materials:
For each student:
- Copies of “Museum Disaster”
- Copies of “Geometric shapes in the skull”
For each group of 2-4 students:
- Modeling clay
- Simple modelling tools (butter knife)
- Computers with MFStudio software
Matter and Form 3D scanner</td><td colspan="2">Teacher prep (~20 min):
- Portion modelling clay (lighter color preferred as darker colors are more difficult to scan)
- Print out materials for students
- Install MFStudio software on classroom computer(s)
- Set up 3D scanner</td></tr>
<tr><td colspan="4">ETS1.B: Developing Possible Solutions</td></tr>
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1. The class begins with a discussion of some human features. The instructor asks the class to consider how their human form differs from others. For example, asking the question “How is a human different from a bird?” may yield observations such as “humans don’t have feathers” or “humans don’t have beaks”. The conversation is directed to discuss some of the characteristics common to all apes: humans have excellent binocular vision due to eyes positioned beside each other. Ancestral species developed this adaptation to cope with a life in the treetops, where gauging the distance between branches is a matter of life and death for primates. Humans lost the hand-like feet of their cousins in favor of walking upright. Students may also note, of course, that humans have large brains, and the well-developed skulls to carry them.

2. The instructor distributes copies of the story, “Museum Disaster” (Appendix A). Students encounter the story of a tragic museum fire that destroys some of the prize possessions: a series of skulls from different hominids. Fortunately, the notes left by the paleoanthropologist, Archibald Caldwell, who discovered all the skulls in this selection left behind all the information needed to reconstruct the skulls.

3. Divide students into groups of 2-4. Each group receives modeling clay to reconstruct hominid skulls from the destroyed collection. As the instructor familiarizes students with project, emphasis is placed on modeling a complex structure, such as the skull.

4. Copies of “Geometric shapes in the skull” (Appendix B) are handed out and based on the information provided students in each group make observations of each other’s heads as they attempt to produce a skull from modeling clay with just the underlying geometric

shapes introduced in the material. The instructor offers feedback, particularly about the angles formed by the chin, nose, and forehead. These will be important characteristics to note as the project progresses.

5. When students are happy with the result, they save it by using the 3D scanner to capture a 3D model and save the OBJ file to a shared location, accessible to the whole class.

6. Students think about the accuracy of their models, and share their thoughts with other members of their groups. They may either open OBJ files from other groups from the shared location to compare work, or elect student representatives to travel among the other groups to allow them to scan their models to make comparisons.

Wrap up

As an Exit Ticket, each member of the class provides an estimate from 1-10 on how accurate their model is, with 10 being the most and 1 being the least. Students must also provide reasoning that led to this decision. For example: “On a scale of 1-10, I believe our model’s accuracy is about a 4. I think this because I noticed other groups had the jaw stick out a lot further.” The instructor collects the Exit Tickets at closure of the period (formative self-assessment).

Part II	**Explore (I)**	**50 min**
This phase provides students with a common base of experiences by manipulating materials.		
Materials: For each student: - Copies of "Skull Diagram" - Copies of "Notes of Archibald Caldwell" - Exit tickets of Part I For each group of 2-4 students: - Modeling clay - Simple modelling tools (butter knife) - Computers with MFStudio software - Matter and Form 3D scanner	**Teacher prep (~20 min):** - Portion modelling clay (lighter color preferred as darker colors are more difficult to scan) - Print out materials for students - Set up 3D scanner	
ETS1.B: Developing Possible Solutions, ETS1.C: Optimizing the Design Solution		

1. The class begins with the teacher returning Exit Tickets of Part I to the students who wrote them. Students share with their group members how they felt about the accuracy of their models. The instructor then redirects them to approach their model with more detail

2. Students are given a "Skull Diagram" (Appendix C). This generic diagram of a human skull is to familiarize students with the individual bones that compose the skulls of all primates. Students repeat their work from the prior period, either shaping bones from scratch and assembling them into a skull, or reworking their previous clay model of geometric shapes as a guide for sizing the bones. Students focus on features, particularly processes and foramens (as noted in Appendix C).

3. The instructor should discuss the limitations of modeling with the entire class. Their model can only be as accurate as the source material, and it is meant to communicate. This may mean sacrificing some accuracy to communicate better. For instance, making a foramen more prominent can clarify its position, making it more useful for identification.

4. Once students have completed their skull models, they 3D scan their model and save the OBJ file in a shared location. They can compare their work with other groups by opening the saved OBJ files, or by travelling between groups to allow them to scan the different skulls.

5. Groups spend about 5-10 minutes discussing the success of their model thus far.

Wrap up

At the end of the class students describe how their new skull differs from their original, making reference to at least two features that were not adequately communicated with the geometric shapes model of the skull. For example: "Both skulls have a brain base and jaw bone. However, the second skull also models the foramen and teeth. At this scale of model, the teeth proved

difficult to model and do not effectively communicate." The instructor will collect the answers to assess (formative assessment).

Part II	**Explore (II)**	**50 min**
This phase provides students with a common base of experiences by manipulating materials.		
Materials: For each student: - Copies of "Skull Diagram" - Copies of "Notes of Archibald Caldwell" - Exit tickets of Part I For each group of 2-4 students: - Modeling clay - Simple modelling tools (butter knife) - Computers with MFStudio software - Matter and Form 3D scanner	**Teacher prep (~20 min):** - Portion modelling clay (lighter color preferred as darker colors are more difficult to scan) - Print out materials for students - Set up 3D scanner	
ETS1.B: Developing Possible Solutions, ETS1.C: Optimizing the Design Solution		

1. The class begins with the teacher returning Exit Tickets of the previous day to the students who wrote them. Students share with their group members how they felt about the accuracy of their models.

2. The instructor distributes each different group a set of notes from the late paleoanthropologist, Archibald Caldwell (Appendix D). Each group works from a different set of notes from a different specimen. Students observe the drawings carefully. How does the skull they just crafted compare to the information they just obtained? By elongating, adding features to their clay model, each group either models from scratch or converts their human skull to a hominid skull model. The instructor discusses with students how working from drawings is limited by inconsistencies of the artwork, and that quite often artwork is generated from damaged source material.

3. Each group makes the necessary modifications to their skulls and scans the results. They save the OBJ file to a shared location. Any remaining time in the class period is spent opening other groups' models to make a comparison, or collecting scans from other groups in preparation for the next class.

Wrap up

At the end of the class students describe how their new skull differs from their original, making reference to at least two features that are dissimilar and one that is alike. For example: "Both of our skulls have canine teeth and they both have a large foramen underneath. However, the canine teeth of the skull we received notes on are much larger than they are in the human skull." The instructor will collect the answers to assess (formative assessment).

Part III	**Explain**	**50 min**
This phase helps students explain the concepts they have been exploring. They have opportunities to verbalize their conceptual understanding or to demonstrate new skills or behaviors. This phase also provides opportunities for teachers to introduce formal terms and definitions.		
Materials: For each student: - Copies of "Hominid Research Grid" For each group of 2-4 students: - Computers with MFStudio software - Matter and Form 3D scanner	**Teacher prep (~10 min):** - Print out materials for students - Set up 3D scanner	
LS4.A: Evidence of Common Ancestry and Diversity, ETS1.C: Optimizing the Design Solution		

1. Student representatives from different groups continue to collect and provide their updated models to other groups to capture and compare scans. As the scanning process continues, students complete the activity "Hominid Research Grid" (Appendix E) to explore the differences between the skulls and habits of gorillas, *Australopithecus*, *Homo habilis*, *Homo erectus*, *Homo neanderthalensis* and chimpanzee.

2. As students complete their research, the instructor calls frequent group discussion breaks so they can share findings and compare what they are discovering to what they have already made. The .obj-file exported from the skull scans serves as a useful manipulative while conducting research.

3. The instructor encourages students to superimpose two scans from different groups and compare the overlapped meshes. As before, attention should be directed at critical features, such as how far the snout produces, and the size of the braincase in relation to the rest of the skull.

4. As the class finishes finding all of the pertinent information about the hominid groups, they discuss which hominid skull they may have. Every team constructs a hypothesis that makes specific reference to evidence leading to this prediction: "Our skull appears to be _____. We made this prediction because we observed _____. Research into the hominid family showed us _____. We therefore think our skull belongs to _____."

   Sample Hypothesis:

   > "Our skull appears to be that of *Homo habilis*. We made this prediction because we observed a heavily protruding snout, but no sagittal crest. Research into the hominid family showed us that gorillas, chimpanzees, and some types of *Australopithecus* have a feature called a sagittal crest on top of their skulls, while *Homo habilis* does not. We therefore think our skull belongs to *Homo habilis*."

5. When each group has a completed and recorded the hypothesis, students find a partner from another group to complete a Think-Pair-Share. Each partner reads the hypothesis of a different group. They then take turns providing feedback on the reasoning of the hypothesis.

   Sample:

   Student A: "I agree that the lack of sagittal crest indicates a *Homo habilis*, but I think it could also be a species of *Australopithecus*. Not all of them had sagittal crests."
   Student B: "I agree that the large canines you reference indicate a gorilla. I can't think of any hominid we study that has canines that large.

6. Groups reform and share their findings from the rest of the class.

Wrap up

The teams collectively revise their hypothesis, or write a statement on why they are not revising their hypothesis. These are given to the instructor to assess (formative assessment).

Part IV	**Elaborate**	**50 min**
This phase extends students' conceptual understanding and allows them to practice skills through new experiences. Learners will develop a deeper and broader understanding of major concepts, obtain more information about areas of interest, and refine their skills.		
Materials: For each student: - Copies of "Complete a Phylogeny" For each group of 2-4 students: - Computers with Tinkercad software - 3D printer	**Teacher prep (~10 min):** - Print out materials for students - Set up 3D printer	
LS4.A: Evidence of Common Ancestry and Diversity, ETS1.C: Optimizing the Design Solution		

1. At this point students will have hypothesized the identity of their skull. This phase of the project begins with students joining their teams, but engaging in a full class discussion on the predictions of each group. Students must collectively decide which skull belongs to which hominid. Differences of opinion will be settled by a vote.

2. At this point, the instructor can reveal the identity of each skull and information about the species (Figure 1) on the activity sheet "Hominid Research Grid" (Appendix E). The class is invited to offer any observations on where mistakes were made, as well as the limitations of working without the actual skulls as a reference.

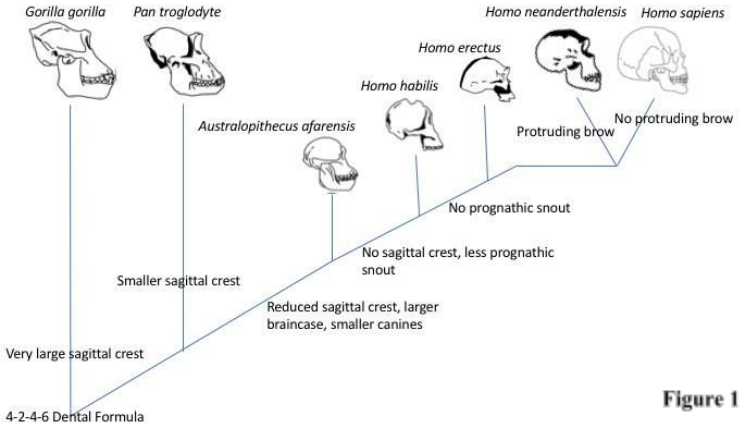

Figure 1

3. The instructor continues the project by picking one of the following features: brow size, facial protrusion, or the length of the canines. As a whole class, students discuss how this feature both indicates common ancestry, as well as diverging paths along the evolutionary line. For example, while our dental formula remains conserved through the apes, the size and shape of teeth varies among species.

4. Students perform the activity "Complete a Phylogeny" (Appendix F), which explains how to use ancestral and derived characters to infer the evolutionary history of an organism.

5. In their respective groups, students use what they have just practiced to draft a phylogeny using the skulls the class build and refined over the past classes. The instructor supports each group by helping them to categorize the different hominids.

6. Once drafts are complete, students will do a Think-Pair-Share with members of other groups to compare their process. Once all groups have finished their draft, a vote will decide on the final phylogeny design.

7. Students now use the various scan files they have collected from classmates to build files to print a full set of skulls for their group's display. They are using Tinkercad, a popular free software that allows students to import, combine, and manipulate .obj and .stl files for 3D-applications. While the skulls are being printed, students prepare individual written statements explaining how the phylogeny was constructed. The following frame can be used to help students organize their thoughts if desired:

   "To construct a phylogeny, organisms are grouped and separated by_____. For Hominidae, the ape family, we used _____ as an ancestral character to unite them. The first ape to diverge was _____, with the _____ character, _____. The second was _____, which has the derived character _____..."

Wrap up

As the class comes to an end, students turn in their draft phylogeny and the statements to the instructor as an exit ticket (formative assessment).

Part V	Evaluate	50 min
This phase encourages students to assess their understanding and abilities and lets instructors evaluate students' understanding of key concepts and skill development.		
Materials: For each group of 2-4 students: - Yarn - Notecards for species names - Sticky notes	**Teacher prep (~10 min):** - Cut yarn for each group - Bundle notecards for each group	
LS4.A: Evidence of Common Ancestry and Diversity		

1. The final phase of the project begins with students reconvening in groups and putting their skulls in place according to the selected phylogeny created the day before. The skulls can be placed on the table, while yarn can be placed and cut to display the branching diagram.

2. A notecard (Figure 2) with the species name and important information, including the age of the fossil and the derived character separating it from the human lineage, is prepared and placed by each skull.

Australopithecus afarensis

The first true member of the human lineage, *Australopithecus* resembled chimpanzees in many ways. However, there are some key differences. The first was that *Australopithecus* was bipedal, spending more time on the ground than up in the trees. In its skull, the *Australopithecus* shows smaller canines than either the gorilla or chimpanzee. It's braincase is more rounded, but not significantly bigger. The rounding and size of the braincase increases with later hominids. It still has a prognathic snout, which means its mouth and nose stick out from the face. Some species had small sagittal crests and some did not, including this species. They appeared around 3.88 million years ago.

Figure 2

3. When the display is complete, students receive their drafts (Part IV) from the instructor. Students freely choose a partner and begin by reading the drafts, then taking turns in providing feedback on their explanation of the phylogeny they constructed.

4. After 5-10 minutes, students return to their seats and revise their statements for final submission (summative assessment). As students complete and turn in their work, the instructor provides them with some sticky notes. They return to the display and provide feedback to different parts of the display. How well does it communicate the history of the Hominid family? What limitations were there, and how were they addressed?

Wrap up

As more students finish writing their final statement, the instructor closes with a whole class discussion, using sticky notes to guide them in critically evaluating the successes and areas for improvement in their work. As a final exit ticket, each student spends a few moments writing something they felt went well in recreating the exhibit, and something they would have done differently.

