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Perspective

Ecomorphological Diversity of Phyllostomid Bats: A model using 3D printing for science outreach

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Abstract: Access to specimens is a common barrier in the development of educational models for science outreach. However, 3D scanning and printing create small files that can be reproduced as scaled 3D objects inexpensively. This technology has the potential to expand the diversity of specimens available for educational outreach. The resulting models can be used to engage individuals (e.g., K-12 students) to novel scientific concepts. Here, the skulls of seven species of phyllostomid bat representing extreme dietary and morphological diversity were microCT scanned, enlarged, and 3D printed as an educational tool for elementary school science outreach programs. These skulls are generally unavailable to the public due to their small size and scarcity. Specimen files for printing (.stl format) and educational fact sheets are included in supplemental materials for others to access and use.

Keywords: science outreach, comparative anatomy, Phyllostomidae, bats, skulls, functional morphology

Introduction

Bringing Specimens Beyond Museums

Natural history museum exhibits are an invaluable resource for informal natural science education, engaging people in critical ways with STEM and making students feel more connected to the natural world. However, in 2023 only 28% of the US adult population had visited a museum (of any type) in the past year (Wilkening 2023). Though data are lacking on specific subsets of the population including children and West Virginia residents, it is not much of a leap to infer that well-documented factors affecting our region, such as geographical and financial barriers, likely limit access to remote resources for many students (Pollard and Jacobsen 2017, Ferris & Vesely 2021).

When they do visit museums, the general population is given access to a subset of the museum's specimens via curated exhibits that draw from the museum's collections. Meanwhile, behind the scenes, these collections contain millions of specimens (e.g., the American Museum of Natural History in New York houses over 32 million specimens (Science Conservation 2025)). However, because museum specimens are often old, rare, delicate, and precisely organized, they are only accessible to researchers who demonstrate scientific need and an ability to handle or store the specimens responsibly (Bradley et al. 2014). Collections facilitate scientific research involving everything from morphological comparison to DNA sequencing, but even for scientists, access to collections has become more challenging in recent years due to decreased museum staffing and increased demand. Therefore, it is safe to assume that many WV students may never set foot inside a natural history museum, and the vast majority will never have access to museum collections. Thus, when researchers can access specimens, they may have the unique opportunity to bring that experience back to their communities.

Using 3D Models in Outreach

During data collection for research, museums specimens are frequently scanned, creating digital models. Though scanning requires training, time, and expensive software and equipment, the digitized models can be stored, shared, and replicated indefinitely (Vollmar et al. 2010). Researchers then have the potential to "bring" museum specimens into novel educational spaces.

In recent years, 3D printing has been used increasingly in educational settings, with well-documented benefits to the learning process (Ford and Marshall 2019, Hansen et al. 2020, Andić et al 2022). 3D printed models have tremendous potential benefits in outreach, facilitating production and easy access to more advanced comparative morphological specimens. Advantages to using 3D printed models for outreach include:

1) Hands-on learning. Students can hold specimens that would otherwise be unavailable. A broad audience can see and touch diverse specimens, including rare and delicate species.
2) Models are durable, and easy and inexpensive to replace if damage or loss occurs.
3) Educators can modify factors like size, so specimens can be *more* durable and visible.
4) 3D printing exposes students to a real-world application of technology, further encouraging engagement with STEM.

Scientific outreach enables researchers and educators to engage with the public and can encourage curiosity, help students develop analytical skills, and introduce higher education and STEM career paths, making them more familiar and accessible to students (Clark et al. 2016, Laursen et al. 2017).

Limitations in Comparative Anatomy Samples

Comparative anatomy is, in many ways, an ideal focus for scientific outreach. Gross anatomical specimens are easy and compelling to inspect, and students can engage via questions about function. Nonetheless, comparative anatomy samples are often limited by factors such as availability, cost, and risk. Educators are forced to weigh the educational benefits of allowing specimens to be handled against the likelihood of damage to the specimens. Other hindrances to research include availability. Most educational models are limited to species that are regionally common and reasonably large/robust, with far less regard for their suitability for the educational goals of the model. For example, the dietary comparative skulls kit available through vendor "Skulls Unlimited" ($344) includes 6 species spanning only 2 of 30 mammalian orders and a relatively small spectrum of dietary diversity (Comparative Skull Kit—Dietary 2025). A more phylogenetically or geographically diverse sample would have greater education benefits. However, the "best" species for the concept may be rare or fragile. Because of this limitation, many students will never get a chance to see specimens representing some of the more fascinating extremes of size and diversity that compel us as researchers.

Here, we provide one example of how these models coupled with 3D printing make digital datasets ideal for scientific outreach. The goal of this paper is twofold: 1) to share our model with any educators who wish to use it; and 2) to inspire other labs to follow suit with additional novel datasets.

Overview of the Phyllostomid Bat Skull Model

In this paper, we present a comparative outreach model developed using microCT scanned skull specimens of representative species of the bat family Phyllostomidae. Phyllostomid bats are remarkably dietarily and morphologically diverse, with the greatest craniofacial diversity found within any mammalian family (Fleming et al. 2020, Wetterer et al., 2000, Santana et al. 2024). Despite the fascinating diversity represented in this group, the skulls are very small and fragile, many of the species are rare, and all are neotropical. Here, we share files for models that can be scaled and 3D printed, and basic information that can be used to develop an easy and inexpensive comparative outreach model (Supplemental Materials). We propose that having a strong and accessible model diminishes many of the challenges (e.g., time, cost, availability of specimens) limiting quality and/or feasibility of outreach for scientists. Using 3D models derived from specimens digitized for research, we can make a wider and more engaging range of specimens available to students who would not otherwise have an opportunity to see the specimens or ask the questions that fascinate us in our own fields.

Materials and Methods

Phyllostomid Bat Skull Model

Figure 1. **3D printed enlarged bat skulls.** From left to right: *Ametrida centurio*, *Artibeus jamaicensis*, *Glossophaga commisarisi*, *Musonycteris harrisoni*, *Vampyrum spectrum*, *Tonatia saurophila*, *Desmodus rotundus*. Small pink skull below is *Musonycteris harrisoni* printed at actual size.

Model Preparation Methods:

Skeletal specimens (skulls and jaws) of representative dietary specialist species (Table 1) were obtained on loan from the American Museum of Natural History (AMNH) and the National Museum of Natural History (NMNH). Only adult specimens with full dentition were used. Crania were scanned using a GE eXplore Locus in vivo Small Animal MicroCT Scanner. All crania were scanned at a slice thickness of 20 µm at 80 kvp and 450 mA. The raw scan data were reconstructed using a bone algorithm and exported as DICOM files. 3D-reconstructions of skulls were produced in Avizo 3D software (RRID:SCR_014431) and exported as .stl (standard tessellation files, common for 3D printing, included in Supplemental Materials). Copies of skulls were 3D printed at actual size (ranging from 1.5-5 cm) and large scale (400-900%, depending on initial size, see Table 1) using white Raise PLA filament on a Raise 2 printer (used due to availability; other 3D printers should work well, too) (Figure 1).

Table 1. Species Used in Phyllostomid Skull Comparative Morphology Model

Species	Subfamily	Diet	Print Scale (%)
Ametrida centurio	Stenodermatinae	fruit	900
Artibeus jamaicensis	Stenodermatinae	fruit	700
Desmodus rotundus	Desmodontinae	blood	700
Glossophaga commissarisi	Glossophaginae	nectar	900
Musonycteris harrisoni	Glossophaginae	nectar	700
Tonatia saurophila	Phyllostominae	animals (insects)	700
Vampyrum spectrum	Phyllostominae	animals (vertebrates)	400

Basic, age-appropriate (elementary school) natural history information was compiled on a fact sheet for each species (included in Supplemental Materials). These sheets were printed, laminated, and brought to present to students during outreach activities.

Program presentation:

First, we addressed the entire class We talked to students about how skull anatomy often reflects ecological and behavioral differences between species, including diet, and pointed out some examples. Then we gave the students some basic background information about phyllostomid bats and explained that the species in our model are all closely related but that they look different because they eat different foods.

Figure 2. **Model facilitates hands-on learning.** Student instructor engages elementary students in making observations using 3D printed bat skull models.

Next, the class was divided into two groups, each with an undergraduate student or faculty instructor and a full set of 3D printed skull models (Figure 2). We asked the students to make observations of their own about the skulls presented. This step empowers students to make educated observations about the skulls in the collection. We explained to the students that six of the seven species can be grouped into pairs with a species that is closely related and has a similar diet. The seventh species (*Desmodus rotundus*) is the only representative member of its group in the collection. We challenged students to use anatomical clues to decide which species are related to which, and had them describe the characteristics that informed their choices. We checked these observations against the fact sheets.

Then, we had the students guess what diets each bat might eat based on tooth and facial shapes. We had students explain how they would use these features to perform these tasks. We then checked these hypotheses against the actual diets and discussed how the features reflect the dietary specialization of each species. We then showed students a case containing 3D printed copies of the skulls at actual size (these may be fragile), facilitating further discussion about the implications of scale on functional morphology of the skulls.

Finally, we provided students with blank paper and pencils and asked them to either draw their favorite skull or design an imaginary skull. We challenged them to explain why a specific skull was their favorite or how features on their designed skull are used by the imaginary species to perform a specific dietary or behavioral task. We had students write a sentence about their skull or about something they learned. Time permitting, it can also be helpful to allow students to present their creations or discuss their drawings. These mementos will also provide launch points for further discussion in class or at home.

Discussion

The phyllostomid skull comparative anatomy model is a novel outreach program that facilitates a hands-on 3D interactive experience that challenges students to think analytically about the "clues" found in a skull. It exposes students who may never have an opportunity to visit the collections at a museum to species and morphological diversity. It also encourages curiosity and scientific thinking, as students engage with the questions we can begin to explore when encountering unfamiliar specimens.

The low cost of materials for this program makes it ideal for hands-on experience in classroom settings. By providing multiple copies of materials, scientists, volunteers, and even classroom teachers can lead small groups in exploration of the phyllostomid skull model. The program can also be easily adjusted to accommodate older audiences that can engage more readily with trickier concepts, including detailed morphological features and evolutionary and phylogenetic relationships.

It is our hope that other educators will: 1) share the bat skull model we have developed with more students via outreach programs; and 2) consider ways that their own datasets can be developed for outreach. We have the potential to do more to bridge the socioeconomic gaps that limit West Virginia students from accessing STEM and higher education at the same rates as their peers across the country.

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Supplemental Materials

Bat Fact Sheets

Ametrida centurio

Little white-shouldered bat

I eat: FRUIT
I am a teeny tiny bat, and I use my flat teeth to eat soft over-ripe fruit

I am related to:
Artibeus jamaicensis

I am such a rare bat that scientists have to guess what my diet is based on my tooth shape. Did you guess it was fruit?

Other mammals with skulls that look like mine:
capuchin, kinkajou, human

Characteristics of frugivores: broad, short snout, wide flat teeth with points for puncturing and grinding fruit

Artibeus jamaicensis

Jamaican fruit bat

I eat: FRUIT
I use the pointy parts of my teeth to carry fruits and puncture their skin; I use the flat parts of my teeth to grind them up.

I am related to:
Ametrida centurio

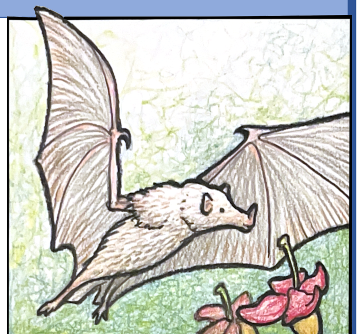
Facts about me:
I can carry fruits as big as my head while I’m flying!

Other mammals with skulls that look like mine:
kinkajou, tayra, sifaka, marmoset

Characteristics of frugivores: broad, short snout, wide flat square teeth with sharp pointy edges for holding and piercing, then grinding fruit

Musonycteris harrisoni

Banana bat



I eat: NECTAR
My teeth are tiny and not good for chewing. I eat with a long, long tongue that I stick into flowers to get out nectar.

I am related to:
Glossophaga commissarisi

Facts about me:
I have the longest snout for my body size. My tongue has bristles like a paintbrush. I eat like a butterfly! And just like a butterfly, I am important for pollinating plants.

Other mammals with skulls that look like mine:
dolphin, anteater

Glossophaga commissarisi

Underwood's long-tongued bat

I eat: NECTAR
I use my long tongue to gather nectar from flowers, but my teeth are a little better for chewing, so I can also eat flowers and fruits sometimes.

I am related to:
Musonycteris harrisoni

Other mammals with skulls that look like mine:
coati, civet

Characteristics of nectarivores:
nectar-eating bats have smaller teeth than other bats and smaller areas for muscles to attach to because they do less chewing

Tonatia saurophila

Stripe-headed round-eared bat

I eat: INSECTS
I use zigzag-shaped back teeth to trap flying insects and crush them up.

I am related to:
Vampyrum spectrum

Facts about me:
Most bats eat bugs! Eating bugs and eating bigger animals is a similar task for a bat. The difference between me and Vampyrum is that I am much smaller!

Other mammals with skulls that look like mine:
hedgehog, tree shrew, mole

Vampyrum spectrum

Spectral bat; Great false vampire bat

I eat: MEAT
I am a predator. I catch birds and bats while they're flying and chew them up with my big teeth.

I am related to:
Tonatia saurophila

Facts about me:
I am the biggest species of bat (other than flying foxes)

Other mammals with skulls that look like mine:
wolf, polar bear, weasel

Characteristics of carnivores: long, narrow snout, tall ridge on my head to attach muscles to, big canine teeth, wide sharp back teeth.

Desmodus rotundus

Common vampire bat

I eat: BLOOD
I use my big front teeth to cut an animal's skin, then I use my tongue to lick the blood from the wound

Facts about me:
My tongue has little "straws" underneath it that I can use to help suck up the blood. I have pockets behind my front teeth that protect my big pointy front teeth and protect me from them! I have to drink so much blood every time I eat that I have to pee while I eat to be able to fly away. My front four teeth are HUGE but the others are teeny tiny.

Other mammals with skulls that look (a little) like mine:
Beaver, Aye-aye

Link to Skull Files:

https://anatomyresources.hsc.wvu.edu/Davis/Bat_skulls.zip