



Evolution in 3D: students use 3D-printed moa bones to learn measurement and phylogenetic mapping of evolutionary characters

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Abstract
For BIOSCI 109: Ecology and Evolution, we developed a new lab practical exercise that uses 3D-printed classroom sets of the bones of fossil moa, and other birds. The goal is to give students hands-on experience in testing hypotheses in evolutionary biology, focusing on the concepts of specimen, species, character, homology, character mapping, form vs. function, and adaptation.

Methods:
3D scan files were obtained from the FaunalToolkit and Aves3D databases. After training at UoA's MakerSpace, 20 classroom sets of bones were printed on 3D printers (2x Makerbot Replicator+ 3D printers; 1x Ender-3 Pro 3D printer). Bones that were too large (e.g. giant moa) or small (e.g. kiwi wings) for the printers were re-sized, with the scale recorded. Students were introduced to the exercise with an HP5 presentation, and had to (A) identify the bones by type (leg vs. wing), (B) match to species, (C) identify/score discrete characters and map onto a phylogeny, (D) measure predefined quantitative characters with calipers, and (E) graph this data and propose a hypothesized explanation, along with how they would test this hypothesis with new data.

1. Museum 3D scans from collections:

Little bush moa skeleton
3D Model
Auckland Museum

Fauna Toolkit: Bird Bones
Bones from living and extinct bird species
A portal to 3D digitised models of bird bones from museum collections.
234 entries from 65 species in 29 families and 19 orders are now available from the Index below.
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Order	Family	Scientific name	Common name	Bone	Side
Dinornithiformes	Dinornithidae	Dinornis robustus	South Island giant moa	Femur	Right
Dinornithiformes	Dinornithidae	Dinornis robustus	South Island giant moa	Tibiotarsus	Right
Dinornithiformes	Dinornithidae	Dinornis robustus	South Island giant moa	Fibula	No data yet
Dinornithiformes	Dinornithidae	Dinornis robustus	South Island giant moa	Tarsometatarsus	Right
Dinornithiformes	Emidiidae	Anomalopteryx didiformis	Little bush moa	Alula	Medial
Dinornithiformes	Emidiidae	Anomalopteryx didiformis	Little bush moa	Axis	Medial
Dinornithiformes	Emidiidae	Anomalopteryx didiformis	Little bush moa	Tarsometatarsus	Right
Dinornithiformes	Emidiidae	Anomalopteryx didiformis	Little bush moa	Skull	Medial
Dinornithiformes	Emidiidae	Pachyornis elephantopus	Heavy-footed moa	Pelvis	Medial

2. 3D printed bones of moa, kiwi, penguins, etc. (some rescaled)

4. Students score characters, measure with calipers, plot data, and propose hypothesis and tests

Scientific Name	Leg bone	Wing bone(s)	Mass of adult bird (kg)	tarsometatarsus length	width	Humeral length	width	ulna length	width	tars length/width ratio	hms length/width ratio	Scientific Name	Max. weight (kg)	tars length/width ratio
<i>Apteryx mantelli</i>	tarsometatarsus	humerus, radius, & ulna	2.8	81	9.8	46	2.3	21.0	1.7	8.2	20	<i>Apteryx mantelli</i>	2.8	8.2
<i>Dinornis robustus</i>	tarsometatarsus	(absent in this species)	230	478	69.2	0	0	0	0	6.9	N/A	<i>Dinornis robustus</i>	230	6.9
<i>Anomalopteryx didiformis</i>	tarsometatarsus	(absent in this species)	30	185	30.8	0	0	0	0	6	N/A	<i>Anomalopteryx didiformis</i>	30	6.0
<i>Struthio camelus</i>	tarsometatarsus	humerus	157	441	33.2	368	19.5	?	?	13.3	18.9	<i>Struthio camelus</i>	157	13.3
<i>Ninox albigacies</i>	tarsometatarsus	humerus & ulna	0.6	71	4.1	79	4.5	86.0	4.4	17.5	17.4	<i>Ninox albigacies</i>	0.6	17.5
<i>Callaeas wilsoni</i>	tarsometatarsus	humerus	0.233	61	2.8	35	2.8	35.0	2.2	21.5	12.7	<i>Callaeas wilsoni</i>	0.233	21.5
<i>Muriwaimanu tuatahi</i>	tarsometatarsus	(not available)	12	105	32.1	?	?	?	?	3.3	?	<i>Muriwaimanu tuatahi</i>	12	3.3
<i>Pygoscelis antarctica</i>	(not available)	humerus & ulna	5	?	?	72	15.3	46.0	12.9	?	4.7	<i>Pygoscelis antarctica</i>	5	?
<i>Aptenodytes patagonicus</i>	(not available)	humerus & ulna	15	?	?	74	16.9	?	?	?	4.4	<i>Aptenodytes patagonicus</i>	15	?

3. H5P exercise for BIOSCI 109

BIOSCI 109

Lab 4: Mystery bones

The concepts of homology, adaptation, form and function, character, and character state are fundamental for all of your future instruction in evolution, comparative biology, and phylogenetics, so in this lab you will work on developing an intuition about how biologists use these concepts in comparative morphology, in order to interpret the bones of a number of living and extinct birds.

Conclusion:
3D-printing can revolutionise introductory evolution teaching because rare fossil specimens that are usually only seen in museums or textbooks can, as 3D-printed specimens, be handled, measured, and discussed by students.

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3D scan .OBJ files courtesy of: Daniel Thomas, Massey University (<https://www.faunatoolkit.com/>)

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