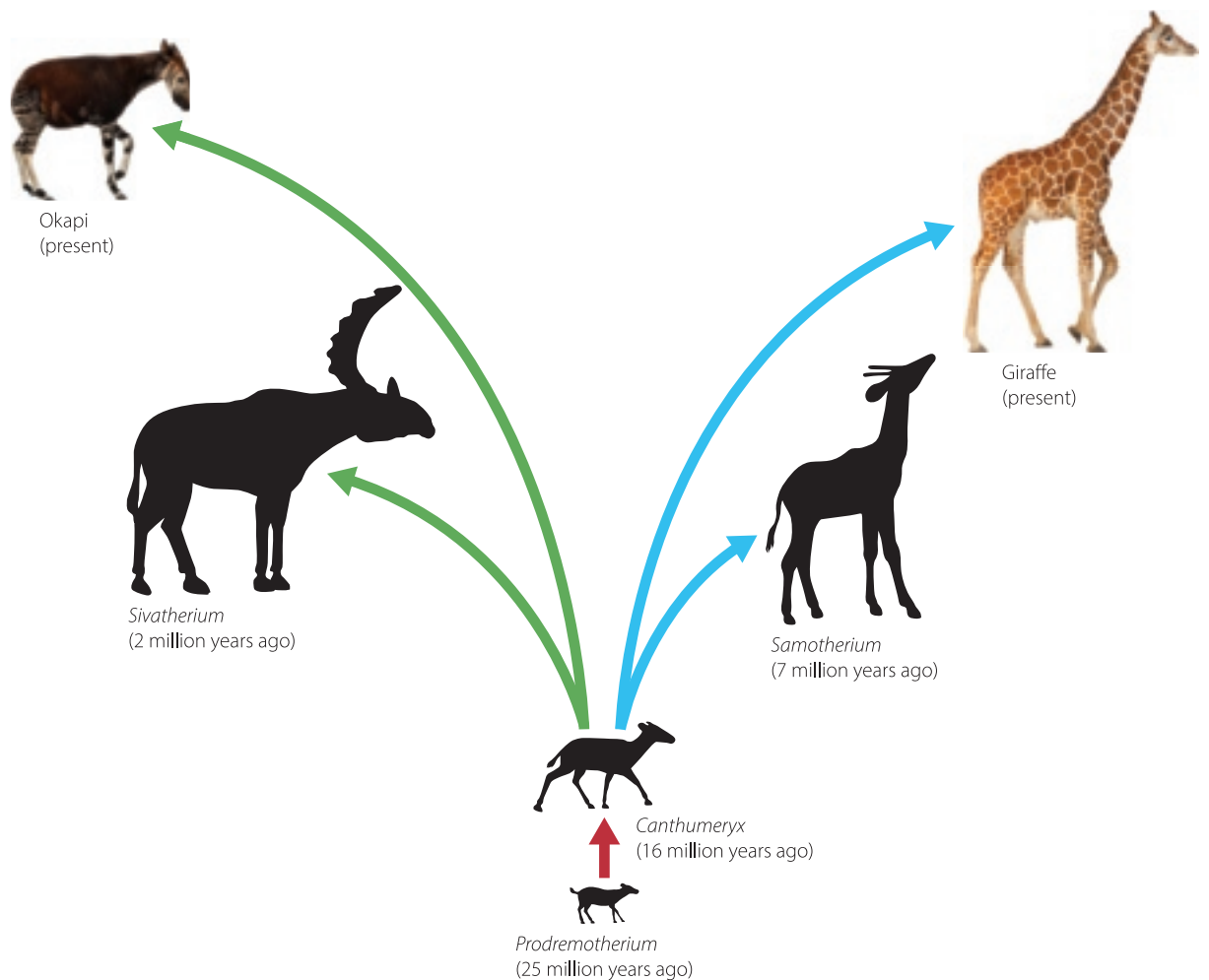


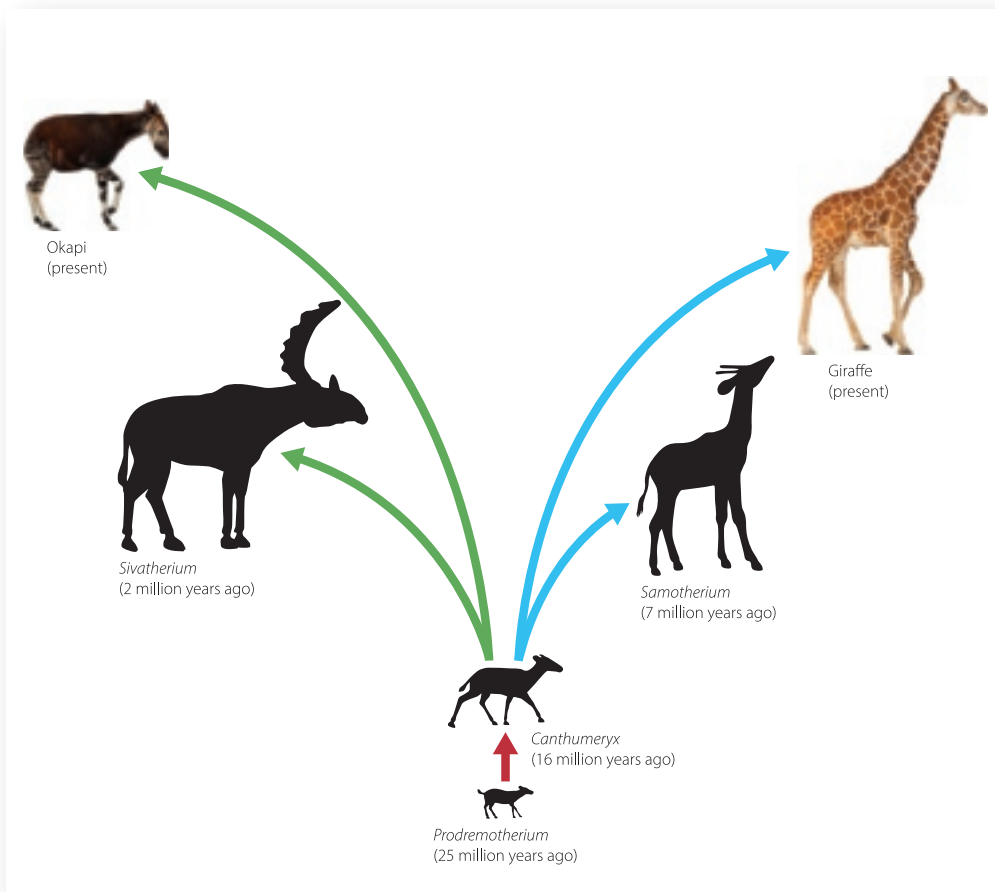
Unit 6

Natural Selection and Common Ancestry:

How could things living today be connected to the things that lived long ago?

Student Work Pages





Natural Selection and Common Ancestry

How could things living today be connected
to the things that lived long ago?

Student Work Pages

Core Knowledge Science



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Natural Selection and Common Ancestry:

How could things living today be connected
to the things that lived long ago?

Table of Contents

Lesson 1: Penguin Comparison	1	Lesson 4: Reference: Analyzing and	
Lesson 1: Predictions on Other Penguins		Interpreting Fossil Data	47
That Lived Long Ago.....	3	Lesson 4: Exit Ticket – Trait Variation	49
Lesson 1: Initial Explanations.....	5	Lesson 5: Patterns for My Organism:	51
Lesson 2: Reference: External Structures		Lesson 5: Guiding Questions to Compare	
and Behaviors Key	7	Our Models	55
Lesson 2: Data Strips: External Structures		Lesson 7: Cliff Swallow Data Packet	57
and Behaviors in Modern Penguins		Lesson 7: Finch Data Packet	71
and Pedro	9	Lesson 7: Mustard Plant Data Packet	87
Lesson 2: Reference: Internal Structures Key	15	Lesson 7: Peppered Moth Data Packet	101
Lesson 2: Data Strips, Internal and External		Lesson 7: Stickleback Data Packet	117
Structures in Modern Penguins		Lesson 7: Using the CCC Lens	131
and Pedro	17	Lesson 7: Develop a System Model	133
Lesson 2: New Questions and Ideas for		Lesson 8: How can we use our model	
Data We Need	23	to make predictions?	135
Lesson 3: Data Strips, Internal and External		Lesson 9: Flagella Image for Word Wall	137
Structures in Modern Penguins		Lesson 9: Investigation 1	139
and Pedro	25	Lesson 9: Refining and Applying our general	
Lesson 3: Data Strips for Ancient		Model for Natural Selection	141
Penguin Fossils	31	Lesson 10: Different Environmental	
Lesson 3: Extension, Data Strips of More		Conditions and Results.....	143
Incomplete Ancient Penguin Fossils ...	33	Lesson 10: My Model for Changes in	
Lesson 3: Timeline Sections	35	Bacteria Populations	145
Lesson 3: Ancient Penguin Sorting Exit Ticket ...	41	Lesson 11: Model Scaffold for Green	
Lesson 4: Three Explanations.....	43	Lizard Explanation	147
Lesson 4: Word Wall Image for Population.....	45		

Lesson 11: Peer Feedback	
Self-Assessment	149
Lesson 14: Egg-Laying Embryos	151
Lesson 14: Live Birth Embryos	153
Lesson 14: Alternate: Non-egg-laying Embryos.....	155
Lesson 14: New Ideas and Questions Connected to Embryo Comparisons	157

Lesson 15: Reviewing Our Driving Question Board	159
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Science Literacy Exercise Pages

Collection 1: Exercise Page 1	161
Collection 2: Exercise Page 2	163
Collection 3: Exercise Page 3	165
Collection 4: Exercise Page 4	167

Name: _____

Date: _____

Penguin Comparison

PENGUIN SPECIES ↓	Physical characteristics	Behaviors

Name: _____

Date: _____

Predictions on Other Penguins That Lived Long Ago

Dig location: _____

Draw, list, or describe traits or characteristics the penguin would have had <u>when it was alive</u> and predict whether they would be the same as or different from those of penguins living today.	Why do you think this?
When the penguin you described above was alive, do you think it was the only species of penguin living on Earth? Why?	

Name: _____

Date: _____

Initial Explanations

Where did all the ancient penguins go?

Claim	Possible mechanism	Evidence we need to support our claim	Evidence that would refute our claim

Where did all the different species of modern penguins come from?

Claim	Possible mechanism	Evidence we need to support our claim	Evidence that would refute our claim

Reference: External Structures and Behaviors Key

		Structures and Behaviors		Variations		
Feathers	A	scale-like feathers	absent (0)	present (1)		
	B	shape of the central shaft of the feathers	cylindrical (0)	flat and broad (1)		
	C	pattern on underside of flipper edge	white (0)	incompletely dark (1)	completely dark and wide (2)	
	D	crown feather color (top of head)	black (0)	yellow (1)		
	E	head plumes	absent (0)	present (1)		
	F	compactness of head plumes, if present	compact (0)	fluffy (1)		
Beak	G	shape of the top of beak tip	pointed (0)	weakly hooked (1)	strongly hooked (2)	
	H	bottom of the beak color	black (0)	reddish (1)	pink (2)	yellowish (3)
	I	top of the beak color	black (0)	red (1)	orange (2)	
Eye	J	white eyebrow	absent (0)	narrow, behind eye (1)	narrow, in front of eye (2)	wide, in front of eye (3)
	K	fleshy eye ring	absent (0)	present (1)		
	L	white eye ring	compact (0)	fluffy (1)		
	M	top of foot color	dark (0)	pinkish (1)	orange (2)	whitish (3)
Feet	N	soles of the feet are darker than the tops	no (0)	yes (1)		
	O	foot nail shape	flat (0)	compressed (1)		
Nest, eggs, and chicks	P	nest	no nest, incubation over the feet (0)	nest in rock cracks or buried in sand (1)	open nest in a shallow depression (2)	
	Q	egg shape	oval (0)	conical (1)	spherical (2)	
	R	clutch size (number of eggs at a time)	two eggs (0)	one egg (1)		
	S	chicks have feathers	yes (0)	no (1)		

Lesson 2 Data Strips External Structures and Behaviors in Modern Penguins and Pedro	Emperor		King		Chinstrap		Gentoo		Adélie		Yellow-eyed	
	A	1	A	1	A	1	A	1	A	1	A	1
	B	1	B	1	B	1	B	1	B	1	B	1
	C	0	C	1	C	0	C	1	C	1	C	0
	D	0	D	0	D	0	D	0	D	0	D	1
	E	0	E	0	E	0	E	0	E	0	E	0
	F	-	F	-	F	-	F	-	F	-	F	-
	G	0	G	0	G	1	G	1	G	1	G	1
	H	0	H	0	H	0	H	1	H	1	H	2
	I	0	I	0	I	0	I	0	I	0	I	1
	J	0	J	0	J	0	J	0	J	0	J	0
	K	0	K	0	K	0	K	0	K	0	K	1
	L	0	L	0	L	0	L	1	L	1	L	0
	M	0	M	0	M	1	M	2	M	1	M	1
	N	0	N	0	N	0	N	0	N	1	N	0
	O	0	O	0	O	0	O	0	O	0	O	1
	P	0	P	0	P	2	P	2	P	2	P	2
	Q	1	Q	1	Q	2	Q	2	Q	2	Q	0
	R	1	R	1	R	0	R	0	R	0	R	0
	S	1	S	1	S	0	S	0	S	0	S	0

Southern rockhopper		Macaroni		Northern rockhopper		Fiordland		Snares		Royal		E-crested	
A	1	A	1	A	1	A	1	A	1	A	1	A	1
B	1	B	1	B	1	B	1	B	1	B	1	B	1
C	1	C	1	C	2	C	1	C	2	C	1	C	2
D	1	D	1	D	1	D	1	D	1	D	1	D	1
E	1	E	1	E	1	E	1	E	1	E	1	E	1
F	1	F	1	F	0	F	0	F	0	F	1	F	0
G	1	G	1	G	1	G	1	G	1	G	1	G	1
H	1	H	1	H	1	H	1	H	1	H	1	H	1
I	1	I	1	I	1	I	1	I	1	I	1	I	1
J	0	J	0	J	0	J	0	J	0	J	0	J	0
K	0	K	0	K	0	K	0	K	0	K	0	K	0
L	0	L	0	L	0	L	0	L	0	L	0	L	0
M	1	M	1	M	1	M	1	M	1	M	1	M	1
N	1	N	1	N	1	N	1	N	1	N	1	N	1
O	1	O	1	O	1	O	1	O	1	O	1	O	1
P	2	P	2	P	2	P	2	P	2	P	2	P	2
Q	0	Q	0	Q	0	Q	0	Q	0	Q	0	Q	0
R	0	R	0	R	0	R	0	R	0	R	0	R	0
S	0	S	0	S	0	S	0	S	0	S	0	S	0

Little		African		Magellanic		Humboldt		Galápagos		Water king/ Pedro	
A	1	A	1	A	1	A	1	A	1	A	1
B	1	B	1	B	1	B	1	B	1	B	1
C	1	C	1	C	0	C	1	C	1	C	?
D	0	D	0	D	0	D	0	D	0	D	?
E	0	E	0	E	0	E	0	E	0	E	?
F	-	F	-	F	-	F	-	F	-	F	?
G	1	G	1	G	1	G	1	G	1	G	0
H	0	H	0	H	0	H	0	H	2	H	?
I	0	I	0	I	0	I	0	I	0	I	?
J	0	J	3	J	2	J	2	J	1	J	?
K	0	K	1	K	1	K	1	K	1	K	?
L	0	L	0	L	0	L	0	L	0	L	?
M	3	M	0	M	0	M	0	M	0	M	?
N	0	N	0	N	0	N	0	N	0	N	?
O	1	O	1	O	1	O	1	O	1	O	?
P	1	P	1	P	1	P	1	P	1	P	?
Q	0	Q	0	Q	0	Q	0	Q	0	Q	?
R	0	R	0	R	0	R	0	R	0	R	?
S	0	S	0	S	0	S	0	S	0	S	?

Reference: Internal Structures Key

		Structures	Variations		
Beak and skull	AA	shape of the top of the beak tip	pointed (0)	weakly hooked (1)	strongly hooked (2)
	BB	depression on the side of the skull	separated by a wide surface (0)	less separated; almost meeting at midline of skull (1)	
	CC	depth of the depression described above in BB	flat (0)	shallow (1)	deep (2)
Shoulder blade	DD	shape of the shoulder blade	blade-like (0)	slightly expanded (1)	broadly expanded, paddle-shaped (2)
	EE	size of the projection on the shoulder blade where the biceps are attached	greatly expanded (0)	moderately expanded (1)	
	FF	shape of the projection on the shoulder blade where the biceps are attached	convex (0)	concave (1)	flat (2)
Leg and foot	GG	kneecap	shallow groove (0)	deep groove (1)	perforated (2)
	HH	ratio of length to width for lower leg bone	slender (0)	shortened (1)	very shortened (2)
	II	opening(s) in the upper foot for an artery	a single opening on the inner side of the upper foot (0)	openings on both sides of the upper foot—inner and outer foot (1)	a single opening on the outer side of the upper foot (2)
Humerus (upper wing bone)	JJ	humerus shaft width	thins or maintains width as you move toward the end of it (0)	widens as you move toward the end of it (1)	
	KK	humerus shaft curvature	absent or weak (0)	strong (1)	
	LL	shape of a bony projection on the middle front of the humerus	absent (0)	compact (1)	long (2)
	MM	slope on the surface of the top rounded end of the humerus	in line with the midline of the body (0)	slanted toward the front of the body (1)	
	NN	shape and direction of a scar on the humerus where a muscle is attached	not elongated, semicircular (0)	greatly elongated, with long axis parallel to the long axis of humerus (1)	greatly elongated, with long axis not parallel to the long axis of humerus (2)

Lesson 2 Data Strips Internal and External Structures in Modern Penguins and Pedro	Emperor (internal)		King (internal)		Chinstrap (internal)		Gentoo (internal)		Adélie (internal)		Yellow-eyed (internal)	
	AA	0	AA	0	AA	1	AA	1	AA	1	AA	1
	BB	0	BB	0	BB	0	BB	0	BB	0	BB	0
	CC	1	CC	1	CC	1	CC	1	CC	1	CC	2
	DD	2	DD	2	DD	2	DD	2	DD	2	DD	2
	EE	1	EE	1	EE	1	EE	1	EE	1	EE	1
	FF	1	FF	1	FF	1	FF	1	FF	1	FF	1
	GG	0	GG	0	GG	2	GG	1	GG	1	GG	1
	HH	2	HH	2	HH	2	HH	2	HH	2	HH	2
	II	1	II	1	II	1	II	1	II	1	II	1
	JJ	1	JJ	1	JJ	1	JJ	1	JJ	1	JJ	1
	KK	0	KK	0	KK	0	KK	0	KK	0	KK	0
	LL	0	LL	0	LL	0	LL	0	LL	0	LL	0
	MM	1	MM	1	MM	1	MM	1	MM	1	MM	1
	NN	2	NN	2	NN	2	NN	2	NN	2	NN	2
	Emperor		King		Chinstrap		Gentoo		Adélie		Yellow-eyed	
	A	1	A	1	A	1	A	1	A	1	A	1
	B	1	B	1	B	1	B	1	B	1	B	1
	C	0	C	1	C	0	C	1	C	1	C	0
	D	0	D	0	D	0	D	0	D	0	D	1
	E	0	E	0	E	0	E	0	E	0	E	0
	F	-	F	-	F	-	F	-	F	-	F	-
	G	0	G	0	G	1	G	1	G	1	G	1
	H	0	H	0	H	0	H	1	H	1	H	2
	I	0	I	0	I	0	I	0	I	0	I	1
	J	0	J	0	J	0	J	0	J	0	J	0
	K	0	K	0	K	0	K	0	K	0	K	1
	L	0	L	0	L	0	L	1	L	1	L	0
	M	0	M	0	M	1	M	2	M	1	M	1
	N	0	N	0	N	0	N	0	N	1	N	0
	O	0	O	0	O	0	O	0	O	0	O	1
	P	0	P	0	P	2	P	2	P	2	P	2
	Q	1	Q	1	Q	2	Q	2	Q	2	Q	0
R	1	R	1	R	0	R	0	R	0	R	0	
S	1	S	1	S	0	S	0	S	0	S	0	

Southern rockhopper (internal)		Macaroni (internal)		Northern rockhopper (internal)		Fiordland (internal)		Snares (internal)		Royal (internal)		E-crested (internal)	
AA	1	AA	1	AA	1	AA	1	AA	1	AA	1	AA	1
BB	0	BB	0	BB	0	BB	0	BB	0	BB	0	BB	0
CC	2	CC	2	CC	2	CC	2	CC	2	CC	2	CC	2
DD	2	DD	2	DD	2	DD	2	DD	2	DD	2	DD	2
EE	1	EE	1	EE	1	EE	1	EE	1	EE	1	EE	1
FF	1	FF	1	FF	1	FF	1	FF	1	FF	1	FF	1
GG	1	GG	1	GG	1	GG	1	GG	1	GG	1	GG	1
HH	2	HH	2	HH	2	HH	2	HH	2	HH	2	HH	2
II	1	II	1	II	1	II	1	II	1	II	1	II	1
JJ	1	JJ	1	JJ	1	JJ	1	JJ	1	JJ	1	JJ	1
KK	0	KK	0	KK	0	KK	0	KK	0	KK	0	KK	0
LL	0	LL	0	LL	0	LL	0	LL	0	LL	0	LL	0
MM	1	MM	1	MM	1	MM	1	MM	1	MM	1	MM	1
NN	2	NN	2	NN	2	NN	2	NN	2	NN	2	NN	2
Southern rockhopper		Macaroni		Northern rockhopper		Fiordland		Snares		Royal		E-crested	
A	1	A	1	A	1	A	1	A	1	A	1	A	1
B	1	B	1	B	1	B	1	B	1	B	1	B	1
C	1	C	1	C	2	C	1	C	2	C	1	C	2
D	1	D	1	D	1	D	1	D	1	D	1	D	1
E	1	E	1	E	1	E	1	E	1	E	1	E	1
F	1	F	1	F	0	F	0	F	0	F	1	F	0
G	1	G	1	G	1	G	1	G	1	G	1	G	1
H	1	H	1	H	1	H	1	H	1	H	1	H	1
I	1	I	1	I	1	I	1	I	1	I	1	I	1
J	0	J	0	J	0	J	0	J	0	J	0	J	0
K	0	K	0	K	0	K	0	K	0	K	0	K	0
L	0	L	0	L	0	L	0	L	0	L	0	L	0
M	1	M	1	M	1	M	1	M	1	M	1	M	1
N	1	N	1	N	1	N	1	N	1	N	1	N	1
O	1	O	1	O	1	O	1	O	1	O	1	O	1
P	2	P	2	P	2	P	2	P	2	P	2	P	2
Q	0	Q	0	Q	0	Q	0	Q	0	Q	0	Q	0
R	0	R	0	R	0	R	0	R	0	R	0	R	0
S	0	S	0	S	0	S	0	S	0	S	0	S	0

Little (internal)		African (internal)		Magellanic (internal)		Humboldt (internal)		Galápagos (internal)		Water king/ Pedro (internal)	
AA	1	AA	1	AA	1	AA	1	AA	1	AA	0
BB	0	BB	1	BB	1	BB	1	BB	1	BB	1
CC	2	CC	2	CC	2	CC	2	CC	2	CC	2
DD	2	DD	2	DD	2	DD	2	DD	2	DD	1
EE	1	EE	1	EE	1	EE	1	EE	1	EE	0
FF	1	FF	1	FF	1	FF	1	FF	1	FF	0
GG	1	GG	1	GG	1	GG	1	GG	1	GG	2
HH	2	HH	2	HH	2	HH	2	HH	2	HH	2
II	1	II	1	II	1	II	1	II	1	II	2
JJ	1	JJ	1	JJ	1	JJ	1	JJ	1	JJ	0
KK	0	KK	0	KK	0	KK	0	KK	0	KK	0
LL	0	LL	0	LL	0	LL	0	LL	0	LL	0
MM	1	MM	1	MM	1	MM	1	MM	1	MM	0
NN	2	NN	2	NN	2	NN	2	NN	2	NN	0
Little		African		Magellanic		Humboldt		Galápagos		Water king/ Pedro	
A	1	A	1	A	1	A	1	A	1	A	1
B	1	B	1	B	1	B	1	B	1	B	1
C	1	C	1	C	0	C	1	C	1	C	?
D	0	D	0	D	0	D	0	D	0	D	?
E	0	E	0	E	0	E	0	E	0	E	?
F	-	F	-	F	-	F	-	F	-	F	?
G	1	G	1	G	1	G	1	G	1	G	0
H	0	H	0	H	0	H	0	H	2	H	?
I	0	I	0	I	0	I	0	I	0	I	?
J	0	J	3	J	2	J	2	J	1	J	?
K	0	K	1	K	1	K	1	K	1	K	?
L	0	L	0	L	0	L	0	L	0	L	?
M	3	M	0	M	0	M	0	M	0	M	?
N	0	N	0	N	0	N	0	N	0	N	?
O	1	O	1	O	1	O	1	O	1	O	?
P	1	P	1	P	1	P	1	P	1	P	?
Q	0	Q	0	Q	0	Q	0	Q	0	Q	?
R	0	R	0	R	0	R	0	R	0	R	?
S	0	S	0	S	0	S	0	S	0	S	?

New Questions and Ideas for Data We Need

Make a claim and support it.

Do you think Pedro could be an ancient ancestor of any of the modern penguins? Why or why not?

Pose new questions and identify data needed to answer questions.

Record what new questions you now have and any ideas for what data we need to analyze to begin to figure out some of these questions.

Questions	Data we need

Lesson 3
Data Strips
Internal
and
External
Structures
in Modern
Penguins
and Pedro

Emperor (internal)		King (internal)		Chinstrap (internal)		Gentoo (internal)		Adélie (internal)		Yellow-eyed (internal)	
AA	0	AA	0	AA	1	AA	1	AA	1	AA	1
BB	0	BB	0	BB	0	BB	0	BB	0	BB	0
CC	1	CC	1	CC	1	CC	1	CC	1	CC	2
DD	2	DD	2	DD	2	DD	2	DD	2	DD	2
EE	1	EE	1	EE	1	EE	1	EE	1	EE	1
FF	1	FF	1	FF	1	FF	1	FF	1	FF	1
GG	0	GG	0	GG	2	GG	1	GG	1	GG	1
HH	2	HH	2	HH	2	HH	2	HH	2	HH	2
II	1	II	1	II	1	II	1	II	1	II	1
JJ	1	JJ	1	JJ	1	JJ	1	JJ	1	JJ	1
KK	0	KK	0	KK	0	KK	0	KK	0	KK	0
LL	0	LL	0	LL	0	LL	0	LL	0	LL	0
MM	1	MM	1	MM	1	MM	1	MM	1	MM	1
NN	2	NN	2	NN	2	NN	2	NN	2	NN	2
Emperor		King		Chinstrap		Gentoo		Adélie		Yellow-eyed	
A	1	A	1	A	1	A	1	A	1	A	1
B	1	B	1	B	1	B	1	B	1	B	1
C	0	C	1	C	0	C	1	C	1	C	0
D	0	D	0	D	0	D	0	D	0	D	1
E	0	E	0	E	0	E	0	E	0	E	0
F	-	F	-	F	-	F	-	F	-	F	-
G	0	G	0	G	1	G	1	G	1	G	1
H	0	H	0	H	0	H	1	H	1	H	2
I	0	I	0	I	0	I	0	I	0	I	1
J	0	J	0	J	0	J	0	J	0	J	0
K	0	K	0	K	0	K	0	K	0	K	1
L	0	L	0	L	0	L	1	L	1	L	0
M	0	M	0	M	1	M	2	M	1	M	1
N	0	N	0	N	0	N	0	N	1	N	0
O	0	O	0	O	0	O	0	O	0	O	1
P	0	P	0	P	2	P	2	P	2	P	2
Q	1	Q	1	Q	2	Q	2	Q	2	Q	0
R	1	R	1	R	0	R	0	R	0	R	0
S	1	S	1	S	0	S	0	S	0	S	0

Southern rockhopper (internal)		Macaroni (internal)		Northern rockhopper (internal)		Fiordland (internal)		Snares (internal)		Royal (internal)		E-crested (internal)	
AA	1	AA	1	AA	1	AA	1	AA	1	AA	1	AA	1
BB	0	BB	0	BB	0	BB	0	BB	0	BB	0	BB	0
CC	2	CC	2	CC	2	CC	2	CC	2	CC	2	CC	2
DD	2	DD	2	DD	2	DD	2	DD	2	DD	2	DD	2
EE	1	EE	1	EE	1	EE	1	EE	1	EE	1	EE	1
FF	1	FF	1	FF	1	FF	1	FF	1	FF	1	FF	1
GG	1	GG	1	GG	1	GG	1	GG	1	GG	1	GG	1
HH	2	HH	2	HH	2	HH	2	HH	2	HH	2	HH	2
II	1	II	1	II	1	II	1	II	1	II	1	II	1
JJ	1	JJ	1	JJ	1	JJ	1	JJ	1	JJ	1	JJ	1
KK	0	KK	0	KK	0	KK	0	KK	0	KK	0	KK	0
LL	0	LL	0	LL	0	LL	0	LL	0	LL	0	LL	0
MM	1	MM	1	MM	1	MM	1	MM	1	MM	1	MM	1
NN	2	NN	2	NN	2	NN	2	NN	2	NN	2	NN	2
Southern rockhopper		Macaroni		Northern rockhopper		Fiordland		Snares		Royal		E-crested	
A	1	A	1	A	1	A	1	A	1	A	1	A	1
B	1	B	1	B	1	B	1	B	1	B	1	B	1
C	1	C	1	C	2	C	1	C	2	C	1	C	2
D	1	D	1	D	1	D	1	D	1	D	1	D	1
E	1	E	1	E	1	E	1	E	1	E	1	E	1
F	1	F	1	F	0	F	0	F	0	F	1	F	0
G	1	G	1	G	1	G	1	G	1	G	1	G	1
H	1	H	1	H	1	H	1	H	1	H	1	H	1
I	1	I	1	I	1	I	1	I	1	I	1	I	1
J	0	J	0	J	0	J	0	J	0	J	0	J	0
K	0	K	0	K	0	K	0	K	0	K	0	K	0
L	0	L	0	L	0	L	0	L	0	L	0	L	0
M	1	M	1	M	1	M	1	M	1	M	1	M	1
N	1	N	1	N	1	N	1	N	1	N	1	N	1
O	1	O	1	O	1	O	1	O	1	O	1	O	1
P	2	P	2	P	2	P	2	P	2	P	2	P	2
Q	0	Q	0	Q	0	Q	0	Q	0	Q	0	Q	0
R	0	R	0	R	0	R	0	R	0	R	0	R	0
S	0	S	0	S	0	S	0	S	0	S	0	S	0

Little (internal)		African (internal)		Magellanic (internal)		Humboldt (internal)		Galápagos (internal)		Water king/ Pedro (internal)	
AA	1	AA	1	AA	1	AA	1	AA	1	AA	0
BB	0	BB	1	BB	1	BB	1	BB	1	BB	1
CC	2	CC	2	CC	2	CC	2	CC	2	CC	2
DD	2	DD	2	DD	2	DD	2	DD	2	DD	1
EE	1	EE	1	EE	1	EE	1	EE	1	EE	0
FF	1	FF	1	FF	1	FF	1	FF	1	FF	0
GG	1	GG	1	GG	1	GG	1	GG	1	GG	2
HH	2	HH	2	HH	2	HH	2	HH	2	HH	2
II	1	II	1	II	1	II	1	II	1	II	2
JJ	1	JJ	1	JJ	1	JJ	1	JJ	1	JJ	0
KK	0	KK	0	KK	0	KK	0	KK	0	KK	0
LL	0	LL	0	LL	0	LL	0	LL	0	LL	0
MM	1	MM	1	MM	1	MM	1	MM	1	MM	0
NN	2	NN	2	NN	2	NN	2	NN	2	NN	0
Little		African		Magellanic		Humboldt		Galápagos		Water king/ Pedro	
A	1	A	1	A	1	A	1	A	1	A	1
B	1	B	1	B	1	B	1	B	1	B	1
C	1	C	1	C	0	C	1	C	1	C	?
D	0	D	0	D	0	D	0	D	0	D	?
E	0	E	0	E	0	E	0	E	0	E	?
F	-	F	-	F	-	F	-	F	-	F	?
G	1	G	1	G	1	G	1	G	1	G	0
H	0	H	0	H	0	H	0	H	2	H	?
I	0	I	0	I	0	I	0	I	0	I	?
J	0	J	3	J	2	J	2	J	1	J	?
K	0	K	1	K	1	K	1	K	1	K	?
L	0	L	0	L	0	L	0	L	0	L	?
M	3	M	0	M	0	M	0	M	0	M	?
N	0	N	0	N	0	N	0	N	0	N	?
O	1	O	1	O	1	O	1	O	1	O	?
P	1	P	1	P	1	P	1	P	1	P	?
Q	0	Q	0	Q	0	Q	0	Q	0	Q	?
R	0	R	0	R	0	R	0	R	0	R	?
S	0	S	0	S	0	S	0	S	0	S	?

Lesson 3 Data Strips Data Strips for Ancient Penguin Fossils	Harris'		<i>S. urbinai</i>		Slender-footed		Tiny rower		<i>Pa. antarcticus</i>		Lopdell's	
	AA	?	AA	2	AA	?	AA	?	AA	?	AA	?
	BB	1	BB	1	BB	?	BB	?	BB	1	BB	?
	CC	2	CC	2	CC	?	CC	?	CC	2	CC	?
	DD	2	DD	?	DD	2	DD	?	DD	?	DD	?
	EE	1	EE	1	EE	1	EE	?	EE	?	EE	0
	FF	1	FF	1	FF	1	FF	?	FF	?	FF	0
	GG	?	GG	?	GG	1	GG	?	GG	2	GG	?
	HH	?	HH	2	HH	2	HH	2	HH	2	HH	2
	II	?	II	1	II	2	II	2	II	1	II	1
	JJ	1	JJ	1	JJ	1	JJ	1	JJ	1	JJ	?
	KK	0	KK	0	KK	0	KK	0	KK	0	KK	?
	LL	0	LL	0	LL	0	LL	0	LL	0	LL	0
	MM	1	MM	1	MM	1	MM	1	MM	1	MM	?
	NN	?	NN	2	NN	1	NN	1	NN	1	NN	?

Lowe's		Simpson's		Giant spear-billed		Colossus		P. gunnari		W. tuatahi		P. devriesi	
AA	?	AA	?	AA	0	AA	?	AA	?	AA	?	AA	?
BB	?	BB	?	BB	1	BB	?	BB	?	BB	?	BB	1
CC	?	CC	?	CC	2	CC	?	CC	?	CC	2	CC	2
DD	?	DD	1	DD	?	DD	?	DD	?	DD	?	DD	?
EE	0	EE	1	EE	?	EE	?	EE	?	EE	0	EE	?
FF	0	FF	0	FF	?	FF	?	FF	?	FF	?	FF	?
GG	2	GG	?	GG	?	GG	?	GG	?	GG	?	GG	?
HH	?	HH	?	HH	?	HH	0	HH	0	HH	0	HH	1 or 2
II	?	II	?	II	?	II	2	II	2	II	0	II	?
JJ	1	JJ	1	JJ	0	JJ	1	JJ	1	JJ	1	JJ	?
KK	1	KK	0	KK	0	KK	0	KK	0	KK	1	KK	1
LL	0	LL	0	LL	0	LL	2	LL	?	LL	1	LL	1
MM	0	MM	0	MM	0	MM	0	MM	0	MM	1	MM	0
NN	1	NN	?	NN	0	NN	?	NN	0	NN	1	NN	0

The trait variation data used in this lesson were compiled and merged from two resources.

1. The first was the supporting online material published along with *Fossil Evidence for Evolution of The Shape and Color of Penguin Feathers*, published 12 November 2010 in Science, DOI: 10.1126/science.1193604.
2. The second was the appendix published along with *Paleogene Equatorial Penguins Challenge The Proposed Relationship Between Biogeography, Diversity, and Cenozoic Climate Change*. Published July 2007 in Proceedings of the National Academy of Sciences, DOI: 10.1073/pnas.0611099104.

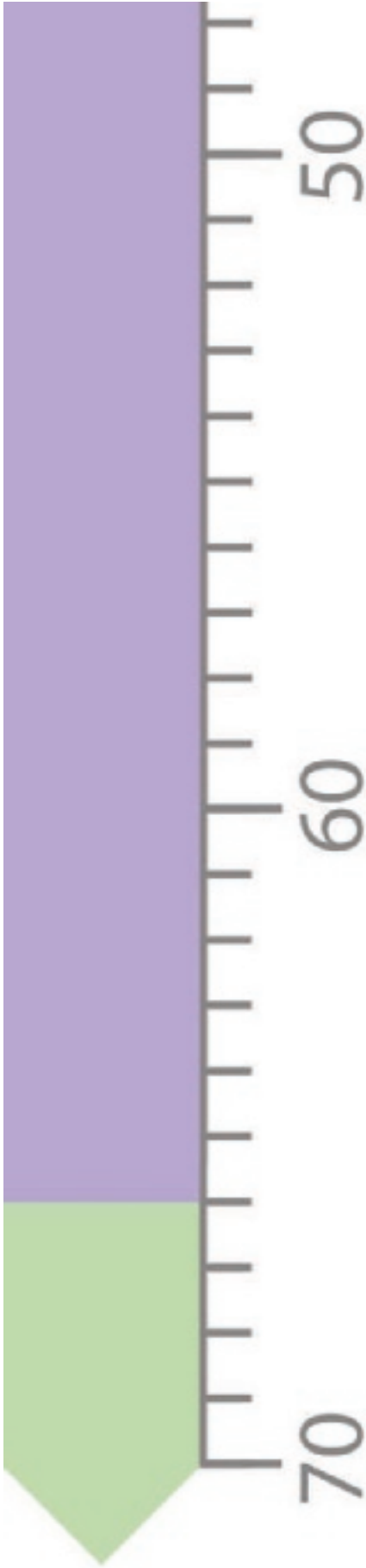
Extension: Data strips for more incomplete ancient penguin fossils

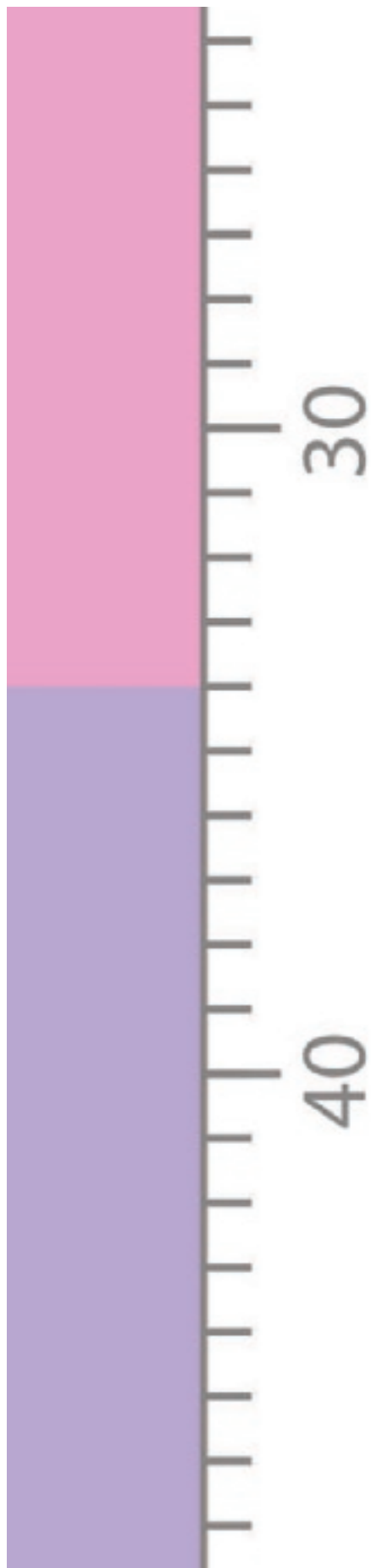
Megabeak		Wide-flipped		Nordenskjoeldi		Grandis		Larseni		Polaris		Exilis		W. Manneringi	
AA	2	AA	?	AA	?	AA	?	AA	?	AA	?	AA	?	AA	?
BB	1	BB	?	BB	?	BB	?	BB	?	BB	?	BB	?	BB	?
CC	2	CC	?	CC	?	CC	?	CC	?	CC	?	CC	?	CC	?
DD	?	DD	?	DD	?	DD	?	DD	?	DD	?	DD	?	DD	?
EE	?	EE	?	EE	?	EE	?	EE	?	EE	?	EE	?	EE	?
FF	?	FF	?	FF	?	FF	?	FF	?	FF	?	FF	?	FF	?
GG	?	GG	?	GG	?	GG	?	GG	?	GG	?	GG	?	GG	?
HH	?	HH	?	HH	1	HH	1	HH	0	HH	0	HH	0	HH	0
II	?	II	?	II	2	II	2	II	0	II	1	II	1	II	0
JJ	?	JJ	1	JJ	?	JJ	?	JJ	?	JJ	?	JJ	?	JJ	?
KK	?	KK	0	KK	?	KK	?	KK	?	KK	?	KK	?	KK	?
LL	?	LL	0	LL	?	LL	?	LL	?	LL	?	LL	?	LL	?
MM	?	MM	?	MM	?	MM	0	MM	?	MM	?	MM	?	MM	?
NN	?	NN	?	NN	?	NN	?	NN	?	NN	?	NN	?	NN	?

The trait variation data used in this lesson were compiled and merged from two resources.

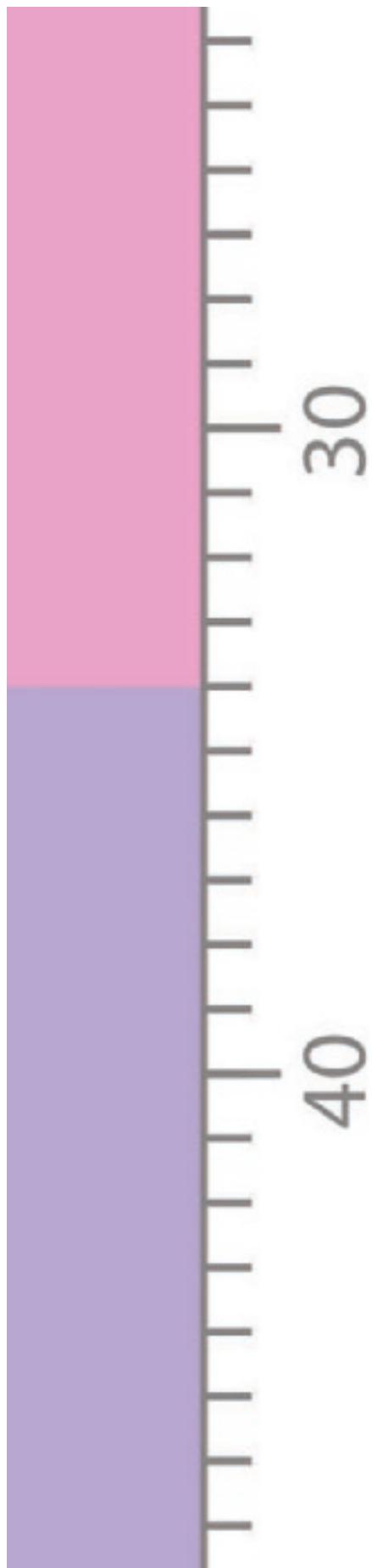
1. The first was the supporting online material published along with *Fossil Evidence for Evolution of the Shape and Color of Penguin Feathers*, published 12 November 2010 in Science, DOI: 10.1126/science.1193604.
2. The second was the appendix published along with *Paleogene equatorial penguins challenge the proposed relationship between biogeography, diversity, and Cenozoic climate change*. Published July 2007 in Proceedings of the National Academy of Sciences, DOI: 10.1073/pnas.0611099104.

Timeline Sections





million years ago (mya)



million years ago (mya)



Name: _____

Date: _____

Ancient Penguin Sorting Exit Ticket

Use your Progress Tracker entry from earlier in this lesson and recall what you figured out from your work with the penguin data cards and data strips to answer the question: **How do the body structures of other ancient penguins compare to modern penguins?** Use words and/or pictures to support your thinking.

Name: _____

Date: _____

Three Explanations

Question 1: *Where did all the ancient penguins go?*

Explanation (in words and/or pictures):

Evidence from our penguin groupings:

Evidence we need:

Question 2: *Where did all the different species of modern penguins come from?*

Explanation (in words and/or pictures):

Evidence from our penguin groupings:

Evidence we need:

Question 3: *Why are there similarities and differences in the body structures of modern and ancient penguins?*

Explanation (in words and/or pictures):

Evidence from our penguin groupings:

Evidence we need:

Word Wall Image for Population

This photo includes a large **sample** of Adélie penguins, but it does not show the entire population. A sample is a random smaller group chosen to represent the characteristics from a whole population.



Name: _____

Date: _____

Reference: Analyzing and Interpreting Fossil Data

Ancient penguin	Number of fossils discovered so far	Percent of fossils discovered with the same variation in the structure of the humerus bone
Water King/Pedro	1	n/a
<i>P. devriesi</i>	1	n/a
Harris'	1	n/a
Simpson's	1	n/a
Lowe's	1	n/a
Lopdell's	1	n/a
Giant spear-billed	1	n/a
Slender-footed	2	100
Tiny rower	3	100
<i>S. urbinai</i>	4	100
<i>W. tuatahi</i>	4	100
Colossus	7	100
<i>Gunnari</i>	11	100

Data from Paleobiology Database (2021). The Paleobiology Database. Checklist dataset
<https://doi.org/10.15468/zzoyxi> accessed via GBIF.org on 2022-02-21.

Name: _____

Date: _____

Exit Ticket - Trait Variation

Select another body structure or behavior that the Galápagos and king penguins share. Using information from the penguin cards, describe what you predict the variation in that body structure or behavior looks like *between* the Galápagos penguins and king penguins and *within* each population. Use words and/or pictures to share your thinking in the space below.

Name: _____

Date: _____

Patterns for My Organism: _____

The factor my group investigated: (circle one)

- **location and environment where they live(d)**
- **when and how far apart in time they live(d)**

How patterns of body structures are connected to my factor

Patterns of body structures that match the **location and environment where they lived**

Organism	How patterns of body structures are connected to <i>where</i> they lived

Patterns of body structures that match **when and how far apart in time they lived**

Organism	How patterns of body structures are connected to <i>when</i> they lived

Name: _____

Date: _____

Guiding Questions to Compare Our Models

Discussion questions	Horseshoe crabs	Horses	Whales
How does your model incorporate <u>when</u> these organisms lived?			
How does your model incorporate <u>where</u> these organisms lived?			
What similarities did you notice across all three organisms as students shared their arguments for the patterns shown in their models?			
What new questions do you have?			

Cliff Swallow Data Packet

Overview: Cliff Swallows Wings

Cliff swallows are songbirds that gather in large colonies and build nests out of mud that they attach to hard or rocky vertical areas with overhanging surfaces, like those found on many cliffs. Sometimes there are thousands of nests in one colony.



Cliff swallows spend half the year in South America and migrate north in large flocks to nest and produce young during the summer months. This behavior of staying with the flock and returning to their colonies makes it more likely that each bird will find a mate and be able to reproduce. Their colonies are established near muddy areas close to water sources which provide them sufficient mud for nest building as well as sufficient food sources. Their diet is made up of flying insects.



As the number of highways expanded throughout much of the United States, large populations of cliff swallows left their original nesting sites on natural cliffs and began nesting in highway overpasses and culverts and beneath bridges. Soon there were huge colonies nesting under highways.



These man-made areas were more protected than the cliffs where the birds had been nesting before, and they had the same kinds of hard, vertical surfaces with overhangs that the swallows needed in order to build their nests. In addition, since many of these overpasses and bridges were built over rivers and other waterways, there were plenty of muddy areas and a lot of flying insects near the highways.



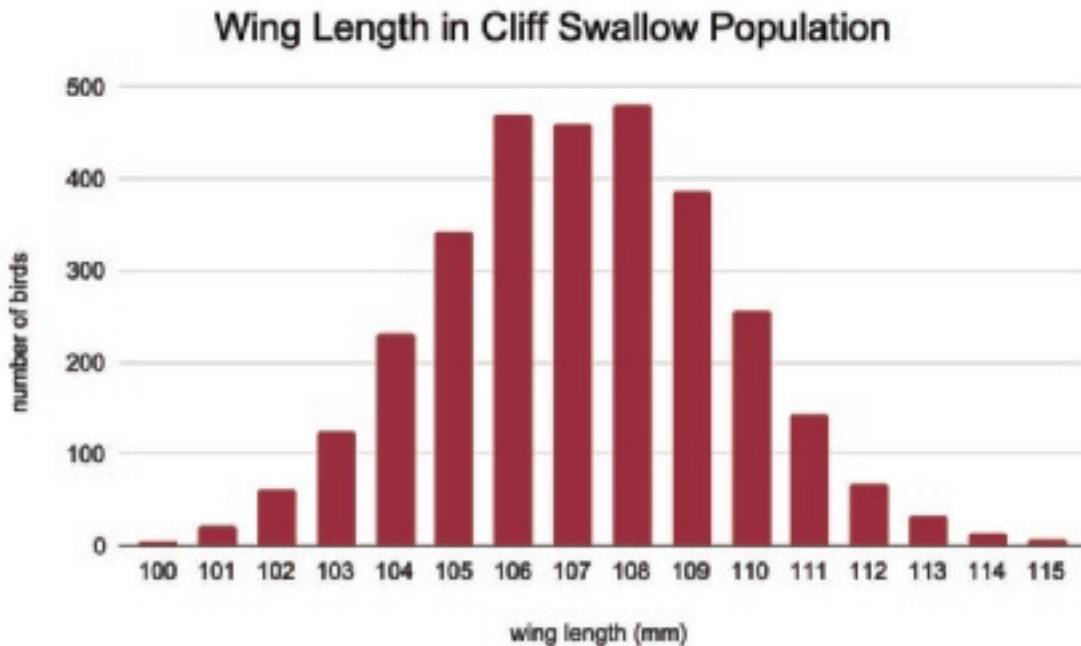
Researchers Charles Brown and Mary Bomberger Brown were interested in whether there would be any change in the birds themselves when they changed the locations where they nested from cliffs to under highways. Starting in the mid-1980s and continuing for many years, they studied large numbers of colonies of these birds that nested near highways in Nebraska, collecting specimens and banding, counting, measuring, and keeping track of birds over time.

From 1983 to 2012, the researchers observed that the average length of the wings of the population of cliff swallows in Nebraska changed.

Data Subset 1: Studies of the Population of Cliff Swallows at the Beginning

For this study, scientists captured birds from several different colonies nesting under highways in Nebraska in 1992 and 1996, banded and weighed them, and measured and recorded the length of their wings and several other parts of the birds' bodies. Scientists already knew from studying other kinds of birds that longer wings allow birds to fly better over long distances, such as during their yearly migration. Shorter wings allow birds to take off from the ground more quickly and maneuver more easily as they fly.

When scientists measured the length of the wings of a large number of birds during two years in the middle of their study (in 1992 and 1996), they saw this:



Graph created using data from Brown, C. & Bomberger Brown, M. (1998). Intense Natural Selection on Body Size and Wing and Tail Asymmetry in Cliff Swallows During Severe Weather. *Evolution*, 52(5), pp. 1461-1475.

All data adapted from the following source:

- Brown, C. R., & Brown, M. B. (1998). Intense Natural Selection on Body Size and Wing Tail Asymmetry in Cliff Swallows During Severe Weather. *Evolution*, 52, 1461-1475.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data?

- What is the trait of interest in this study?
- What is the range of variations for this trait in the population?
- What is the median value for this trait in the population?

Your summary:

B. Interpret: What does this mean?

- How many different categories of variation are there in this trait?
- What do you think might be the effect of having longer wings for the swallows living under highways?
- What do you think might be the effect of having shorter wings for the swallows living under highways?

Your summary:

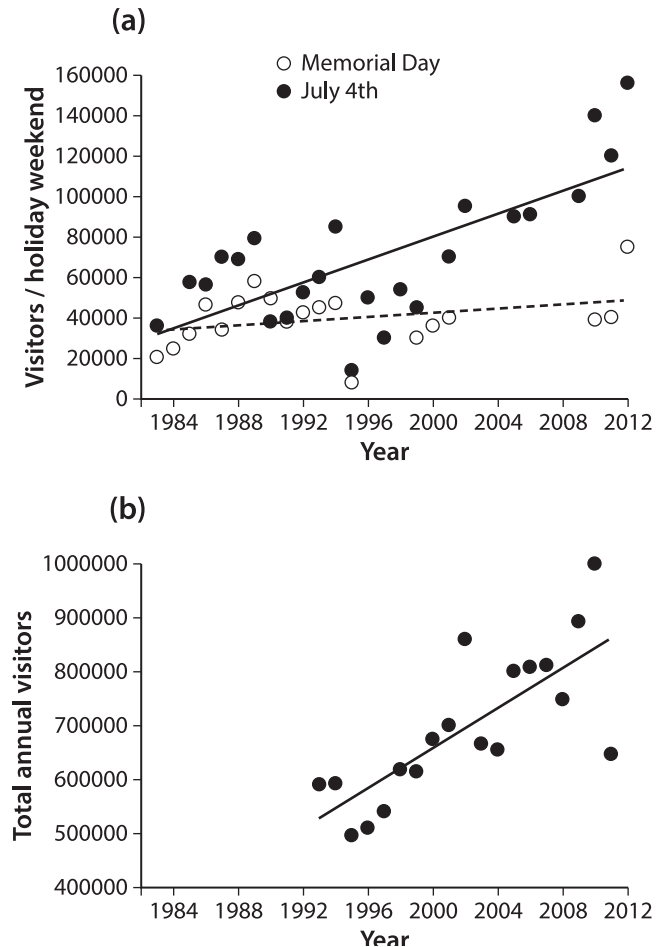
Data Subset 2: Environmental Studies

Cliff swallows got their name because, historically, they nested on cliffs. But during the mid-1900s, many new highways were built in the United States. The swallows began relocating their nests under highway bridges. As they moved into nesting sites underneath and around highways, one of the biggest changes in their environment was that there were now cars moving through the areas near their nesting sites. Their original nesting sites on cliffs were generally far away from roads and did not encounter much traffic. Very few swallows were killed by cars in these low-traffic nesting sites.

Scientists were interested in what effect nesting so near highways might have on the cliff swallows. First, they wanted to know how much traffic the birds were encountering. So, they gathered data about the car traffic that was present in the area where they were working in Nebraska during the years of their study.

Since they could not count the exact number of cars that actually were moving through the cliff swallows' environment throughout the entire time of their study, they estimated the likely amount of traffic during that time based on how many people drove to the Lake McConaughy recreation area in Nebraska on the same holiday weekends every year (the Memorial Day weekend and the July 4th weekend). This recreation area is in the middle of the region in Nebraska where many of the cliff swallows were. People visiting this recreation area would have to drive on the highways where cliff swallows were nesting to get there. The graphs here show what they found.

Estimation of Traffic Near Nesting Sites



All data adapted from the following source:

Brown, C. R., & Brown, M. B. (2013). Where Has All the Road Kill Gone? *Current Biology*, 23(6), R233–R234.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

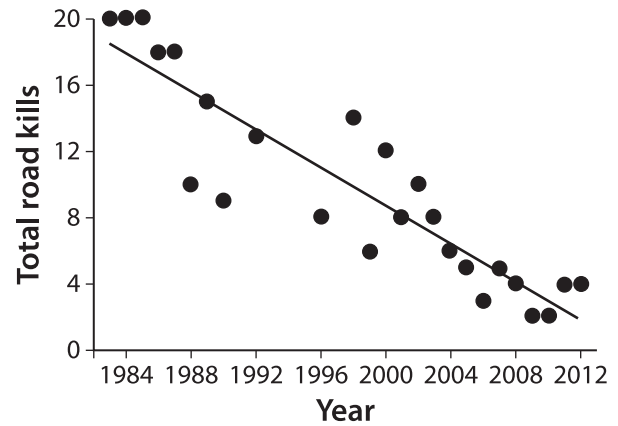
A. Identify: What do I see in the data? • How did the cliff swallows' environment change? • What was the greatest difference between their previous environment and their new environment? Your summary:	B. Interpret: What does this mean? • What change occurred in the traffic over the time scientists were studying the cliff swallows? • How do you think this might have affected the cliff swallows over time? • What would swallows need to be able to do to survive in their new environment? Your summary:
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Data Subset 3: Survival and Reproduction Studies

Cliff swallows generally live only 4-6 years. During that time, they form mating pairs and build nests each year during the nesting season in many places throughout North America. The behavior of staying together with their flock as they migrate increases the likelihood that they will form a mating pair and be able to reproduce. The population that was studied nested in Nebraska. Each pair raises 2-4 offspring every year. By the end of the nesting season, the offspring are fully able to fly and can migrate south with their parents to the winter feeding grounds. They then return to Nebraska the following year to mate and, if successful, raise another generation of offspring.

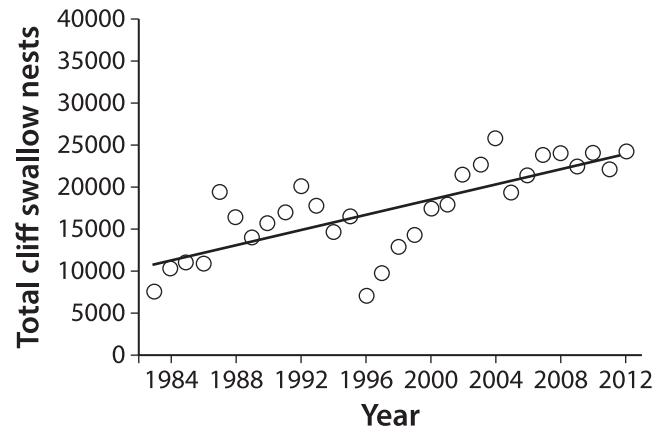
Survival: When they began their studies of the cliff swallows nesting near highways, the scientists noticed along the sides of the roads many swallows that had been killed by cars. Every year, the scientists drove approximately the same number of miles over the same roads while they conducted their research. They watched along the side of the road and collected all the road-killed specimens they saw each year. This is what they found:

Number of Road-Killed Swallows per Year



Reproduction: Scientists wondered if the changes they saw in the number of cliff swallows killed by cars was happening because the overall population of cliff swallows was decreasing. They estimated the number of cliff swallows in their study area each year by counting the number of nests. There are 2-6 birds inhabiting each nest. This is what they found:

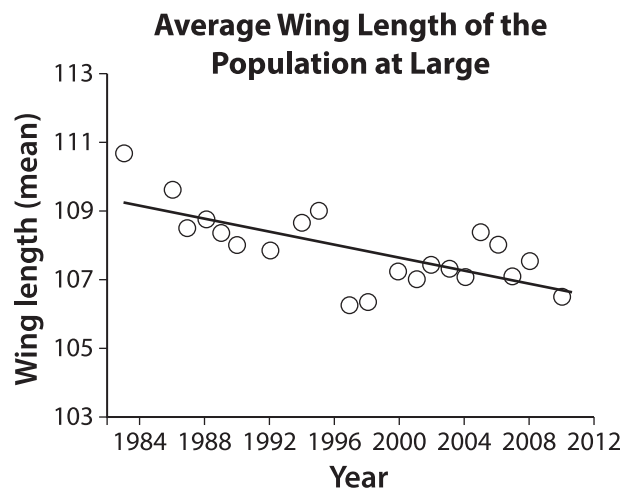
Number of Swallow Nests per Year



All data adapted from the following source:

Brown, C. R., & Brown, M. B. (2013). Where Has All the Road Kill Gone? *Current Biology*, 23(6).

Characteristics of the swallow population: Each year, the researchers collected all the road-killed specimens and measured and recorded information about them. They also collected and measured a set of birds that represented the population at large. That is, they had the same characteristics as the entire population of swallows living that year. They were especially interested in their wing length because they knew from studying other kinds of birds that longer wings allowed birds to fly better over long distances, such as during their yearly migration, while shorter wings allowed birds to take off from the ground more quickly and maneuver more easily as they fly. This is what they observed:



All data adapted from the following source:

Brown, C. R., & Brown, M. B. (2013). Where Has All the Road Kill Gone? *Current Biology*, 23(6), R233–R234.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data? • What is the trend in the data for the survival of the swallows? • What is the trend in the data for the reproduction of the swallows? • What is the trend in the data in the characteristics of the population at large? Your summary:	B. Interpret: What does this mean? • What do you think might be causing the change in survival in the population over time? • What do you think might be causing a change in overall population size over time? • What do you think might cause a change in the characteristics of survivors in this population over time? Your summary:
--	--

Data Subset 4: Offspring and Inheritance Studies

The scientists studying cliff swallows did not do any experiments to determine whether wing length was an inherited trait in cliff swallows. However, scientists in southern France, studying a different bird called the European Bee Eater, did collect information about parents and offspring living in the wild in order to find out whether offspring mostly inherited their wing length from their parents or whether they developed their wing length mostly as a result of their diet and how they exercised.

Characteristics of offspring: These scientists banded the birds the year they were born and measured their weight and wing length when they were fully grown at the end of that year. Then each following year, they recaptured and remeasured the adult birds while they were nesting. Once again, they banded and measured the baby birds that were in the nest. Now they had information about the weight and wing size of both the offspring and their parents over several years. They found the following things:

- Once birds were adults, their weight often changed by as much as 7.5 grams on average from year to year and even during a single breeding season.
- There was no association between the weight of parents and the weight of their adult offspring.
- Once birds were adults, their wing size did not change from year to year.
- There was an association between the wing length of parents and the wing length of their adult offspring.

They calculated the most common wing length in offspring from different sets of parents:

Most common wing length in offspring from pairs of parents with different wing lengths		
Male parent wing length	Female parent wing length	Offspring wing length (most common)
long	long	long
short	short	short
long	short	medium
short	long	medium

Genetic studies: By doing genetic studies, the scientists were able to calculate that about 60% of the variation in wing length of offspring was due to genes.

All data adapted from the following source:

- Lessells, C. M., & Ovenden, G. N. (1989). Heritability of Wing Length and Weight in European Bee-Eaters (*Merops apiaster*). *The Condor*, 91(1), 210–14.

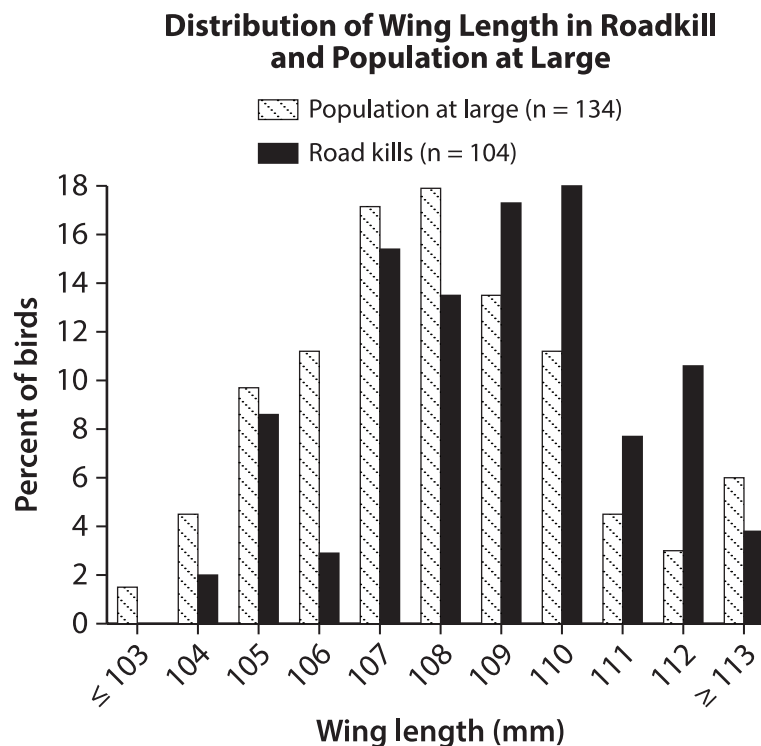
Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data? • Do the characteristics of offspring show evidence that wing length is mostly heritable in swallows? Explain. • Do the genetic studies show evidence that wing length is mostly heritable in swallows? Explain. Your summary:	B. Interpret: What does this mean? • Would the weight or the wing length be more likely to be passed from parent to offspring? • Why would it matter if a trait is heritable or not if we are trying to understand what could cause changes in a whole population of descendants over several generations? Your summary:
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Data Subset 5: Studies of the Population of Cliff Swallows at the End

As the scientists studied the cliff swallows, they collected a lot of measurements of the birds. Over all the years of the study, from 1983 to 2012, they measured the wing length of two different sets of birds. One set was birds killed by cars. The researchers collected all the road-killed birds they found each year. The second set was birds that died accidentally while being captured for banding. To band birds, they caught the live swallows in mist nets, untangled them from the nets, then banded and released them. The vast majority of the birds caught and banded in this way were released totally unharmed. However, during the mist net capture, a few of the birds that were caught in the nets each year accidentally died. These dead birds were collected and studied as well. The mist net-killed birds represented the birds in the population that were not killed by cars (i.e., the population at large).

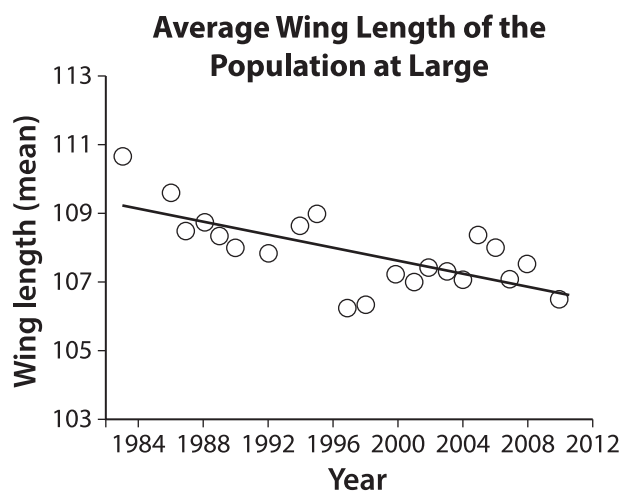
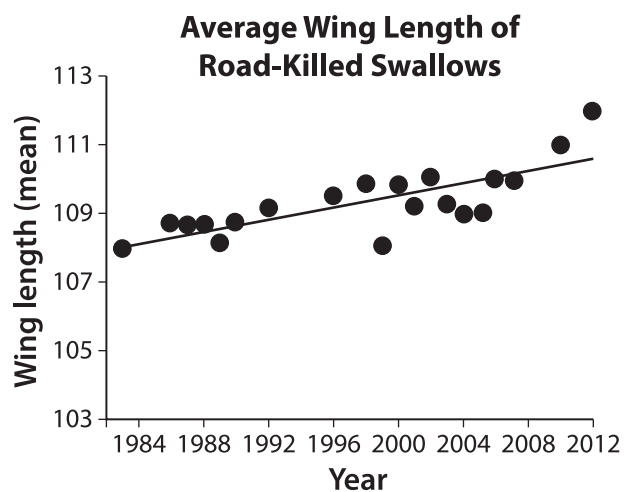
Distribution of wing length in the two groups: Scientists were interested in the wing lengths of the swallows since they already knew from studying other kinds of birds that longer wings allow birds to fly better over long distances, such as during their yearly migration. Shorter wings allow birds to take off from the ground more quickly and maneuver more easily as they fly. For each year that the researchers measured wing length, they had a set of road-killed birds and a set of birds representing the population at large. Overall, they had 104 road-killed birds and 134 birds representing the population at large that they had collected throughout 1983-2012. When they compared the wing lengths in the set of roadkill and the set representing the population at large that were not killed by cars, this is what they saw:



All data adapted from the following source:

Brown, C. R., & Brown, M. B. (2013). Where Has All the Road Kill Gone? *Current Biology*, 23(6).

Average wing length over time: In addition, for each year they determined the average wing length of the road-killed birds and the average wing length of the birds representing the population at large that they collected during that particular year. Their data showing average wing length from 1983 to 2012 are shown below.



All data adapted from the following source:

Brown, C. R., & Brown, M. B. (2013). Where Has All the Road Kill Gone? *Current Biology*, 23(6), R233–R234.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data?

- What is the trait of interest in this study?
- What is the most common value for this trait for road-killed birds? What is the most common value for the population at large?
- What is the trend over time in the average value for this trait for the population at large?
- What is the average value for this trait in the population at large in 1983? What is the average value in the population at large in 2010?

Your summary:

B. Interpret: What does this mean?

- What change occurred in this trait over time in the population at large?
- What do you think might be the effect of having longer wings for the swallows living under highways?
- What do you think might be the effect of having shorter wings for the swallows living under highways?

Your summary:

Finch Data Packet

Overview: Finches Beaks

The medium ground finches are one of 14 different types of finches that live on the Galápagos Islands off the coast of Ecuador. They typically live their entire lives on a single island. Where this population of ground finches lives is a desert-like island with sparse vegetation that is called Daphne Major. It is only about a half mile across at its widest point. No people have ever lived there.

On Daphne Major the ground finches, as their name suggests, forage for food that they find on the ground. They occasionally catch and eat insects, but they mostly survive by eating the seeds of the few plants that grow on the island.

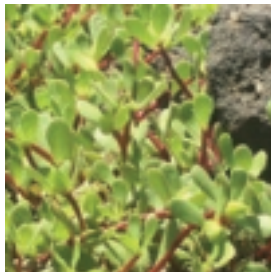
Here are the three types of plants that are the sources of these seeds:

chamaesyce



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portulaca



Rebecca Johnson CC BY-
NC 4.0

tribulus



Rebecca Johnson CC BY-
NC 4.0

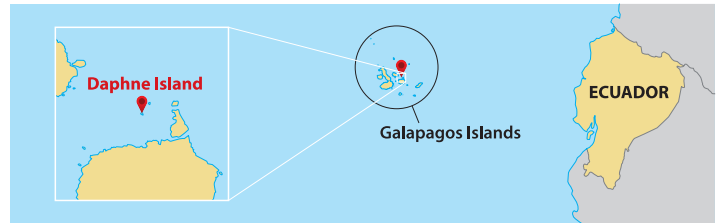
Each year, these finches start to look for mates as soon as the rainy season begins. This behavior increases their odds of reproducing. They mate, lay eggs, and produce offspring called fledglings during the wet, rainy season that typically lasts from January through May. The fledglings grow to adulthood during the dry season that typically lasts from June through December. These young birds can mate and reproduce during the following wet season. The adult female ground finches and the fledglings are speckled brown in color. The adult males are black.



David Cook, CC BY-NC 2.0

The finches on the Galápagos Islands have been studied for more than 160 years, starting with research done by Charles Darwin. Modern researchers Peter Grant and Rosemary Grant were interested in finding out whether they could observe any differences among the populations of finches on some of these small islands. So starting in 1973, they set out to collect as much data as they could about the finches and the islands they live on.

In their studies, the Grants traveled to the isolated Daphne Major island each year during the wet season and during the dry season. While there, they caught and banded as many of the finches that lived on the island as possible. Then, when they returned each year, they collected, counted, observed, and measured all the finches they could.



Created with ArcGIS: Earthstar Geographics, Esri, DGIAR, USGS, HERE, Garmin, METI/NASA, National Geographic, Imagery

find, recording data about the ones they had banded in earlier years and banding new ones they found. They also collected data on other organisms living on Daphne Major. They kept records of the number and kind of plants on the island and how many seeds they produced each year. They recorded information about more than 1,000 individual finches over the course of their study from 1973 to 1978. During the years 1976-1978 they saw the average length of the beaks of the population of finches on Daphne Major change.

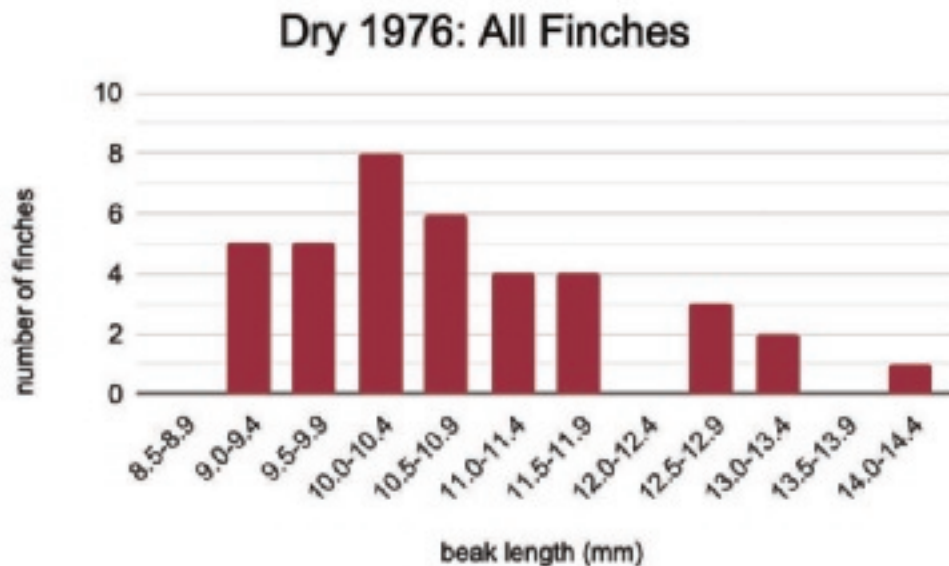
This document shares some of the data that Peter Grant and Rosemary Grant found in their study of the finches. The data in this packet is simplified from their actual data to make it easier for you to work with. The graphs and tables that follow show a smaller subset of the finches that is based on the larger sample of finches the Grants actually studied.

Data Subset 1: Studies of the Population of Finches at the Beginning

For this study, the researchers caught, banded, and measured many of the finches living on Daphne Major during the years 1973-1978. Each year some of the birds died and some new birds hatched and grew to adulthood. They collected data from each one of the finches they found. Over all 5 years of this study, they saw the following range of variations in the traits they measured:

Trait variation in the adult finch population from 1973 to 1978	
Leg length (mm)	17.70 to 19.94
Beak length (mm)	8.90 to 14.35
Wing length (mm)	62.51 to 73.67
Weight (g)	11.01 to 19.10

The researchers were particularly interested in the size of the birds' beaks since that usually predicts what kind of seeds it will eat. Smaller-beaked birds are able to eat only small seeds, while larger-beaked birds can break open larger seeds and eat those. When researchers measured the length of the beaks of the adult birds in 1976 during the dry season when all the birds on the island had reached their adult size, they saw this:



All data adapted by:

- Tabak, I. (1999). *Unraveling the development of scientific literacy: Domain-specific inquiry support in a system of cognitive and social interactions* [Ph.D. Dissertation, Northwestern University]. Evanston, IL.

from the findings in the following source:

- Grant, P. R. (1986) *Ecology and evolution of Darwin's Finches*. Princeton, NJ: Princeton University Press.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

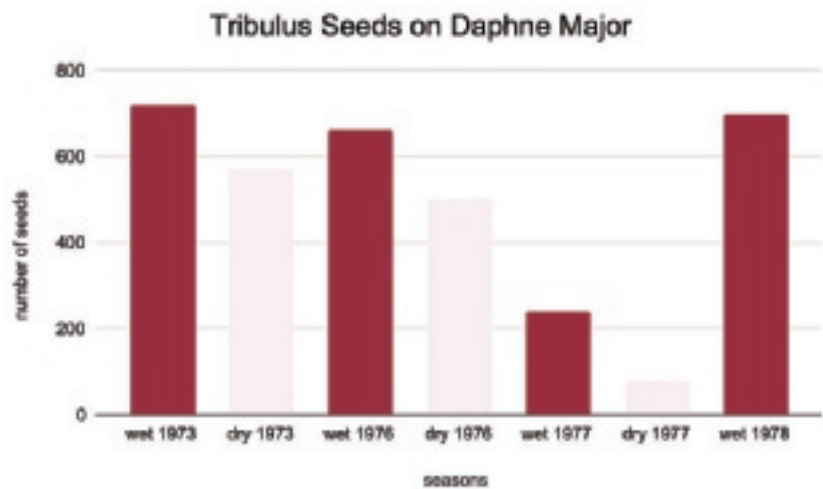
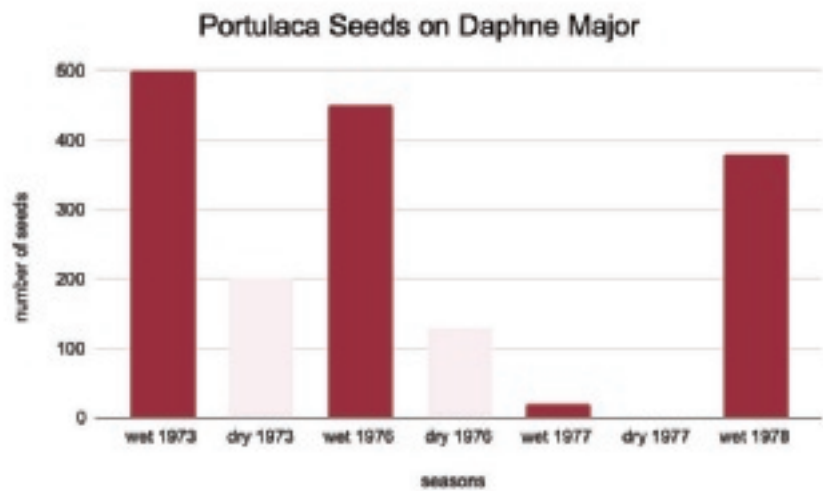
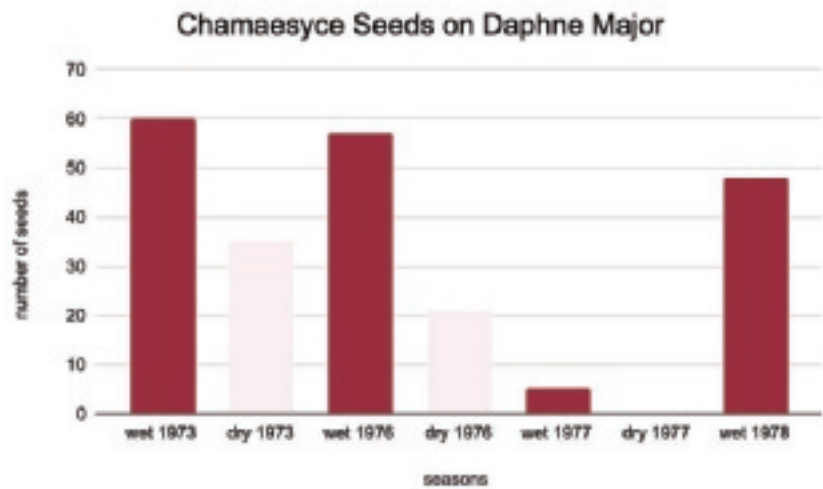
A. Identify: What do I see in the data? • What is the trait of interest in this study? • What is the range of variations for this trait in the population? • What is the median value for this trait in the population? Your summary:	B. Interpret: What does this mean? • Is this a trait with many variations? • What do you think might be the effect of having a longer beak for finches living on Daphne Major? • What do you think might be the effect of having a shorter beak for finches living on Daphne Major? Your summary:
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Data Subset 2: Environmental Studies

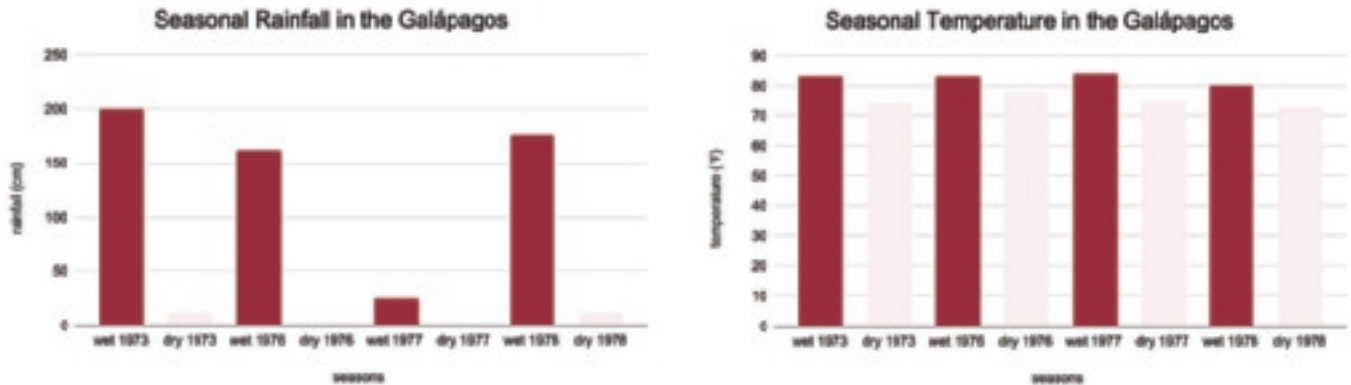
The Grants began their research study in 1973. The Grants wanted to understand how the finches interacted with their environment. So in addition to recording data about the finches, they also kept a record of key variables in the environment, like temperature, rainfall, and the finches' food sources on the island. Ground finches mostly eat plant seeds that they find as they forage on the ground, though they will also eat the occasional insect. The researchers' records of the three plants (*chamaesyce*, *portulaca*, and *tribulus*) that produced the seeds providing most of the finches' food sources showed this:

Plant	Seed length	Seed volume	Seed rigidity
chamaesyce	0.8 mm	0.3 mm ³	soft
portulaca	1.0 mm	1.8 mm ³	soft
tribulus	5.8 mm	12.0 mm ³	hard

The scientists usually found many more portulaca and tribulus seeds than chamaesyce seeds on Daphne Major. When looking at the following graphs, be careful to notice that the chamaesyce scale on the y axis is much smaller than the portulaca and tribulus scales.



Rainfall and temperature: Scientists noticed an interesting pattern in the seed data. They wondered what might have caused it, so they analyzed the record they had for other things in the environment, such as the total rainfall and average temperature on the island in the dry and wet seasons for each year. Their records of temperature and rainfall are shown in the graphs below.



All data adapted by:

- Tabak, I. (1999). *Unraveling the development of scientific literacy: Domain-specific inquiry support in a system of cognitive and social interactions* [Ph.D. Dissertation, Northwestern University]. Evanston, IL.

from the findings in the following source:

- Grant, P. R. (1986) *Ecology and evolution of Darwin's Finches*. Princeton, NJ: Princeton University Press.

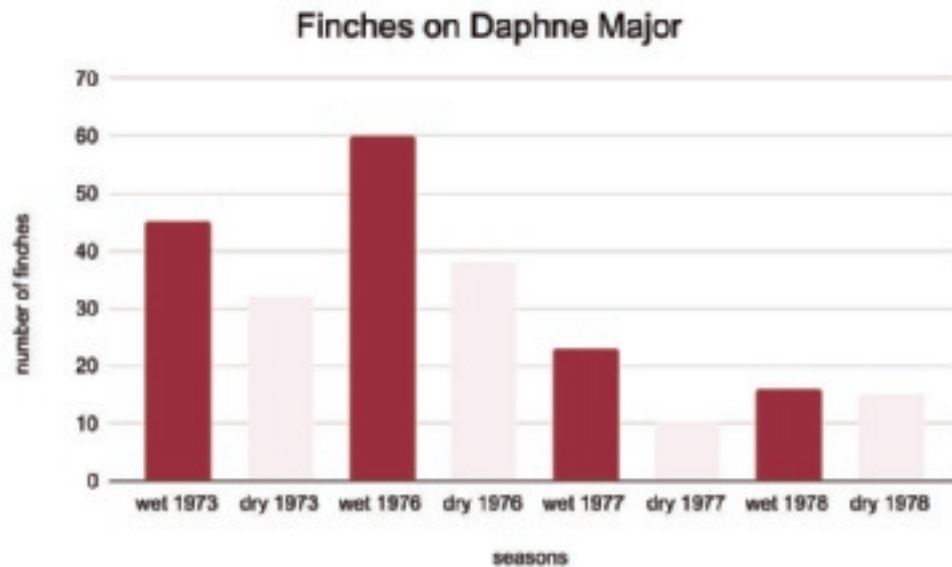
Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data? • What patterns do you notice in seeds available over these years? • What patterns do you notice in temperature and rainfall data over these years? Your summary:	B. Interpret: What does this mean? • What change in the environment could have caused the change in the seeds available? • How do you think this might have affected the finches? Your summary:
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Data Subset 3: Survival and Reproduction Studies

Medium ground finches in the Galápagos Islands may live for up to 12 years, though most do not live that long. Adult finches find mates and breed soon after the first big rain of each wet season in the Galápagos, which usually starts in January and lasts through May. The baby birds hatch, are fed by their parents, and grow to fledglings during the remainder of the wet season. Breeding during the wet season is advantageous because food on the islands is plentiful, which increases the odds that the birds will be able to successfully reproduce. During the dry season, from about June to December, when food is scarcer, fledglings achieve their full adult size and hunt for food on their own. They are able to mate and produce offspring during the next wet season.

Number of survivors: Over the course of the study, the researchers kept track of the total number of finches surviving on the island during each season. This is what they saw:



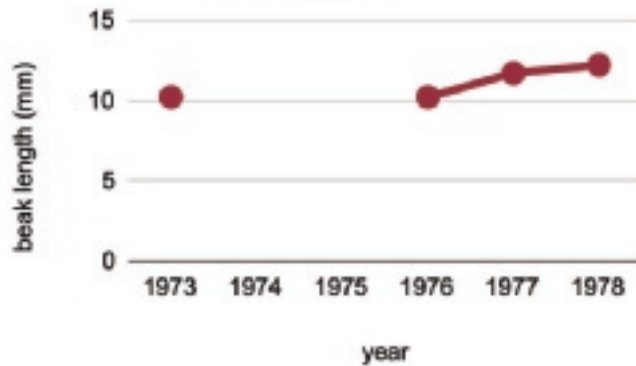
Number of offspring: They were also interested in how many offspring would be produced each year. This is what they saw:

Year	Total # of breeding adults	Total # of offspring
1973	21	24
1976	31	29
1977	23	0
1978	8	8

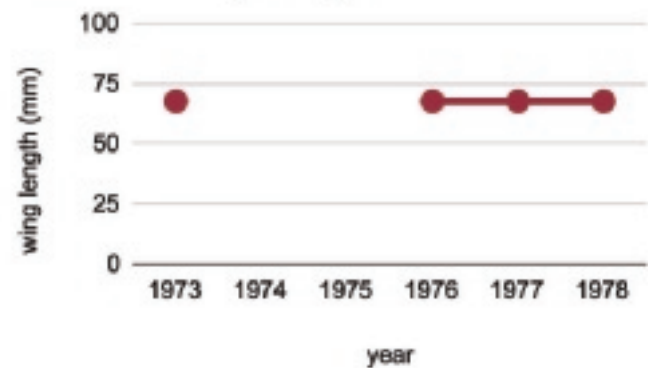
Characteristics of survivors: Based on the pattern the researchers saw in the number of finches in each season, they wanted to know more about the characteristics of the birds that survived during 1976-1978 when the overall size of the population changed significantly compared to those that did not. During the dry season of each year, those fledglings that survive have grown to their adult size, so they measured the birds during the dry season. The population of birds during the dry season includes the birds that were adults at the beginning of the year together with any adult offspring. They knew that the weight of the birds changed a lot even after they were adults, so they measured some of the traits that did not change once the birds were full grown-wing length and beak length.

Scientists already knew from studying other kinds of birds that longer wings allow birds to fly better over long distances, such as between the islands and the mainland. Shorter wings allow birds to take off from the ground more quickly and maneuver more easily as they fly. They also knew that the size of a bird's beak usually predicts what kind of seeds it can eat. Smaller-beaked birds are able to eat only small seeds, while larger-beaked birds can break open larger seeds and eat those. For each characteristic, they determined the median length for the whole population. This is what they saw:

Median Beak Length



Median Wing Length



All data adapted by:

- Tabak, I. (1999). *Unraveling the development of scientific literacy: Domain-specific inquiry support in a system of cognitive and social interactions* [Ph.D. Dissertation, Northwestern University]. Evanston, IL.

from the findings in the following source:

- Grant, P. R. (1986) *Ecology and evolution of Darwin's Finches*. Princeton, NJ: Princeton University Press.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data? • What is the trend in the data for the survival of the finches? • What is the trend in the data for the number of offspring? • What is the trend in the data in the characteristics of survivors? Your summary:	B. Interpret: What does this mean? • What do you think might be causing the effects on survival that you saw? • What do you think might be causing the effects on the number of offspring produced? • What do you think might cause the trend in the characteristics of survivors? Your summary:
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Data Subset 4: Offspring and Inheritance Studies

The scientists studying the finches were unable to determine exactly which birds were the parents of each fledgling they caught and banded. However, for each year, they did know many of the birds that were the breeding adults that could be the parents of one or more of the offspring that year, and which birds were hatched during that year (offspring). They recorded the number of breeding adults and the number of offspring each year. This is what they saw:

Year	Total # of breeding adults	Total # of offspring
1973	21	24
1976	31	29
1977	23	0
1978	8	8

Characteristics of parents and offspring: The Grants tracked as many birds individually as possible, collecting data on their weight and their leg, beak, and wing lengths each year. So the researchers knew what the characteristics of many of the breeding population (parents) were each year, and they knew what the characteristics were of many of the offspring that were hatched each year. They found the following things:

- Each year, the offspring had characteristics that were similar to but not exactly the same as the parents.
- Once birds were adults, their weight varied a lot. It typically changed by about a gram between the wet and the dry seasons of a single year. It also changed as much as 3.5 grams from one year to the next.
- Once birds were adults, their beak lengths, wing lengths, and leg lengths did not change from season to season or from year to year.

Genes affecting beak length: Another set of researchers looked carefully at whether particular genes were involved in determining how long finches' beaks were. They were particularly interested in the size of the birds' beaks since that usually predicts what kind of seeds a bird will eat. Smaller-beaked birds are able to eat only small seeds, while larger-beaked birds can break open larger seeds and eat those. They found that there is a gene that has a large effect on determining how long the beak of the finch is. This gene is called *HMGA2* and has a long allele (L) and a short allele (S). They examined the genetic information from 71 medium ground finches and determined which alleles each bird had (genotype). This is what they found:

Genotype	Number of birds	Median beak length
LL	20	significantly longer than SS birds
LS	32	midway between LL and SS birds
SS	19	significantly shorter than LL birds

The population data were adapted by:

- Tabak, I. (1999). *Unraveling the development of scientific literacy: Domain-specific inquiry support in a system of cognitive and social interactions* [Ph.D. Dissertation, Northwestern University]. Evanston, IL.

from the findings in the following source:

- Grant, P. R. (1986) *Ecology and evolution of Darwin's Finches*. Princeton, NJ: Princeton University Press.

The genetics data were adapted from the following source:

- Lamichhaney, S., Han, F., Berglund, F., Wang, C., Lmen, M., Webster, M., Grant, B., Grant, P., & Andersson, L. (2016). A beak size locus in Darwin's finches facilitated character displacement during a drought. *Science*, 352, 470-474.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data?

- What is the trend in the data over time for the number of offspring?
- Do the characteristics of offspring show evidence that beak length is heritable in finches? Explain.
- Do the gene studies show evidence that beak length is heritable in finches? Explain.

Your summary:

B. Interpret: What does this mean?

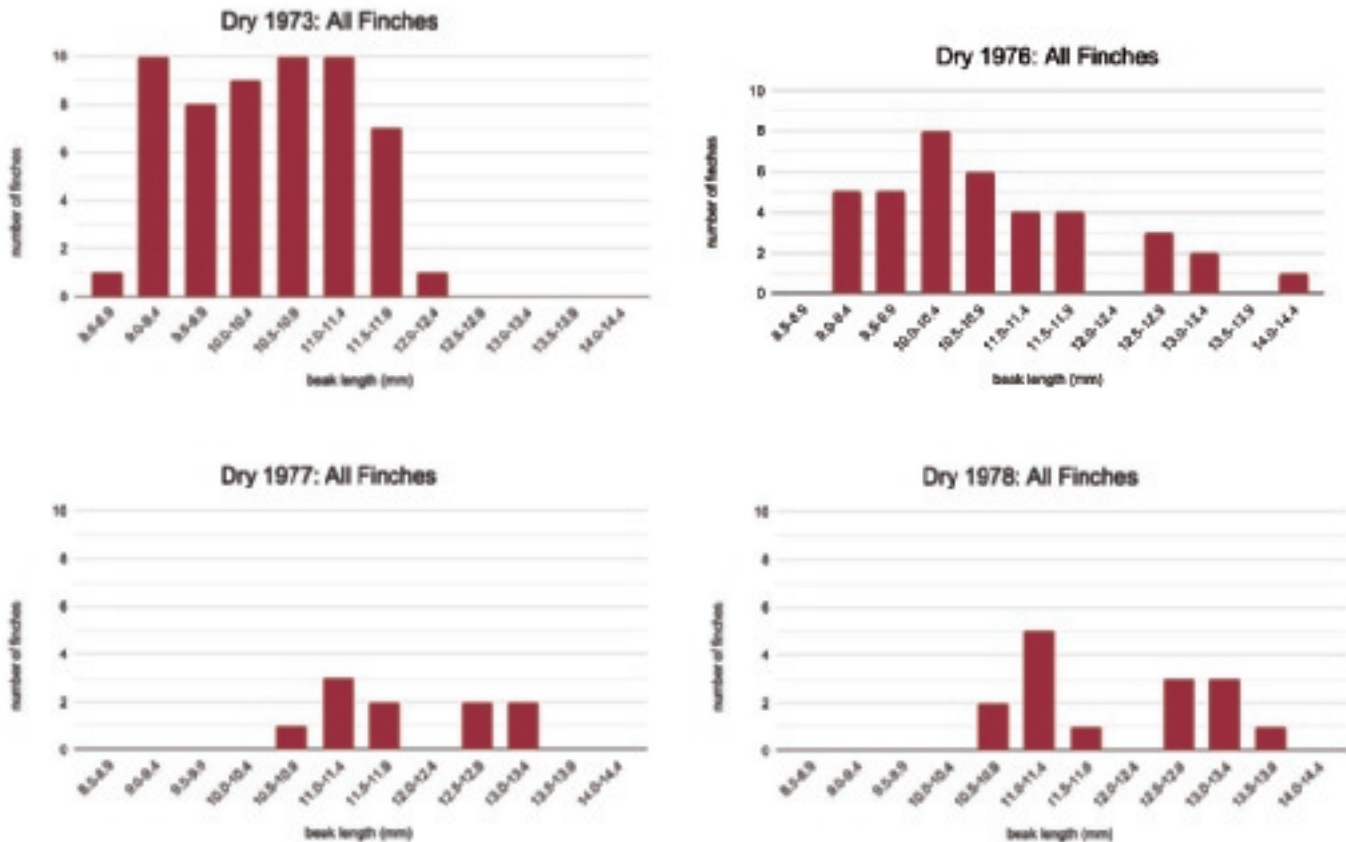
- Would the weight or the beak length be more likely to be passed from parent to offspring?
- Why would it matter if a trait is heritable or not if we are trying to understand what could cause changes in a whole population of descendants over several generations?

Your summary:

Data Subset 5: Studies of the Population of Finches at the End

As the scientists studied the medium ground finches, they collected a lot of measurements of many of the birds on the island of Daphne Major. They were particularly interested in the size of the birds' beaks since that usually predicts what kind of seeds a bird will eat. Smaller-beaked birds are able to eat only small seeds, while larger-beaked birds can break open larger and harder seeds and eat those. Over all the years of the study, they measured the beak length of many of the finches living on the island.

When researchers measured the length of the beaks of all the adult birds surviving on the island each year from 1973 through 1978, they saw this:



AU data adapted by:

- Tabak, I. (1999). *Unraveling the development of scientific literacy: Domain-specific inquiry support in a system of cognitive and social interactions* [Ph.D. Dissertation, Northwestern University]. Evanston, IL.

from the findings in the following source:

- Grant, P. R. (1986) *Ecology and evolution of Darwin's Finches*. Princeton, NJ: Princeton University Press.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data? • What is the trait of interest in this study? • What is the range of variations in 1976? What is the range in 1978? • What is the median value for this trait in 1978? • Describe any differences in the distribution of the trait in 1976 and 1978. Your summary:	B. Interpret: What does this mean? • What change occurred? • What do you think might be the effect of having a longer beak for finches living on Daphne Major? • What do you think might be the effect of having a shorter beak for finches living on Daphne Major? Your summary:
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Mustard Plant Data Packet

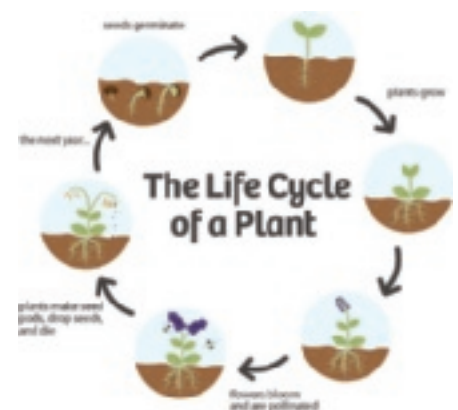
Overview: Mustard Plant Time to Flowering

The mustard plant is known as *Brassica rapa* by scientists. Selective breeding of mustard plants over long periods of time has resulted in the production of vegetables as diverse as turnips, napa cabbage, and bok choy. The mustard plant is commonly used in genetic experiments in laboratories because it is easy to grow, grows quickly, and has many different traits that are easy to see and measure. However, mustard plants also grow in the wild throughout much of coastal California, where they are considered weeds. Wild mustard plants were probably introduced to California about 300 years ago from Asia or Europe, where the mustard plant also grows in the wild.



The wild mustard plants in California are an annual plant, meaning that they sprout—or germinate—from seeds, grow to full size, bloom, produce seeds, and die all in one year. The following year, the new seeds sprout and the cycle starts again. No individual plant grows for more than one year.

In California, wild mustard plants typically sprout and begin to grow sometime between October and January, right after the first rain of the season. They continue to grow as long as they have enough rain. When they are fully grown, they produce flowers, typically sometime between January and April. The flowers of one plant pollinate the flowers of neighboring plants, fertilizing them so that seeds are produced. When neighboring plants bloom close to the same time, it increases the likelihood that pollination will occur. Each fertilized flower produces several seeds in a pod which falls to the ground. These seeds will then sprout at the start of the next year's growing season and produce the next generation of plants. The length of time that it takes for a plant to become fully grown and produce its first flower is referred to as the "time to flowering" or "flowering time".



Scientists working in Southern California were interested in whether the wild mustard plants growing near them would show the same variety of different traits as the mustard plants they grew in the lab. Wild mustard plants grew in several, different locations near the scientists. They had noticed that in some of those populations, the plants seemed to bloom earlier in the year than in others. Because the climate in Southern California is changing, they wanted to know what the effect of that might be on the wild mustard plants. They collected seeds from plants that grew in the same place in 1997 and in 2004 and made observations about how they grew. Between 1997 and 2004 they saw a change in the flowering time of the mustard plants.



Created with ArcGIS: Esri, USGS, California State Parks, HERE, Garmin, FAO, NOAA, Bureau of Land Management, Maxar, Esri Community Maps Contributors, City of Irvine, City of Newport Beach, County of Los Angeles, National Geographic, Imagery Hybrid

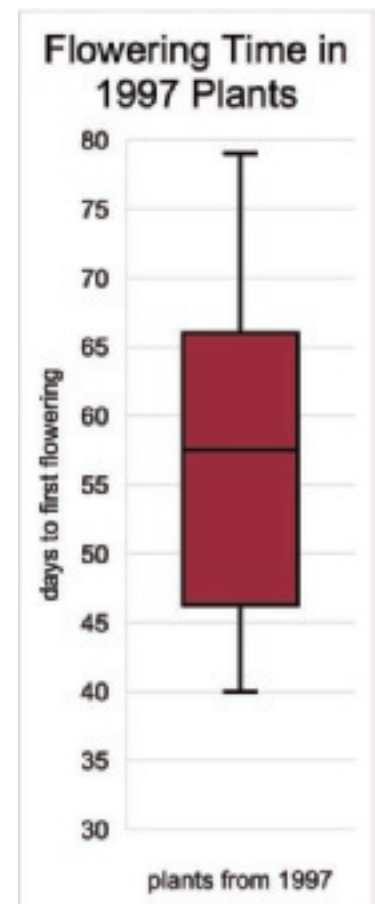
Data Subset 1: Studies of the Population of Mustard Plants at the Beginning

All the plants in a population of mustard plants need to bloom close to the same time so that pollen from a flower on one plant can fertilize a flower from a neighboring plant. Scientists wanted to see how long it took the plants in a population to grow to full size and produce flowers. They were interested in this because plants that do not get enough water can wilt and die before they have a chance to bloom. Since most of the rain usually falls close to the beginning of the growing season, plants that have a shorter time to flowering have a better chance to bloom and produce seeds each year. For this study, scientists gathered seeds from many hundreds of plants from a wet, marshy growing site in 1997. They brought the seeds into the laboratory and grew 100 plants under exactly the same conditions. For each plant they recorded the number of days it took for the plant to go from sprouting to producing its first flower (days to first flowering).

This box-and-whisker plot shows what they saw. The center bar in the shaded box indicates the median time to flowering. The box shows the range of flowering time for the middle 50% of the population; the lines indicate the times between which 90% of the plants flowered.

All data adapted from the following source:

- Franks, S. J., Sim, S., & Weis, A. E. (2007). Rapid evolution of flowering time by an annual plant in response to a climate fluctuation. *Proceedings of the National Academy of Sciences*, 104(4), 1278-1282.



Data source: Franks, S.J., et al. Rapid evolution of flowering time by an annual plant in response to a climate fluctuation. PNAS 2007 104(4) 1278-1282.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

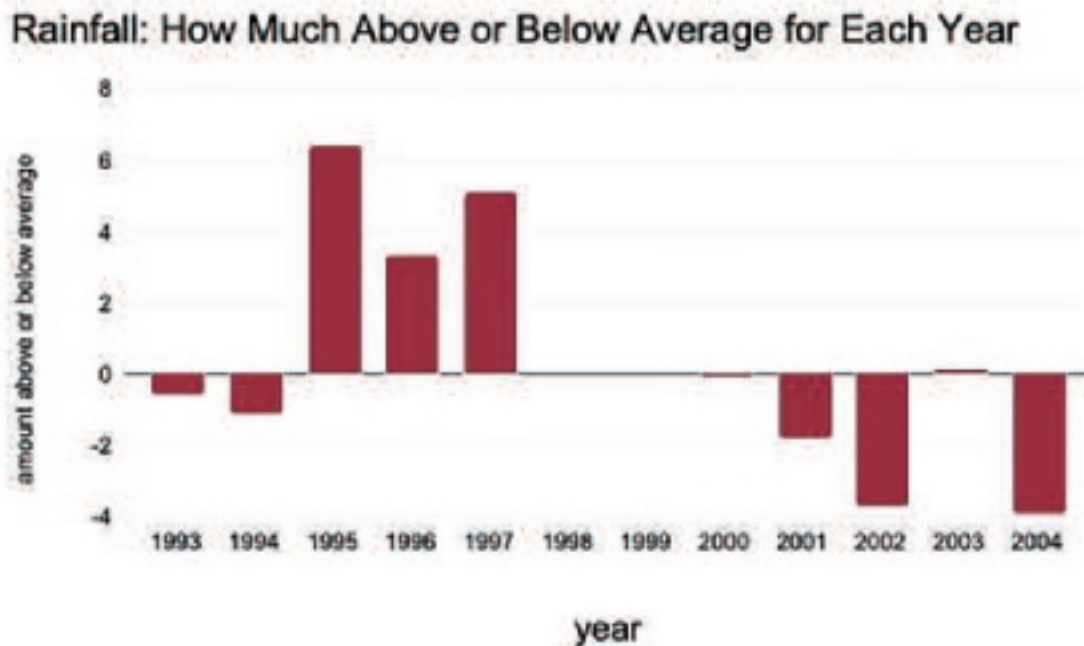
A. Identify: What do I see in the data? • What is the trait of interest in this study? • What is the range of variations for this trait in the population? • What is the median value for this trait in the population? Your summary:	B. Interpret: What does this mean? • Is this a trait with many variations? • What do you think might be the effect of having a shorter time to flowering for mustard plants? • What do you think might be the effect of having a longer time to flowering for mustard plants? Your summary:
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Data Subset 2: Environmental Studies

In the area of Southern California where the mustard plants grow, it is usually warm and dry. The temperature does not vary much. The average monthly temperature varies by less than 20°F throughout the year. The average temperature in August (the warmest month) is 83°F. The average temperature in December (the coldest month) is 64°F.

Overall, not much rain falls each year in Southern California. The average amount of rainfall each year is only about 15 inches. However, the amount of rain varies substantially over the course of the year. Summer is the dry season, while winter is usually the rainy season. Almost 95% of the rain each year falls between October and April, during the growing season for the mustard plants. The actual amount of rain that falls during the mustard plant's growing season usually varies a little bit each year.

Scientists studied and compared mustard plants that grew in 1997 and in 2004. They collected information about the rainfall during the growing season of the mustard plants throughout the time of their study. This is what they found:



Data source: Franks, S.J., et al. Rapid evolution of flowering time by an annual plant in response to a climate fluctuation. PNAS 2007, 104(4) 1278-1282.

All data adapted from the following source:

- Franks, S. J., Sim, S., & Weis, A. E. (2007). Rapid evolution of flowering time by an annual plant in response to a climate fluctuation. *Proceedings of the National Academy of Sciences*, 104(4), 1278-1282.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

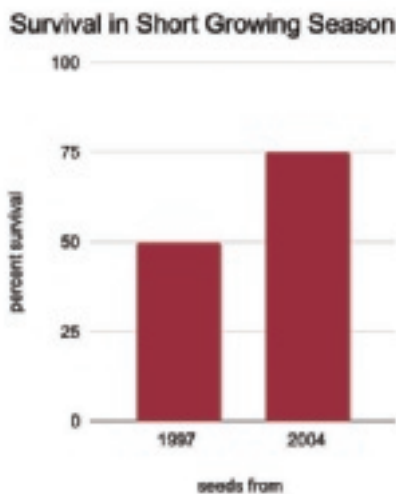
A. Identify: What do I see in the data? • What happened in the environment over the time of the studies on the mustard plants (1997-2004)? • What was the greatest difference between the mustard plants' environment in 1997 and in 2004? Your summary:	B. Interpret: What does this mean? • How do you think this might have affected the mustard plants' survival? • How do you think this might have affected the mustard plants' ability to produce seeds? Your summary:
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Data Subset 3: Survival and Reproduction Studies

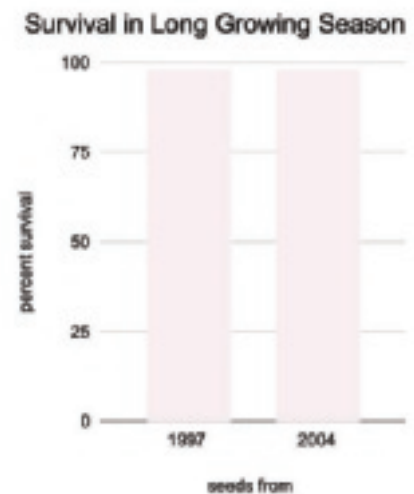
As described in the *Overview*, mustard plants are annuals. Each plant lives only one year, during which it grows, blooms, and produces seeds after being pollinated. The mustard plants are pollinated by many different kinds of insects. The more plants in an area that bloom at the same time, the more likely they are to be pollinated, so they are more likely to be able to reproduce. After pollination (when male sex cells in the pollen in one plant's flower unite with female sex cells in the ovule of another plant's flower), each fertilized ovule develops into a seed. The seeds from pollinated plants will fall to the ground and will germinate the following year. Plants must grow to full size before they can bloom. If plants do not get the amount of water that they need to grow during their growing season, they wilt and die before they can produce flowers. When this happens they will not produce seeds and will have no offspring (seeds) that sprout and grow during the following year. Because most of the rain usually falls close to the beginning of the growing season, plants that have a shorter time to flowering have a better chance to bloom and produce seeds each year.

Survival in a short growing season: Scientists wanted to know whether plants from seeds harvested at the end of 1997 and 2004 were different in terms of survival when they receive insufficient amounts of water. They grew 100 plants from seeds collected from a wet marsh in 1997 and compared them to 100 plants grown from seeds from that same location and population that were collected in 2004. They watered all the pots with the same amount of water each day. The plants all sprouted and began to grow.

After 33 days they stopped watering half the plants to mimic the effect of a short growing season in which plants would have gotten water only at the start of the growing season. They kept watering the other half for 81 days to mimic a longer growing season in which plants would continue to have enough water throughout the whole growing season. They determined the percent of plants that survived in each group (short growing season and long growing season). Their results are shown in the graphs here.



Data source: Franks, S. et al (2007). Rapid evolution of flowering time by an annual plant in response to a climate fluctuation. PNAS, 104(4), pp. 1278-1282.



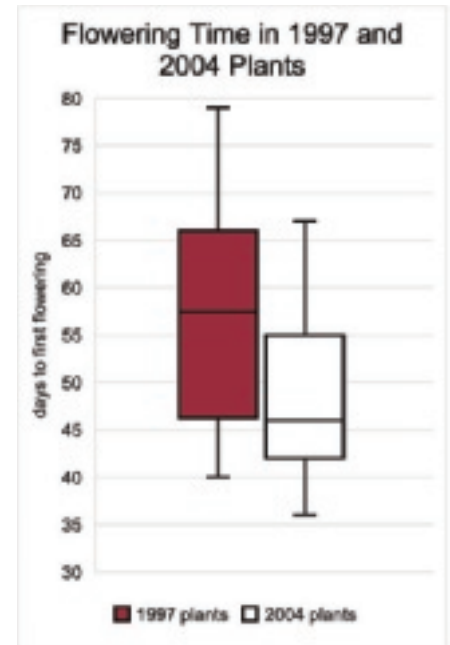
Data source: Franks, S. et al (2007). Rapid evolution of flowering time by an annual plant in response to a climate fluctuation. PNAS, 104(4), pp. 1278-1282.

Reproduction: Scientists were also interested in whether there was a difference in how quickly these plants could reproduce. They planted seeds from both populations, watered them, and measured how many days it took them to begin to bloom after they began to grow (the days to first flowering). They measured 100 plants grown from 1997 seeds and 100 plants grown from 2004 seeds. In this experiment, they gave all the plants all the water they needed to grow and survive.

This box-and-whisker plot shows what they saw. The center bar in each box indicates the median time to flowering for those plants. The boxes show the range of flowering time of the middle 50% of each population; the lines indicate the times between which 90% of the plants flowered.

All data adapted from the following source:

- Franks, S. J., Sim, S., & Weis, A. E. (2007). Rapid evolution of flowering time by an annual plant in response to a climate fluctuation. *Proceedings of the National Academy of Sciences*, 104(4), 1278-1282.



Data source: Franks, S.J., et al. Rapid evolution of flowering time by an annual plant in response to a climate fluctuation. PNAS 2007 104(4) 1278-1282.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data? • What is the difference in the survival of the mustard plants from the 1997 population compared to the 2004 population? • What is the difference in the ability of the mustard plants to reproduce in the 1997 population compared to the 2004 population? Your summary:	B. Interpret: What does this mean? • If water is available only for a short growing season, which flowers will be most likely to reproduce and make seeds for the following year? • If water is available for a long growing season, which flowers will be most likely to reproduce and make seeds for the following year? Your summary:
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Data Subset 4: Offspring and Inheritance Studies

Scientists wanted to know whether any differences they observed between the mustard plant population in 1997 and the population in 2004 were due to inherited traits. They knew that there were differences in the two populations both in how well they survived in a short growing season and in how long it took them to bloom after they sprouted (the days-to-flowering time). So they set up breeding experiments to test this question about inheritance.

Breeding experiments: They grew plants from the seeds they collected in 1997 (1997 population) and from the seeds they collected in 2004 (2004 population). They took pollen from the flowers of one parent population and used it to pollinate the flowers in another parent population. When flowers are pollinated, male sex cells in pollen from one plant's flower (male parent) unite with female sex cells in the ovule of another plant's flower (female parent). Pollinated flowers produce seeds in pods. The seeds are the offspring of the parent plants. The scientists collected all the seeds that were produced in these crosses. These are the crosses they did:

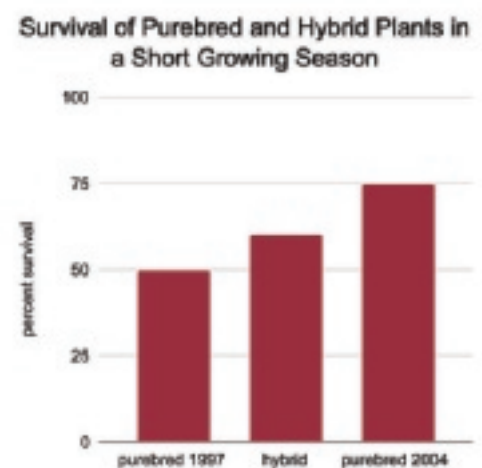
Male parent population (pollen)	Female parent population (ovule)	Offspring population (seeds)
1997	1997	purebred 1997
1997	2004	hybrid
2004	1997	
2004	2004	purebred 2004

Then they tested the offspring populations by planting the seeds from each cross and determining

- how well they survived in a short growing season and
- how long it took them to bloom after they sprouted (days-to-flowering time).

They knew that if the traits were inherited, hybrids between plants from the 1997 and the 2004 populations would be likely to have a variation in survival or in flowering time that was midway between the survival or flowering time of the purebred populations.

Survival in a short growing season: To test for survival in a short growing season, they planted 100 seeds from each offspring population and watered all the pots with the same amount of water each day. The plants all sprouted and began to grow. After 33 days they stopped watering the plants to mimic the effect of a short growing season in which plants would not get enough water over time. They determined the percent of plants that survived in each offspring population. The data they collected are shown in the graph here.



Data source: Franks, S.J., et al. Rapid evolution of flowering time by an annual plant in response to a climate fluctuation. PNAS 2007 104(4) 1278-1282.

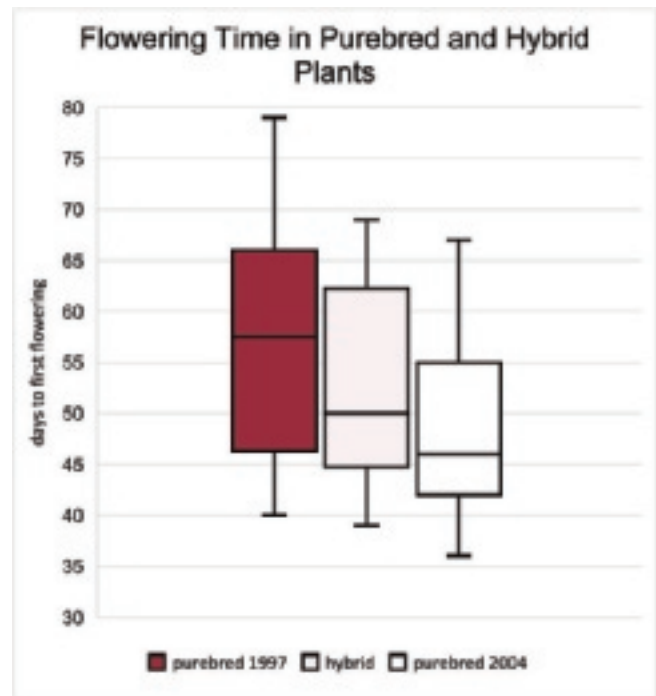
Days-to-flowering time: Scientists were also interested in whether there was a difference in the offsprings' flowering times, so they measured how many days it took for each offspring population's plants to begin to bloom after they began to grow (the days to first flowering). In this experiment, they planted 100 seeds of each offspring population and gave all the plants all the water they needed to grow and survive.

This box-and-whisker plot shows what they saw. The center bar in each box indicates the median time to flowering for those plants. The boxes show the range of flowering time of the middle 50% of each population; the lines indicate the times between which 90% of the plants flowered.

Structural differences: A second group of scientists investigated whether any structures of the mustard plants were different between the 1997 population and the 2004 population. They found that many of the proteins involved in signaling the plant to start to grow or to start to produce flowers were structurally different between the two populations.

All data adapted from the following source:

- Franks, S. J., Sim, S., & Weis, A. E. (2007). Rapid evolution of flowering time by an annual plant in response to a climate fluctuation. *Proceedings of the National Academy of Sciences*, 104(4), 1278-1282.



Data source Franks, S.J., et al. Rapid evolution of flowering time by an annual plant in response to a climate fluctuation. PNAS 2007 104(4) 1278-1282.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data?

- What is the pattern of survival in a short growing season for the three offspring populations?
- Do the characteristics of the three offspring populations show evidence that the ability to survive in a short growing season is heritable in mustard plants? Explain.

Your summary:

B. Interpret: What does this mean?

- Are there structural differences among the populations?
- If a trait is heritable, how does that affect the traits of the offspring in the next generation?
- Why would it matter if a trait is heritable or not if we are trying to understand what could cause changes in a whole population of descendants over several generations?

Your summary:

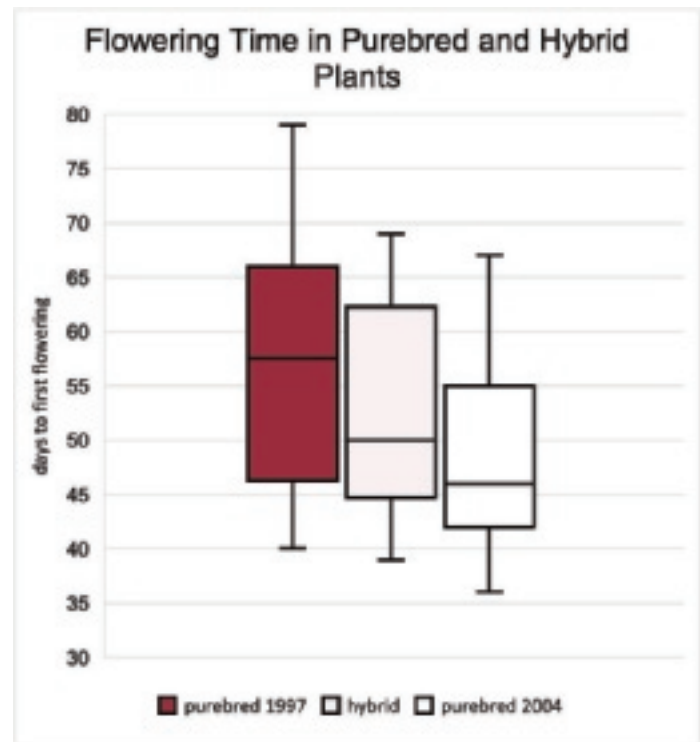
Data Subset 5: Studies of the Population of Mustard Plants at the End

All the plants in a population of mustard plants need to bloom close to the same time so that pollen from a flower on one plant can fertilize a flower from a neighboring plant. Scientists wanted to see how long it took the plants in a population to grow to full size and produce flowers. They were interested in this because plants that do not get enough water can wilt and die before they have a chance to bloom. Since most of the rain usually falls close to the beginning of the growing season, plants that have a shorter time to flowering have a better chance to bloom and produce seeds each year. For this study, scientists gathered seeds from many hundreds of plants from a wet, marshy growing site in 1997 and again from the same location and population of plants in 2004. They brought the seeds from the 1997 plants and the 2004 plants into the laboratory and grew 100 plants of each group under exactly the same conditions.

This box-and-whisker plot shows what they saw. The center bar in each box indicates the median time to flowering for those plants. The boxes show the range of flowering time of the middle 50% of each population; the lines indicate the times between which 90% of the plants flowered.

All data adapted from the following source:

- Franks, S. J., Sim, S., & Weis, A. E. (2007). Rapid evolution of flowering time by an annual plant in response to a climate fluctuation. *Proceedings of the National Academy of Sciences*, 104(4), 1278-1282.



Data source: Franks, S.J., et al. Rapid evolution of flowering time by an annual plant in response to a climate fluctuation. PNAS 2007 104(4) 1278-1282.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data? • What is the trait of interest in this study? • What is the range of variations in the 1997 plants? What is the range in the 2004 plants? • What is the median value for this trait in the 2004 plants? Your summary:	B. Interpret: What does this mean? • What change occurred? • What do you think might be the effect of having a shorter time to flowering for mustard plants? • What do you think might be the effect of having a longer time to flowering for mustard plants? Your summary:
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Peppered Moth Data Packet

Overview: Peppered Moth Color

There is a type of moth that is common in England and in parts of North America that is called the peppered moth. It is called that because many of the moths have a distinctive black and white pattern on their wings. Scientists refer to the lighter-colored peppered moths as the “typical” form. Like many other types of organisms, the peppered moth occurs in more than one color.



Some of the peppered moths are almost entirely black in color. The darker peppered moths are referred to as the “carbonaria” form. These two different forms of the peppered moth are able to breed with each other and produce offspring (much like dogs, cats, or horses of different colors can breed together). Besides their color differences, however, the lighter- and the darker-colored moths do not show a lot of other trait variation.

The moths all live in wooded areas both far away from and close to where people live.

The moths start out as caterpillars in the summer months, then spend the winter underground as pupae. They all emerge as mature moths at about the same time in the spring. This increases the odds that they will find mates. They fly around at night looking for food and mates. During the day they hide from predators by sitting still on the branches and trunks of trees. Since the peppered moths are pretty common, many different kinds of woodland birds prey on the peppered moths. The birds pick the moths off the trees where they find them during the day.



Some of the trees where the moths hide have dark-colored bark, but many are partly covered with growths of lichen (a plant-like organism that often grows on trees), which give the tree trunk and branches a lighter-colored, mottled appearance. The mottled areas of the tree bark are covered with lichen. The darker areas have no lichen on them.

In the 1800s, people began to notice more and more of the carbonaria form of the moth. At the same time that this was occurring, the industrial revolution was taking place in England. Many factories were being built, and a lot of people began heating their homes with coal. There was suddenly much more pollution in England. Scientists at the time wondered whether the change in the moths’ color might have something to do with the increasing pollution in the area where the moths were living which darkened the trees where they rested. But it took until the 1950s before people actually did the research to test these ideas. Their research showed that between 1973 and 1997 the predominant color of a population of moths in England changed over 24 generations.



Can you find the typical-form moth on this tree bark?

Data Subset 1: Studies of the Population of Peppered Moths at the Beginning

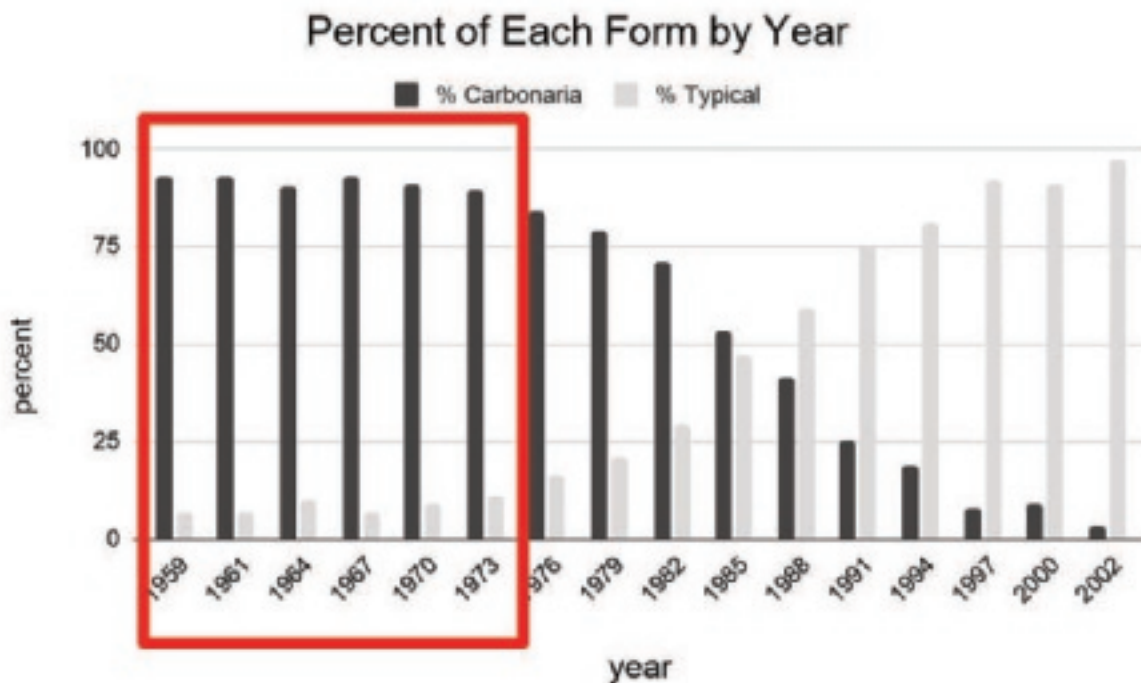
During the 1950s, people in England began to be concerned about the amount of pollution there was in the air in their cities. Large industrial plants had been creating a lot of air pollution. In addition, many people burned coal to heat their homes.

Since air pollution often darkened the trees the moths rested on, scientists had wondered for a long time about whether the color of peppered moths had anything to do with pollution. So they began to study the distribution of traits in the peppered moth population over time.

Numbers over time: In the 1950s, scientists began tracking the number of typical and the number of carbonaria peppered moths that lived in a highly industrialized area called Caldy Common in West Kirby, England. They did this by trapping the moths at night, then counting and releasing them the next day. The same group of scientists collected these data from 1959 to 2002. In all, they collected, identified, and counted over 18,780 moths during the more than 40 years of this study. This is what they saw. Focus on the data from the beginning of the study (1973 and before):



Air pollution in industrial England in the 1950s



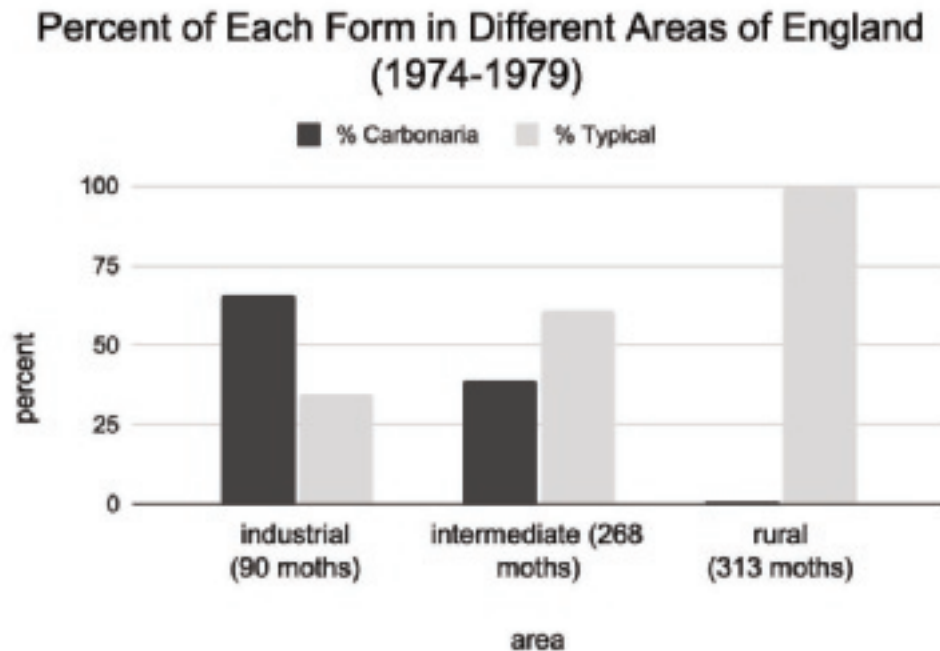
Data source: Grant, B.S. (2005). Industrial melanism. ELS. <https://doi.org/10.1038/npg.els.0004150>

Numbers in different areas: Scientists had also noticed over many years that the carbonaria form seemed to be much more common in certain areas of England compared to others. They noticed that the areas where there seemed to be more carbonaria forms were usually areas where there was a lot of industry.

They wanted to know if the industry or the level of pollution had anything to do with the forms that lived there. So they collected information on the proportion of carbonaria and typical forms in three different areas:

- a highly industrialized area
- an intermediate area where a lot of people lived and burned coal to heat their houses
- a rural area where few people lived

What they found is in the graph shown below:



Data source: Cook, L., et al. (2002). Melanic frequencies in three species. . .Biological Journal of the Linnean Society (75) 475-482

All data adapted from the following sources:

- Cook, L. M., Riley, A. M., & Woidwod, I. P. (2002). Melanic frequencies in three species of moths in post industrial Britain. *Biological Journal of the Linnean Society*, 75, 475-482.
- Cook, L. M. (2003). The Rise and Fall of the Carbonaria Form of the Peppered Moth. *The Quarterly Review of Biology*, 78, 399-417.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data?

- What is the trait of interest in this study?
- What are the variations for this trait in the population?
- What is the proportion of those variations in the population in 1973?
- What is the difference in proportions in different areas?

Your summary:

B. Interpret: What does this mean?

- What do you think might be the effect of having a lighter, speckled color (typical) for moths in each area?
- What do you think might be the effect of having a darker color (carbonaria) for moths in each area?

Your summary:

Data Subset 2: Environmental Studies

During the 1950s, people in England began to be concerned about the amount of pollution there was in the air in their cities. The industrial revolution had begun almost 100 years earlier. Since then, more and more industrial plants had been built throughout northern England.

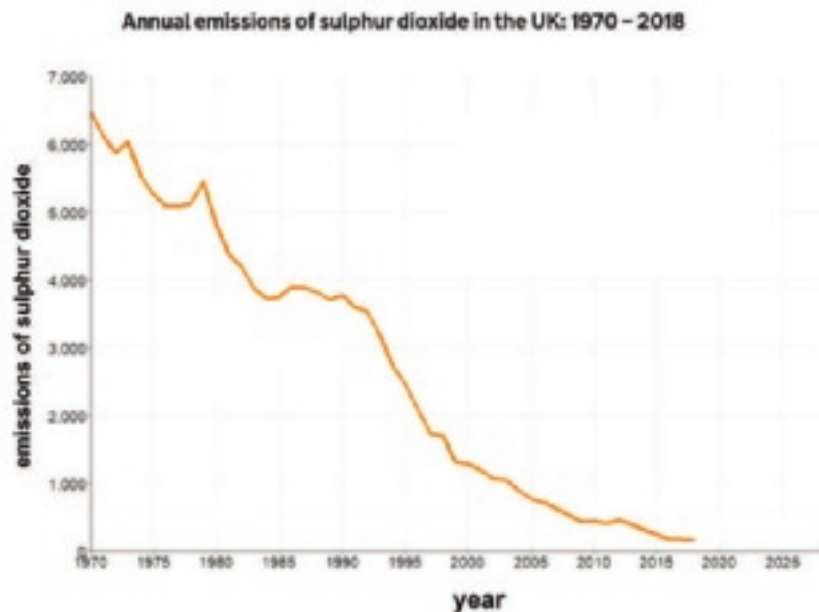
Large industrial plants had been creating a lot of air pollution in the form of smoke and sulfur dioxide that they released into the air. People were also burning coal to heat their homes. Coal burning also releases smoke and sulphur dioxide into the air.

Scientists had seen that the different forms of peppered moth could camouflage on tree trunks based on their appearance. The typical forms were lighter in color and speckled, similar to the lichen coverage on trees. The carbonaria forms were darker in color, similar to tree bark without lichen coverage. They wanted to know whether the air pollution was affecting the way that lichen grew on trees and what effect that might have on the moths.

Pollution over time: During the time of the study, the government in the United Kingdom (UK) enacted clean air laws to limit the amount of air pollution. In order to see if the laws were working to reduce the amount of air pollution, the scientists collected information about how much sulfur dioxide air pollution was in the air in England. This is what they saw:

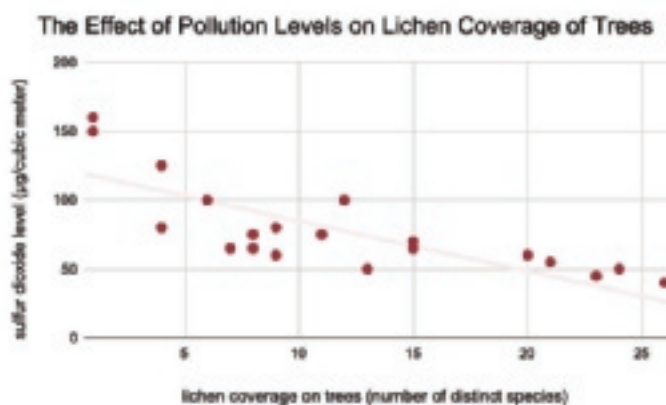


Air pollution in industrial England in the 1950s



UK Department for Environment Food & Rural Affairs, Open Government Licence v3.0

Pollution and lichen coverage: The scientists determined the amount and type of lichen that was growing on trees in many different locations throughout England. They checked whether the lichen coverage was affected by the amount of sulfur dioxide air pollution in the air in those locations. The data they collected are shown in the graph here. Each point represents a different location in England. For each location, the point shows the amount of sulfur dioxide in the air and the amount of lichen coverage on the trees in that location. The line represents the line of best fit for the data.



Data source: Bishop J.A. et al (1975). Moths, Lichens and Air Pollution Along a Transect from Manchester to North Wales. *Journal of Applied Ecology*, 12(1), pp. 83-98.

Lichen coverage and moth forms: While scientists were measuring the amount and type of lichen that was growing on trees throughout England, they also collected, identified, and counted the forms of the peppered moths that they found on the trees. They observed that, in general, when trees had less lichen coverage, there were more carbonaria forms found on them. When there was more lichen, more of the moths on the tree were typical forms.

All data adapted from the following sources:

- Bishop, J. A., Cook, L. M., Muggleton, J., & Seaward, M. R. D. (1975). Moths, Lichens and Air Pollution Along a Transect from Manchester to North Wales. *Journal of Applied Ecology*, 12(1), 83–98.
- Department for Environment, Food & Rural Affairs. (2018). *Defra National Statistics Release: Emissions of air pollutants in the UK, 1970 to 2016*. Retrieved from <https://www.burnright.co.uk/wp-content/uploads/2019/02/Statistics-Defra-air-pollution-graph.pdf>

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

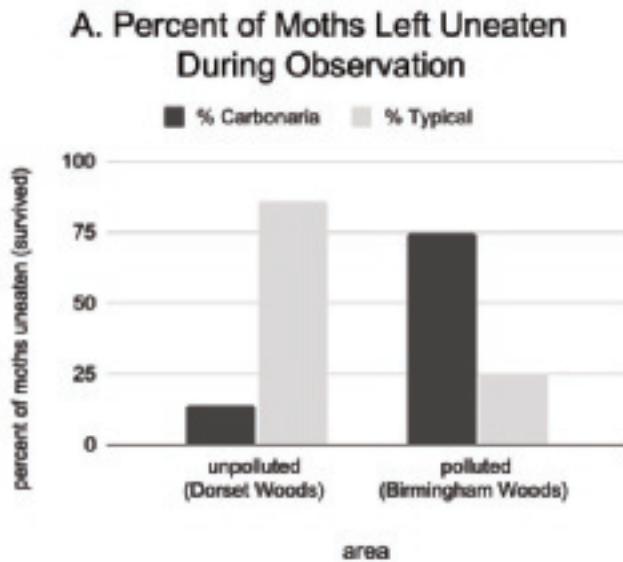
A. Identify: What do I see in the data? • What patterns do you notice in air pollution over 1973-1997? • What pattern do you notice in lichen coverage on trees that relates to pollution levels? Your summary:	B. Interpret: What does this mean? • How do you think any changes might have affected the peppered moths' survival? • How do you think any changes might have affected the peppered moths' ability to find mates and reproduce? Your summary:
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Data Subset 3: Survival and Reproduction Studies

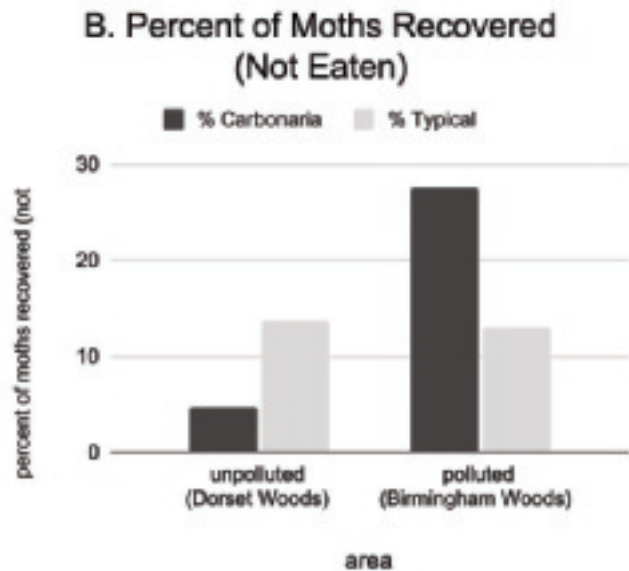
The peppered moths live in wooded areas all over England. They hide on tree branches and trunks during the day and fly around at night looking for food and mates. After mating, the females lay eggs that hatch in midsummer. The caterpillars grow by eating tree leaves throughout the summer. In the fall, the caterpillars become pupae and drop to the ground where they survive in the soil during the winter. The adult moths die during the winter. In the spring, mature moths emerge from the pupae hidden in the soil and begin the life cycle again. The mature moths all emerge near the same time, which helps them find mates and therefore increases the odds of reproduction.

While they are adults, the peppered moths become food for many different kinds of small birds. Since they had noticed more carbonaria moths in polluted areas, scientists were interested in finding out which forms of the moth were able to avoid being eaten by birds in polluted areas and unpolluted areas of England. They set up two different experiments to determine which forms were left uneaten by birds in the woods.

Survival: Scientists caught many hundreds of peppered moths of both forms. In experiment A, shown below, they released equal numbers of both forms of live moths onto trees in a polluted area in Birmingham. They did the same thing in an unpolluted area in Dorset. They filmed which moths were eaten by birds during the day and which moths were left uneaten. In experiment B, shown below, they marked the moths, then released equal numbers of each form early in the morning. In the evening they set out traps to capture the moths and then counted the number of marked moths that they recaptured. They assumed that most of the moths that were not recaptured had probably been eaten by birds. These are the results of both experiments:

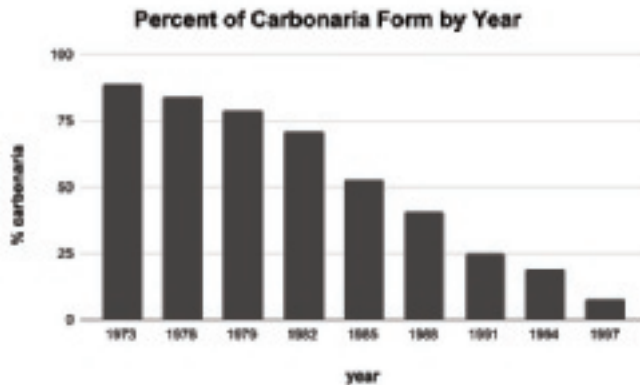


Data sources: Majerus, M.E.N. (2008). Industrial Melanism in the Peppered Moth. . . , *Evo Edu Outreach* 2, 63–74. Rudge, D.W. (2005). The Beauty of Kettlewell's Classic Experimental. . . , *BioScience* 55(4), 369-375.

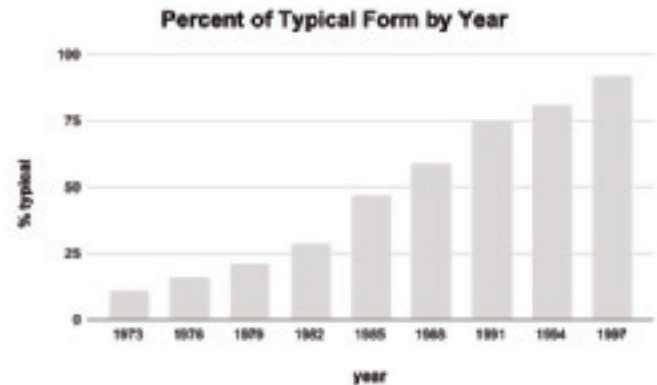


Data sources: Majerus, M.E.N. (2008). Industrial Melanism in the Peppered Moth. . . , *Evo Edu Outreach* 2, 63–74. Rudge, D.W. (2005). The Beauty of Kettlewell's Classic Experimental. . . , *BioScience* 55(4), 369-375.

Characteristics of offspring: During the time of the study, scientists were able to track the proportions of both forms of peppered moth that came from eggs laid each year in a population in a highly industrialized area of England. They did this by collecting and counting adult moths each year, since the adults of that year came from eggs laid the previous year. This is what they saw:



Data source: Grant, B.S. (2005). Industrial melanism. ELS. <https://doi.org/10.1038/npg.els.0004150>



Data source: Grant, B.S. (2005). Industrial melanism. ELS. <https://doi.org/10.1038/npg.els.0004150>

All data adapted from the following sources:

- Cook, L. M. (2003). The Rise and Fall of the Carbonaria Form of the Peppered Moth. *The Quarterly Review of Biology*, 78, 399-417.
- Rudge, D. W. (2005). The Beauty of Kettlewell's Classic Experimental Demonstration of Natural Selection. *Biology in History*, 55(4), 369-375.
- Majerus, M. E. N. (2009). Industrial Melanism in the Peppered Moth, *Biston betularia*: An Excellent Teaching Example of Darwinian Evolution in Action. *Evolution Education Outreach*, 2, 63-74.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data? • What is the trend in the data for survival of each form of moth in different areas? • What is the trend in the data for the offspring? • What is the trend in the data for the forms of the moth over time? Your summary:	B. Interpret: What does this mean? • What do you think might be the effect of coloration on survival in polluted areas? • What do you think might be the effect of coloration on survival in unpolluted areas? • What do you think might explain the change in reproduction of each form over time? Your summary:
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Data Subset 4: Offspring and Inheritance Studies

The peppered moths live in wooded areas all over England. They fly around at night looking for food and mates. They hide on tree branches and trunks during the day. The females lay eggs that hatch in midsummer. The caterpillars grow by eating tree leaves throughout the summer. In the fall, the caterpillars become pupae and drop to the ground where they survive in the soil during the winter. The adult moths die during the winter. In the spring, mature moths emerge from the pupae hidden in the soil and begin the life cycle again.

Scientists wanted to know whether the color pattern of the typical and carbonaria forms was an inherited trait or whether it was produced by something in their environment. However, they were unable to figure out which offspring were a result of which matings in the wild. So, over the years, many different scientists captured moths of different colors and did breeding experiments to determine whether the color pattern was inherited and to figure out if it might be due to a dominant or recessive allele of a gene. They knew that if one of the colors was due to a recessive allele, a cross between two parents of that color would not produce any offspring with the color of the other form. The table below is an example of the kinds of results you would see if you did breeding experiments with these moths.

Parent crosses		# of carbonaria offspring	# of typical offspring
Parent #1	Parent #2		
carbonaria	carbonaria	405	110
carbonaria	typical	350	152
typical	typical	0	509

*These data represent the patterns seen in data from multiple studies that investigated inheritance of the carbonaria and typical phenotypes.

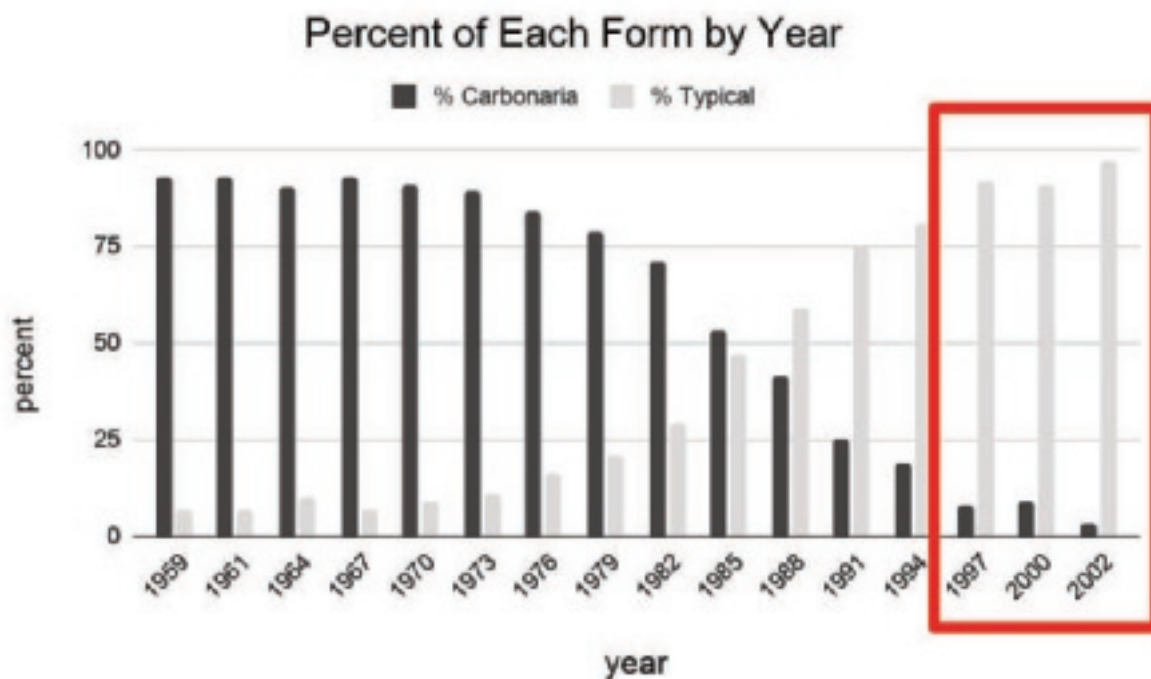
Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data? • Do the characteristics of offspring show evidence that the coloration is heritable in peppered moths? Explain. • What patterns provide evidence for your claim? Your summary:	B. Interpret: What does this mean? • Would color be passed from parent to offspring? • Which color would be more likely to be passed down from parent to offspring? • Why would it matter if a trait is heritable or not if we are trying to understand what could cause changes in a whole population of descendants over several generations? Your summary:
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Data Subset 5: Studies of the Population of Peppered Moths at the End

People in England were concerned about the amount of pollution there was in the air in their cities. Large industrial plants had been creating a lot of air pollution. In addition, many people burned coal to heat their homes. The government in the United Kingdom enacted clean air laws in 1956 to limit the amount of air pollution. Since air pollution often darkened the trees they rested on, scientists had wondered for a long time about whether the color of peppered moths had anything to do with pollution as scientists in the 1800s had originally thought. So they studied the peppered moths as the clean air laws began to take effect and the amount of air pollution began to decrease.

Numbers over time: After the first clean air laws were passed, scientists began tracking the number of typical and carbonaria peppered moths that lived in a highly industrialized area called Caldy Common in West Kirby, England. They did this by trapping the moths at night, then counting them and releasing them the next day. The same group of scientists collected these data over the years from 1959 to 2002. In all, they collected, identified, and counted over 18,780 moths during the nearly 50 years of this study. This is what they saw. Focus on the data from the end of the study (1997 and after):

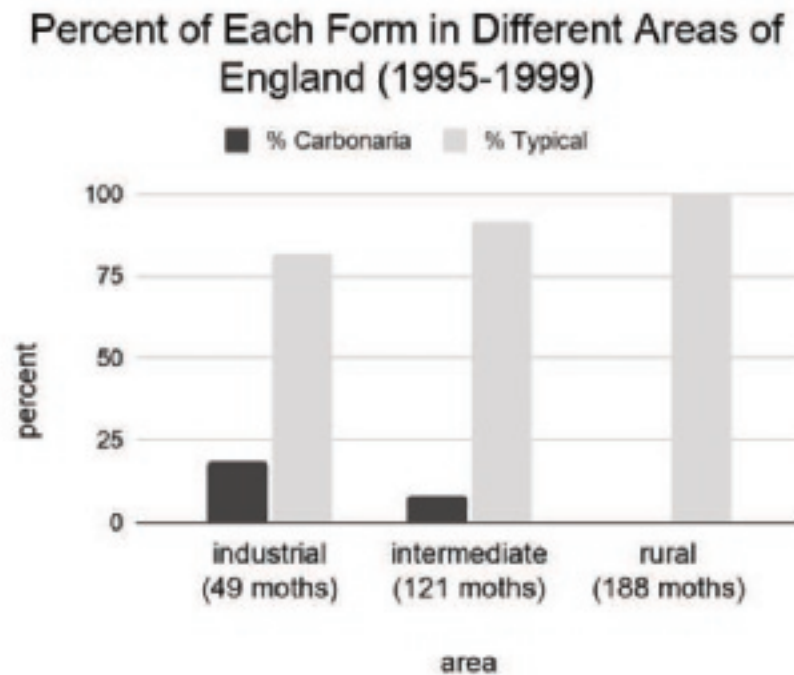


Data source: Grant, B.S. (2005). Industrial melanism. ELS. <https://doi.org/10.1038/npg.els.0004150>

Numbers in different areas: Scientists had also noticed over many years that the carbonaria form seemed to be more common in certain areas of England. They noticed that the areas where there seemed to be more carbonaria forms were usually areas where there was a lot of industry. They wanted to know if the industry or the level of pollution had anything to do with the forms that lived there. So they collected information on the proportion of carbonaria and typical forms in three different areas:

- a highly industrialized area
- an intermediate area where a lot of people lived and burned coal to heat their houses
- a rural area where few people lived

The data they collected are shown in the graph below:



Data source: Cook, L. M., Riley, A. M., & Woidwod, I. P. (2002). Melanic frequencies in three species of moths in post industrial Britain. *Biological Journal of the Linnean Society*, 75, 475-482.

All data adapted from the following sources:

- Cook, L. M., Riley, A. M., & Woidwod, I. P. (2002). Melanic frequencies in three species of moths in post industrial Britain. *Biological Journal of the Linnean Society*, 75, 475-482.
- Cook, L. M. (2003). The Rise and Fall of the Carbonaria Form of the Peppered Moth. *The Quarterly Review of Biology*, 78, 399-417.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data?

- What is the trait of interest in this study?
- What are the variations for this trait in the population?
- What are the proportions of those variations in the population in 1997?
- What is the difference in proportions of those variations in the population in different areas in 1997?
- How do the proportions of those variations in the population shift over time?

Your summary:

B. Interpret: What does this mean?

- What change occurred?
- What do you think might be the effect of having a lighter, speckled color (typical) for moths in each area?
- What do you think might be the effect of having a darker color (carbonaria) for moths in each area?
- What do you think might be the effect of having each color over time?

Your summary:

Stickleback Data Packet

Overview: Stickleback Armor

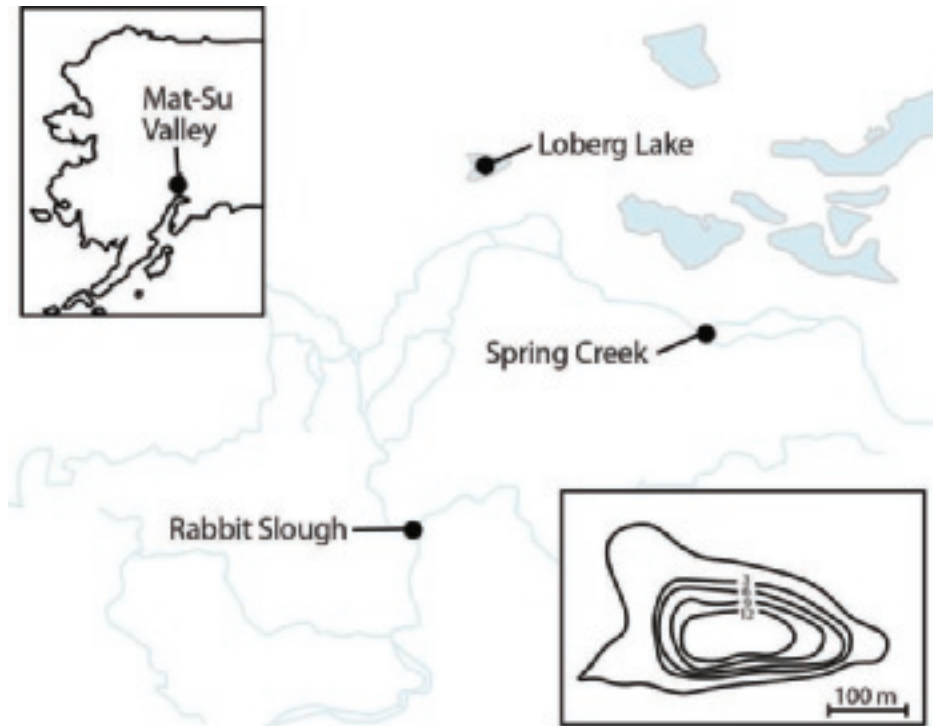
Sticklebacks are a type of small fish, usually no more than about 3 inches (8 cm) long, that are found in most bodies of freshwater as well as in the ocean along the coasts in the Northern Hemisphere. Because they are small and numerous, they have a lot of predators wherever they live. The stickleback fish have a number of different types of “armor” that help protect them from predators. Most have a row of 2-16 sharp spines on their back. Many have spiny fins on their bellies. Some types of sticklebacks also have bony plates along their sides, extending from behind their gills to their tails on both sides, sort of like a suit of armor.

Sticklebacks are known for being found almost everywhere along coasts in the Northern Hemisphere. Some of the sticklebacks live in the ocean but breed in freshwater streams and lakes, so they travel back and forth between saltwater and freshwater. Some of the sticklebacks live and breed only in the ocean or only in freshwater. Wherever they breed, male sticklebacks build nests and perform characteristic mating dances to attract females. The males with the best dances are more likely to breed and reproduce.

Oceanic sticklebacks can be identified because they usually have a lot of bony plates along their sides. Freshwater sticklebacks almost always have very few of these bony plates. Having few of the bony plates allows the fish to swim quickly and hide in small spaces so that they are harder for predator fish to find and catch. Having a lot of the plates makes it harder to swim and hide to avoid predators, but it helps the fish to escape from predators that do catch them because the plates make it difficult for the predators to bite down and hang onto the sticklebacks.

Some of the freshwater sticklebacks lived in Loberg Lake in Alaska. When Loberg Lake was being developed as a recreational area for fishermen and boaters, the sticklebacks were eliminated from Loberg Lake so that the salmon and rainbow trout that often preyed on the sticklebacks would be more likely to take the bait of fishermen. The sticklebacks were removed from Loberg Lake in October 1982. After that time, the lake was examined each year to assess how the salmon and trout populations were doing. No sticklebacks were observed for many years. Then in 1990, a few heavily armored sticklebacks were observed in the lake.



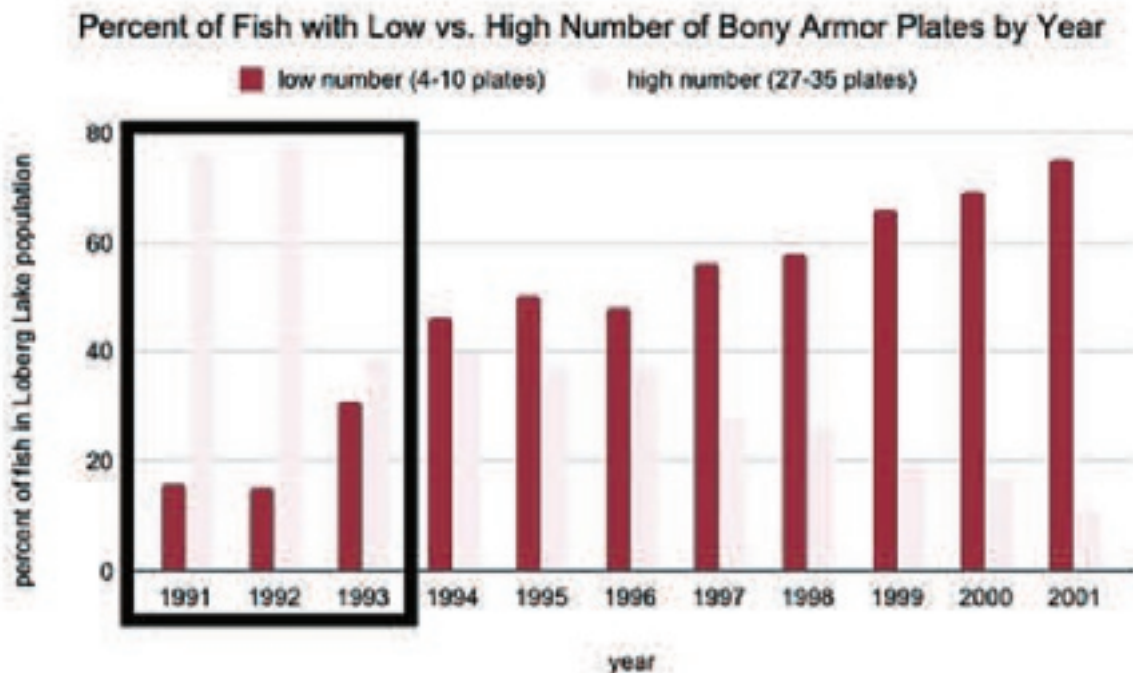


Scientists were interested in where these new sticklebacks had come from and how their population might expand in the lake. So each year from 1991 to 2001, they caught and measured sticklebacks from Loberg Lake. During that time, the number of bony armor plates on the fish in the population changed significantly.

Data Subset 1: Studies of the Population of Sticklebacks at the Beginning

It is well known that sticklebacks with large numbers of bony plates on their sides are oceanic fish. Oceanic sticklebacks do not have many places to hide from predators. They have bony plates on their sides that help them escape from predators that attempt to catch and hold them. Having fewer bony plates allows fish to maneuver and avoid encountering predators in freshwater environments where there are more places for fish to hide. However, in 1990 the new sticklebacks observed in Loberg Lake, a freshwater lake, had a lot of bony plates. This means that somehow some oceanic stickleback fish had gotten into Loberg Lake after the original population of freshwater sticklebacks was eliminated in 1982.

For this study, scientists traveled to Loberg Lake each year and set traps in various locations around the lake. They collected all the adult fish that they caught in the traps and observed their armor. They counted and recorded both the number and the position of the bony plates on the left side of each fish. They categorized the fish into groups based on how many bony plates they had. This is what they saw. Focus on the data from the beginning of the study (1993 and before):



Data source: Bell, M.A. et al (2004). Twelve years of contemporary armor evolution in a threespine stickleback population. *Evolution*, 58(4), pp. 814-824.

All data adapted from the following source:

- Bell, M. A., Aguirre, W. E., & Buck, N. J. (2004). Twelve Years of Contemporary Armor Evolution in a Threespine Stickleback Population. *Evolution*, 58, 814-824.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data? • What is the trait of interest in this study? • What are the variations for this trait in the population? • What is the proportion of those variations in the population in 1991? Your summary:	B. Interpret: What does this mean? • What do you think might be the effect of having fewer bony armor plates for the stickleback in Loberg Lake? • What do you think might be the effect of having more bony armor plates for the stickleback in Loberg Lake? Your summary:
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Data Subset 2: Environmental Studies

Sticklebacks can be found in the ocean in quiet bays or inlets near the coast. They also live in freshwater environments like lakes, ponds, and slow-flowing streams as well as in somewhat salty, brackish waters like harbors and marshes near the shore. They can even be found in ditches and other backwaters. Some populations of sticklebacks live in the ocean but breed and lay their eggs in freshwater areas and return to the ocean after their young have hatched.

The quiet ocean inlets where the sticklebacks live are often relatively open, sandy areas with little vegetation where they travel together in groups (shoals). This makes them easily visible to many larger ocean fish that prey on them. They are frequently chased and caught by larger fish, but their spines and the armor they have from bony plates that line their sides give them some protection.

The brackish waters and the lakes and ponds where sticklebacks live are usually shallower and full of growing vegetation and other places for sticklebacks to hide themselves from predators.

The sticklebacks in Loberg Lake originally had very few bony armor plates. That population of fish was eliminated from Loberg Lake in 1982. In 1990, sticklebacks with large numbers of bony plates were observed in the lake. Sticklebacks with large numbers of bony plates are typically oceanic fish. Scientists wanted to determine where these new sticklebacks in Loberg Lake came from. They compared the new sticklebacks with the sticklebacks found in nearby lakes. Those nearby sticklebacks were known to come from the ocean and use the lakes as freshwater breeding areas.

The scientists found that the new sticklebacks in Loberg Lake had many of the same characteristics as the oceanic sticklebacks that were breeding and raising their young in the nearby lakes and then returning to the ocean. The new sticklebacks may have found a way to get into Loberg Lake through a natural waterway that is underground. Or they may have been released by mistake into Loberg Lake by a fisherman who caught them in a nearby lake and was using them as bait in Loberg Lake. However they got there, they remained in Loberg Lake after that time and their population increased over the years.



Sticklebacks in open water like their ocean environment



Sticklebacks in an area with a lot of vegetation like their freshwater environment

All data adapted from the following source:

- Bell, M. A., Aguirre, W. E., & Buck, N. J. (2004). Twelve Years of Contemporary Armor Evolution in a Threespine Stickleback Population. *Evolution*, 58, 814-824.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data?

- How did the environment of the sticklebacks change when they arrived in Loberg Lake?
- What was the greatest difference between their previous environment and their new environment?

Your summary:

B. Interpret: What does this mean?

- How do you think the change in environment might have affected the stickleback's ability to survive?
- How do you think the change in environment might have affected the stickleback's ability to find mates and reproduce?

Your summary:

Data Subset 3: Survival and Reproduction Studies

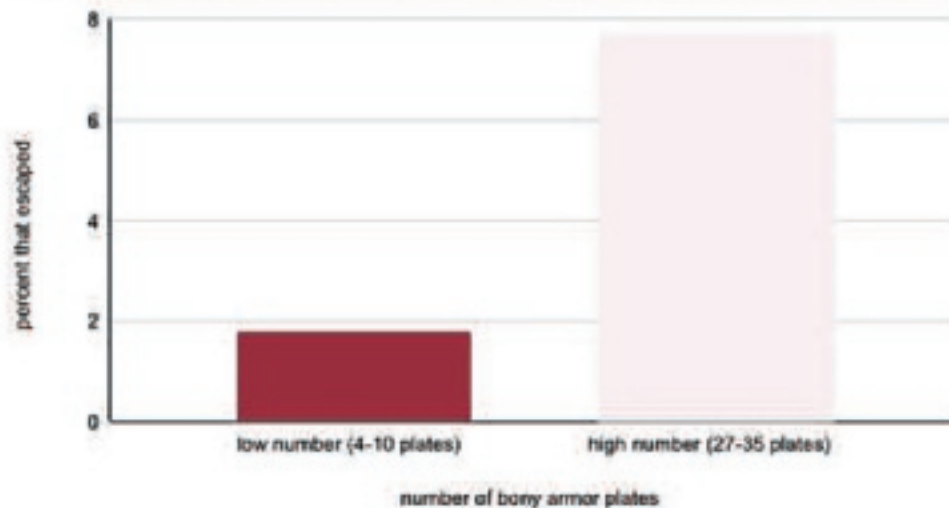
The type of sticklebacks that live in Loberg Lake breed once every two years. Between breeding seasons, they usually live together in groups (shoals), and many of them may be eaten by predators. Sticklebacks are preyed upon by many types of larger fishes in both the ocean and bodies of freshwater. Salmon, trout, perch, and pike all eat sticklebacks. These larger fish are toothed predators that capture the sticklebacks by biting onto them and then manipulating the sticklebacks around so that they fit into their mouths (usually either head first or tail first) and are easy to swallow.

For the sticklebacks that survive, the breeding season starts as the days get longer and warmer in the spring. During the breeding season, all individual male sticklebacks that have survived build tunnel-like nests on the sandy bottom of the area where they live. They then do a zigzag dance to attract females. The females lay eggs in the nest, and the male fertilizes the eggs after they are laid. Several different females may lay eggs in one nest that are then fertilized by the same male. In this way, the males with the best dances are more likely to breed and reproduce.

The male stays with the eggs for about a week, fanning them with his fins. After the offspring hatch, he keeps them together in the nest for several days until they are mature enough to leave the nest on their own. Some of the males may attract more females than others, but virtually all the living females contribute eggs that hatch and become part of the next generation of sticklebacks.

Survival: It is known that sticklebacks with more bony armor plates are less likely to be punctured and wounded by predators' teeth when they bite them. Scientists wanted to examine the effect of the armor on the ability of predators to hold onto and swallow the sticklebacks that they do catch. They put sticklebacks into an aquarium with a cutthroat trout and watched to see whether the trout would be able to swallow the sticklebacks or whether the sticklebacks would be able to escape after the trout caught them. They put sticklebacks with fewer than 10 bony plates in with the trout. The trout caught 283 of these low-plate-number sticklebacks. They recorded how many times the sticklebacks were eaten and how many times they escaped. Then they put sticklebacks with more than 30 bony plates in with the trout and recorded how many were eaten and how many escaped. The trout caught 235 of these high-plate-number sticklebacks. These are the results they recorded:

Percent of Stickleback Fish that Escaped After Being Caught



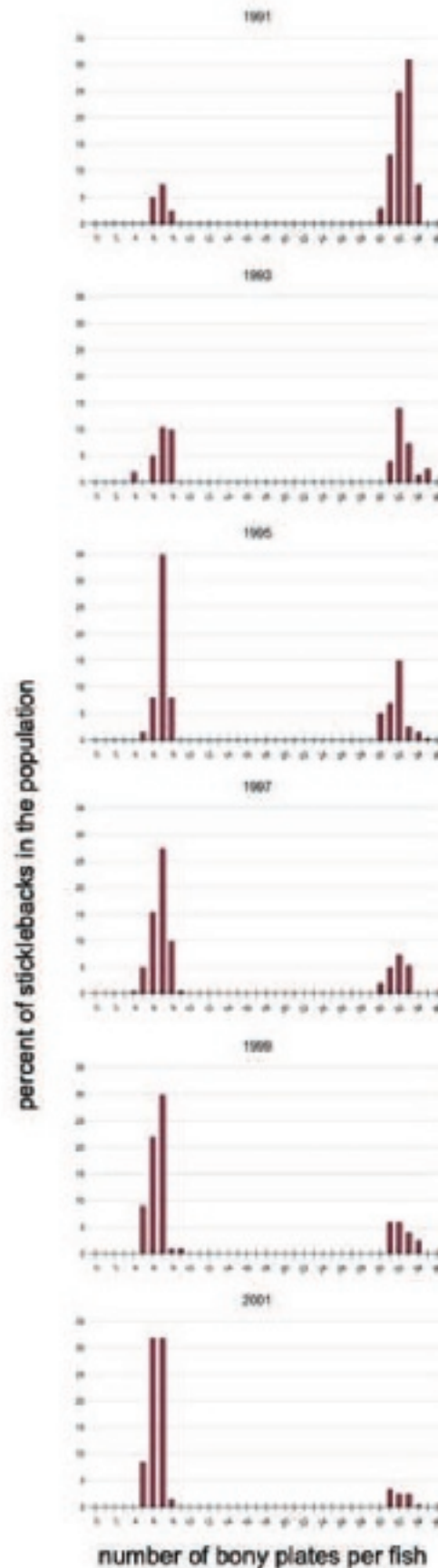
Data source: Reimchen, T.E. (2000). Predator Handling Failures of Lateral Plate Morphs. Behaviour, 137(7/8).

Reproduction: Because of the way the sticklebacks reproduce, each new generation of sticklebacks is very similar to the parent population of sticklebacks that was alive during the breeding season. So examining the fish in Loberg Lake every two years gives a good estimate of which fish are reproducing during the breeding season. Scientists counted the number of bony plates on the sticklebacks they caught in Loberg Lake every two years and saw the pattern shown in these graphs.

All data adapted from the following sources:

- Reimchen, T. E. (2000). Predator Handling Failures of Lateral Plate Morphs in *Gasterosteus aculeatus*: Functional Implications for the Ancestral Plate Condition. *Behaviour*, 137(7-8), 1081–96.
- Bell, M. A., Aguirre, W. E., & Buck, N. J. (2004). Twelve Years of Contemporary Armor Evolution in a Threespine Stickleback Population. *Evolution*, 58, 814-824.

Percent of Sticklebacks in the Loberg Lake Population



Data source: Bell, M.A. et al (2004). Twelve years of contemporary armor evolution in a threespine stickleback population. *Evolution*, 58(4), pp. 814-824.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data? • What fish were more likely to survive being caught by a predator? • What is the trend in the data for the number of bony plates on the fish over time? Your summary:	B. Interpret: What does this mean? • What do you think is the effect of the number of bony plates on survival of the fish in Loberg Lake? • What do you think might explain the change in which fish were reproducing over time? Your summary:
--	--

Data Subset 4: Offspring and Inheritance Studies

Scientists have studied sticklebacks for a long time. In that time, a number of different breeding experiments have been done.

Patterns: When scientists breed sticklebacks that have low numbers of bony plates, almost all their offspring have low numbers of bony plates. When they breed sticklebacks that have high numbers of bony plates, almost all their offspring have high numbers of bony plates.

When they breed a fish with a low number of bony plates with one that has a high number of bony plates, however, the pattern of offspring can be very complex. Some of the offspring have a low number of bony plates, some have a high number, and others have some very different patterns of bony plates on their bodies. Sometimes the offspring have a medium number of plates, sometimes they have a few plates that are spread out over their body. Sometimes they have a lot of plates, but those plates are very small or cover only certain parts of their bodies.

As you know from the *Muscles Unit*, phenotypes that are caused by multiple genes can result in very complicated inheritance patterns. Scientists who study these patterns are called quantitative geneticists. They can figure out how many genes are involved and how many alleles each of those genes have by analyzing the complex inheritance patterns that occur. This complicated analysis has shown that the number of bony plates in sticklebacks is most likely caused by 2 genes, each having 2-3 different alleles. These different alleles for the different genes combine in many ways in the stickleback offspring, resulting in the variety of bony plate phenotypes observed in the sticklebacks.

Specific genes: More recently, molecular geneticists, another type of scientist, have identified that one of the genes involved in determining plate number is the *ectodysplasin* gene. The *ectodysplasin* gene has the genetic information to make a protein that has important functions during embryonic development. It is known that the different alleles for this gene do affect the number of bony plates on a stickleback, but it is not yet known what the protein does that causes differences in the sticklebacks' armor.

All data adapted from the following sources:

- Banbura, J., & Bakker, T. C. M. Lateral Plate Morph Genetics Revisited: Evidence For A Fourth Morph in Three-Spined Sticklebacks, *Behaviour*, 132(15-16), 1153-1171.
- Wiig, E., Reseland, J. E., Østbye, K., Haugen, H. J., & Vøllestad, L. A. (2016) Variation in Lateral Plate Quality in Threespine Stickleback from Fresh, Brackish and Marine Water: A Micro-Computed Tomography Study. *PLoS ONE*, 11(10), e0164578.
- Bell, M. A., Aguirre, W. E., & Buck, N. J. (2004). Twelve Years of Contemporary Armor Evolution in a Threespine Stickleback Population. *Evolution*, 58, 814-824.

Consider the questions listed below in your analysis of the information and what it means. Then write your summary in the box below.

A. Identify: What evidence do I see?

- Do the characteristics of offspring show evidence that the number of bony armor plates is heritable in sticklebacks? Explain.
- What patterns provide evidence for your claim?

Your summary:

B. Interpret: What does this mean?

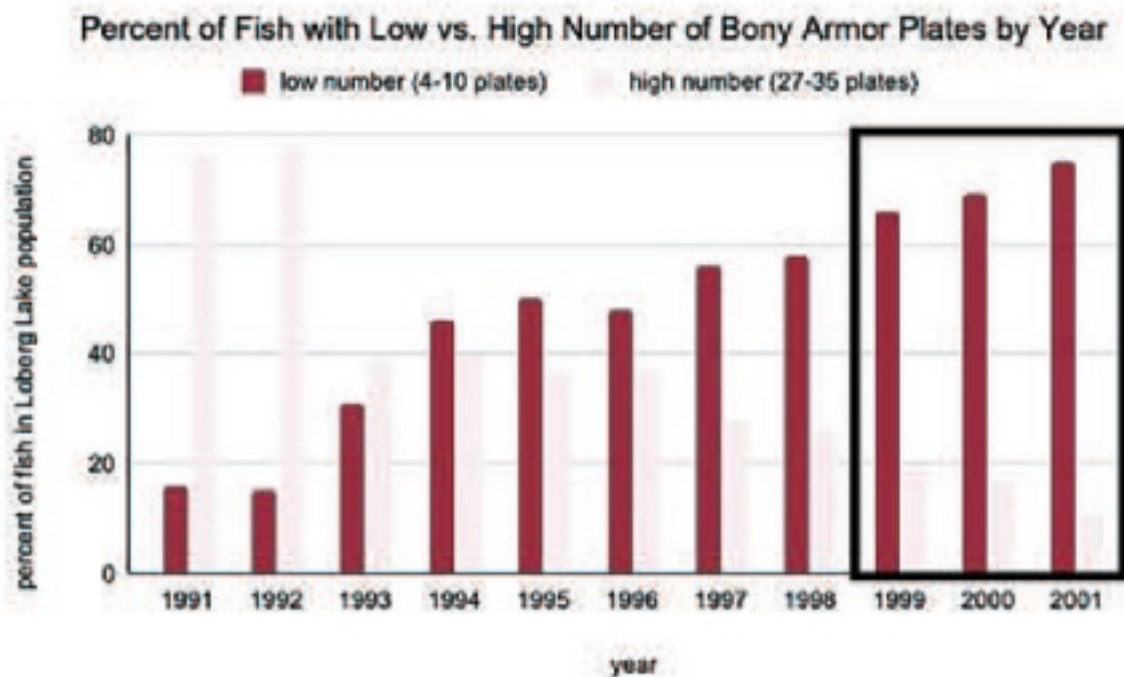
- Would the number of bony armor plates be passed from parent to offspring?
- Why would it matter if a trait is heritable or not if we are trying to understand what could cause changes in a whole population of descendants over several generations?

Your summary:

Data Subset 5: Studies of the Population of Sticklebacks at the End

It is well known that sticklebacks with large numbers of bony plates on their sides are oceanic fish. Oceanic sticklebacks do not have many places to hide from predators. They have bony plates on their sides that help them escape from predators that attempt to catch and hold them. Fewer bony plates allow fish to maneuver and avoid encountering predators in freshwater environments where there are more places for fish to hide. The new sticklebacks that were observed in Loberg Lake in 1990 had a lot of bony plates, like oceanic fish. Because most sticklebacks in freshwater lakes have fewer bony armor plates, scientists were interested in seeing what would happen to the oceanic fish living in the freshwater lake.

For this study, scientists traveled to Loberg Lake each year and set traps in various locations around the lake. They collected all the adult fish that they caught in the traps and observed their armor. They counted and recorded both the number and the position of the bony plates on the left side of each fish. They categorized the fish into groups based on how many bony plates they had. This is what they saw. Focus on the data from the end of the study (1999 and after):



Data source: Bell, M. A. et al (2004). Twelve years of contemporary armor evolution in a threespine stickleback population. *Evolution*, 58(4), pp. 814-824.

All data adapted from the following source:

- Bell, M. A., Aguirre, W. E., & Buck, N. J. (2004). Twelve Years of Contemporary Armor Evolution in a Threespine Stickleback Population. *Evolution*, 58, 814-824.

Consider the questions listed below in your analysis of the data and what they mean. Then write your summary in the box below.

A. Identify: What do I see in the data?

- What is the trait of interest in this study?
- What are the variations for this trait in the population?
- What is the proportion of those variations in the population in 2001?
- How does the proportion of those variations in the population shift over time?

Your summary:

B. Interpret: What does this mean?

- What change occurred?
- What do you think might be the effect of having fewer bony armor plates for the stickleback in Loberg Lake?
- What do you think might be the effect of having more bony armor plates for the stickleback in Loberg Lake?
- What do you think might be the effect on plate numbers in the population over time?

Your summary:

Name: _____

Date: _____

Using the CCC Lens

Use the crosscutting concepts below to help you think more deeply about your case. Respond to the prompts and record your thoughts in each section by writing or drawing.

Structure and Function
What structure(s) is relevant to your case study? What specific functions are affected by variation in the structure?

Trait of interest:	
Cause and Effect on Individuals	
How does having a specific trait variation affect the individual?	How does having a specific trait variation affect the offspring that an individual can produce?
Would that specific trait variation always affect every individual the same way?	Does the trait variation affect how likely the individual would be to produce offspring?

Trait of interest:	
Cause and Effect on Populations	
How does having different trait variations affect the whole population?	How does having different trait variations in the population affect the trait variations that appear in the offspring produced by that population?

What is the probability (how likely do you think it is) that the specific trait variation would affect an individual's ability to survive?

What is the probability (how likely do you think it is) that the specific trait variation would affect an individual's ability to produce offspring?

Name: _____

Date: _____

Develop a System Model

We want to develop a system model to represent what is happening that can explain how and why the population changed over time in the ways we identified. A system model includes key **parts (components)** of the system, and it includes **interactions** among those parts. A system model can be **used to help us explain** how the whole system works.

CCC: Systems and System Models

Parts (components)

- The population (This component should be included in every group's system model.)
What are other key parts (components) that need to be in your system model?

Interactions: What are some key interactions going on between those parts (components) that need to be included in your model?

Use the model to explain phenomena: What will you need to explain using your model?

Our system model helps us explain how and why the population changed from the beginning to the end of the study. In each case there are effects on the **quantity** of individuals in the population and the **proportions** of individuals with particular traits.

CCC: Scale, Proportion, and Quantity

Sketch a diagrammatic model in the space below that shows a population of your organisms at the start of your case study. Then show what happens to the population over the next couple of generations. Be sure to represent effects on **quantity** and **proportion**.

A large, empty rectangular box with a thin black border, intended for a student to sketch a diagrammatic model of a population over generations. The box is currently blank.

Name: _____

Date: _____

How can we use our model to make predictions?

We developed our General Model for Natural Selection by investigating 5 specific populations of organisms with different trait variations. Each population interacted with a particular environmental factor.

The populations we looked at were more-recent, modern examples. How does our model help us answer questions about what could be causing changes in populations of descendants from ancient to modern penguins, horses, whales, and horseshoe crabs over many, many generations and over millions of years?

Let's use our model to make predictions about what would happen

- to any population,
- in any environment, and
- over a different number of generations.

Complete each prompt below using words and/or pictures to share your thinking.

1. What does our model predict would happen in the next generation for any of the populations we investigated? What does our model predict would happen in the next generations after that?

The next generation	The next generations after that

2. What does our model predict would happen if the environment changed gradually or suddenly so that the resources or risks in the environment changed?

The environment changed gradually	The environment changed suddenly

3. What does our model predict would happen if a different population of organisms entered a new environment? Would we see changes in the distribution of the traits in the population in future generations of descendants?

4. What ideas do you have about how we could test our model to see how good it is at predicting and explaining what would happen to other populations, in different environments, or over different lengths of time?

Flagella Image for Word Wall



The structures seen sticking out of some of these individual *salmonella* bacteria are called **flagella**. The bacteria use these structures to move around.

Name: _____

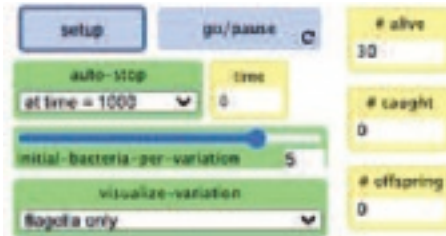
Date: _____

Investigation 1

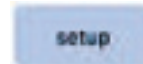
Part A: Simulating a Neutrophil in the Environment

1. Open a web browser and go to the following address: <https://youtu.be/qGX6OHDsVzw>

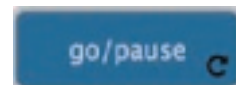
2. Make sure the simulation has the following settings:



3. Input your selections for the simulation by clicking on



4. Start the simulation by clicking on

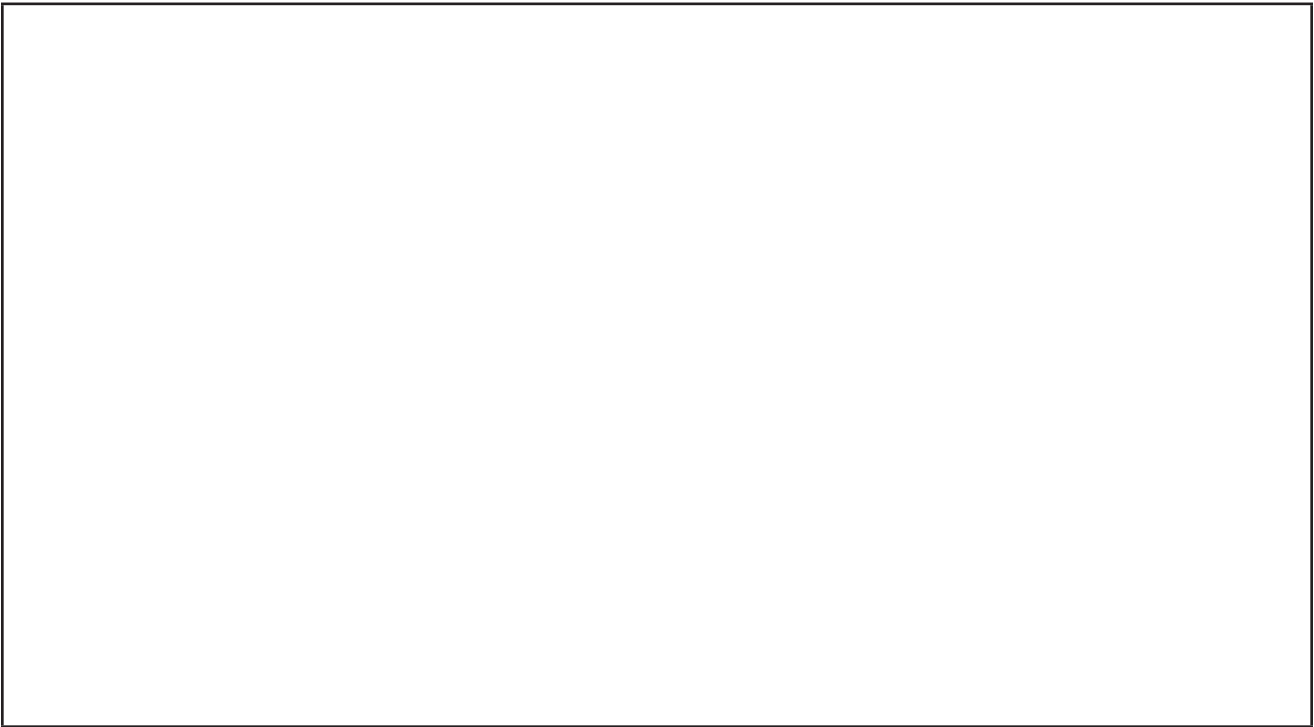


5. Hunt bacteria by chasing them around and clicking on them. See if you can catch more than your partner does in the same amount of time.
6. When the simulation automatically stops, compare your results with your partner. Discuss the following questions:
 - a. What happened to the distribution of the trait variations in your populations?
 - b. Why might you and your partner have gotten similar shifts in the distribution of trait variations but not exactly the same results?

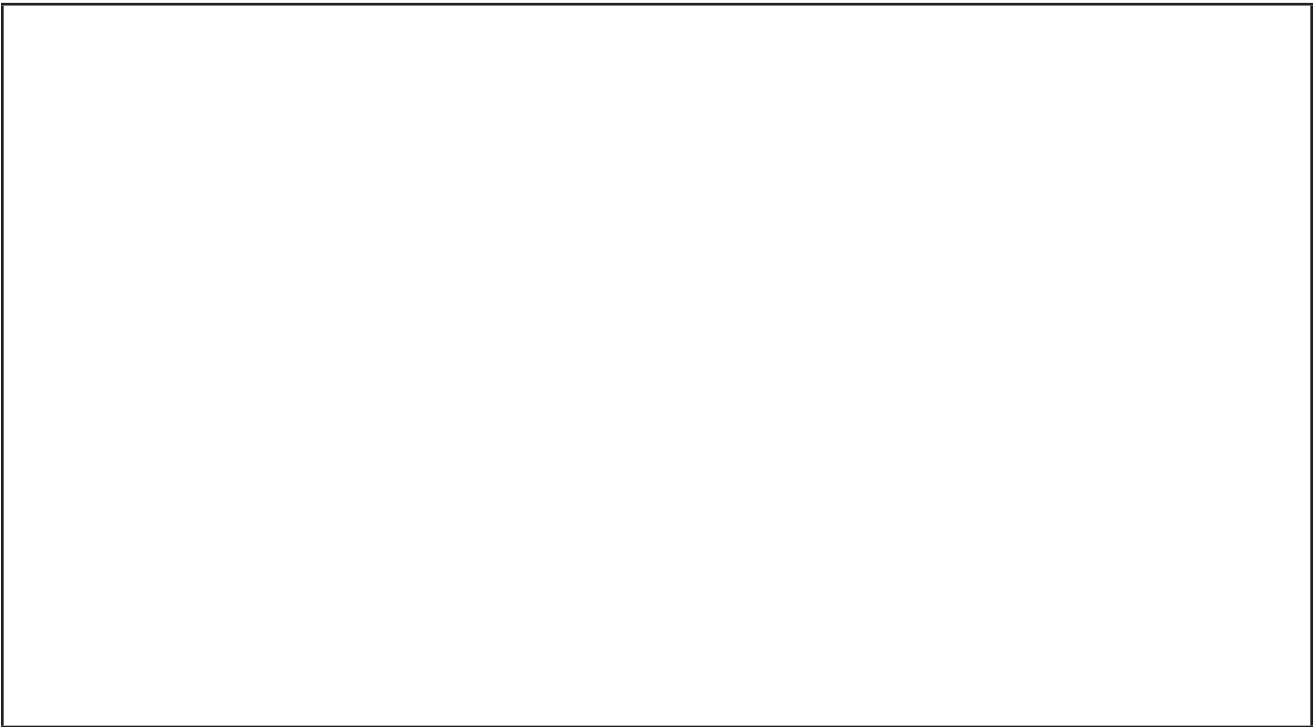
Part B: Making Sense of the Results

Complete each prompt below using words and/or pictures to share your thinking.

1. How did the population change in this environment?



2. Why did the population change in this way?



Name: _____

Date: _____

Refining and Applying Our General Model for Natural Selection

Part A

1. How did using a simulation help us refine our General Model for Natural Selection?

2. We explored what happened to a bacteria population over time when we recreated the interactions with different types of white blood cells. Those white blood cells were a risk to be avoided for this type of organism.

Let's consider other things in the environment that affect bacteria survival and reproduction.

List some resources that bacteria would need from their environment in order to survive and reproduce.	List the things that would need to be changed in the simulation to mimic bacteria interacting with some of these resources.

3. Do you think bacteria with a different number of flagella might have a competitive advantage for surviving or reproducing in environments that have different amounts or distribution of these sorts of resources in them? Why?

Part B (optional)

4. Now consider whether our General Model could be used to explain some things about penguins. Penguins spend about 75% of their lives in the water. Some penguins can swim much faster than the fastest human swimmer. On land, however, all penguins move much slower than humans.

List some of the heritable traits that penguins have that you think contribute to being able to swim so fast in the water.	List some of the heritable traits that penguins have that limit their ability to move fast on land.

5. How could variations in some of these (or other) heritable traits give some individuals a competitive advantage over others in the water? How might that affect their chances of surviving or reproducing?

6. How could variations in some of these (or other) heritable traits give some individuals a competitive advantage over others on land? How might that affect their chances of surviving or reproducing?

Name: _____

Date: _____

Different Environmental Conditions and Results

Use the table below to record how you set up the two environments and the results of multiple runs with those settings.

Part 1

	Environment #1 (left)	Environment #2 (right)
The initial distribution of trait variations in both populations		
The environment		
Length of time you simulated		
# of deaths that occurred over this time		
# of offspring that were produced over this time		
The final distribution of trait variations in each population		

Part 2

	Environment #1 (left)	Environment #2 (right)
How do you know the shift in the distribution of variations was a typical outcome over time in this environment?		
Describe what you typically saw happening to the population in between the start and the end of the model runs.		

Name: _____

Date: _____

My Model for Changes in Bacteria Populations

My explanation for what is causing changes in the population for Environment 1 (left) using our model:



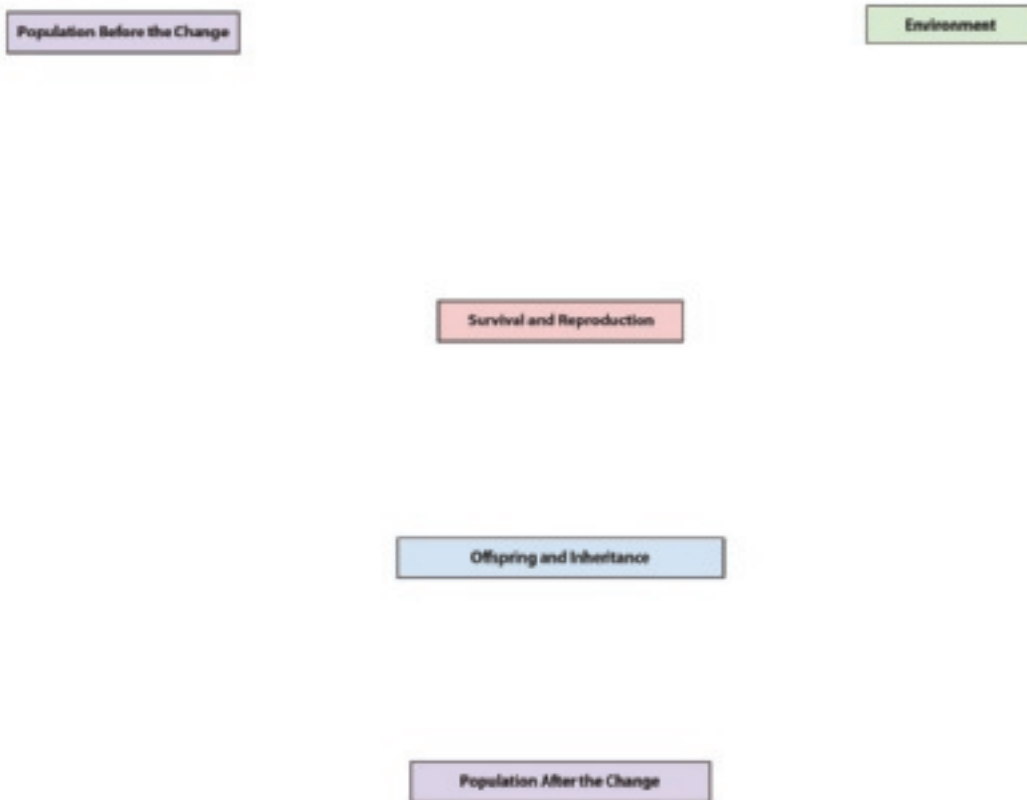
My explanation for what is causing changes in the population for Environment 2 (right) using our model:



Name: _____

Date: _____

Model Scaffold for Green Lizard Explanation



Name: _____

Date: _____

Peer Feedback Self-Assessment

Giving Feedback

How well did you give feedback today?

Today, I . . .	YES	NO
Gave feedback that was specific and about science ideas .		
Shared a suggestion to help improve my peer's work.		
Used evidence from investigations, observations, activities, or readings to support the feedback or suggestions I gave.		

One thing I can do better next time when I give feedback is:

Receiving Feedback

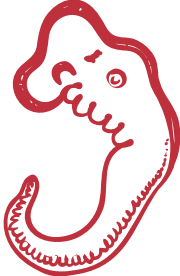
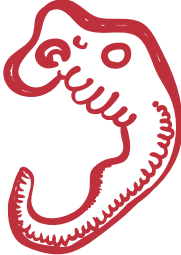
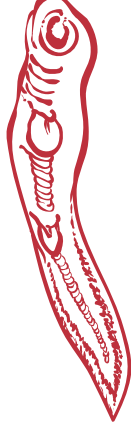
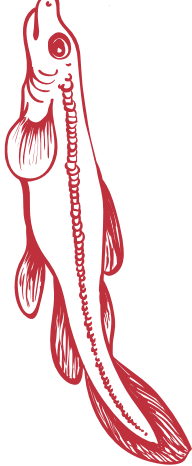
How well did you receive feedback today?

Today, I . . .	YES	NO
Read carefully the feedback I received.		
Asked follow-up questions to better understand the feedback I received.		
Said or wrote why I agreed or disagreed with the feedback.		
Revised my work based on the feedback.		

What is one piece of feedback you received?

What did you add or change to address this feedback?

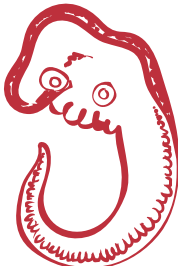
Egg-Laying Embryos

When	Egg-Laying Embryos			
	Chicken	Turtle	Salamander	Fish
Early in development				
Later in development				
Right before hatching				

Name: _____

Date: _____

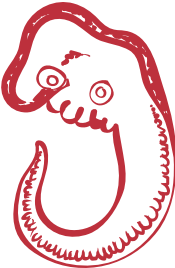
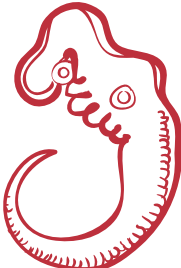
Live Birth Embryos

When	Mammals			
	Rabbit	Pig	Calf	Human
Early in development				
Later in development				
Right before live birth				

Name: _____

Date: _____

Alternate: Non-egg-laying Embryos

When	Mammals		
	Rabbit	Pig	Calf
Early in development			
Later in development			
Right before live birth			

Name: _____

Date: _____

New Ideas and Questions Connected to Embryo Comparisons

A) What new ideas do you have about how to answer our lesson question?	B) What new questions did your analysis of the embryo sketches raise?
C) What patterns in the data you analyzed in this lesson led you to consider these new ideas and/or questions?	

Reviewing Our Driving Question Board

Look through the list of questions from our DQB. Mark how you think the class has answered questions by putting different symbols next to each question:

- We did not answer this question or any parts of it yet: **○** or **?**
- Our class answered some parts of this question, or the ideas we developed help me see how I could now answer some parts of this question: **✓**
- Our class answered this question, or using the ideas we developed, I could now answer this question: **✓✓**

Question	Mark

Question	Mark

Then pick three of the questions you have marked as ✓✓ and write or discuss what you think that answer would be using evidence from class.

Name: _____

Date: _____

Science Literacy Exercise Page 1

Use with Reading Collection 1

Roadmap for Reading

This week's reading collection focuses on how scientists know about the history of life on Earth.

"Collection 1: Earth's Long Life Story" consists of four selections.

- 1 Picturing the Fossil Record
- 2 Gone but Not Forgotten
- 3 Carbon 14's Disappearing Act
- 4 Living Things

As you read:

- Consider the general purpose of each part: is it a description, an explanation, a procedure, or an attempt to persuade?
- Use contextual clues and other knowledge to determine the meaning of unfamiliar words and phrases.
- Consider how each part of the reading relates to knowledge you gained from the previous part.

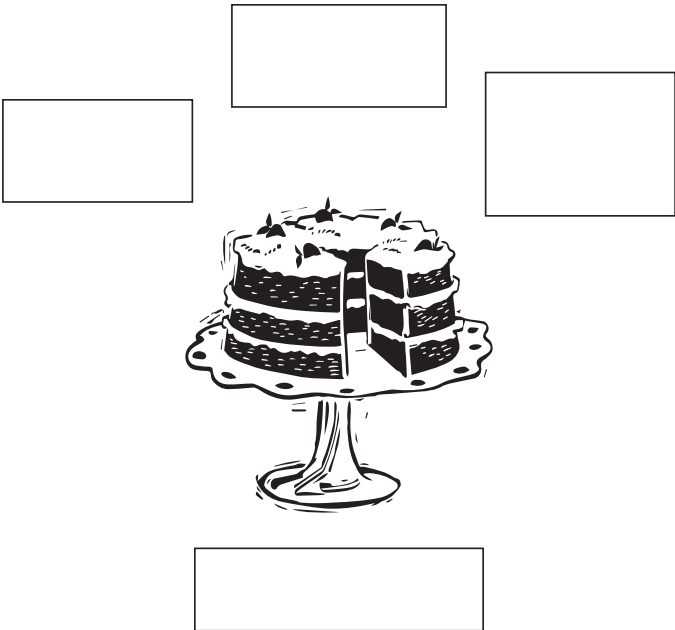
Written Response

Your writing exercise is to complete a "layer cake" graphic organizer to communicate something new you learned from each of the four readings in Collection 1.

- Using the graphic organizer shown as a model, sketch your picture in the center of a separate sheet of paper. Attach this sheet to the front of it when you turn it in.
- Relate something you read in each selection in this collection to the idea of a layer cake. Then label the drawing with one sentence for each reading that explains the relationship. Use arrows to connect your sentences to the part of the picture that relates to it.
- Add color to improve your design. Check your text to make sure it is readable and uses correct spelling and grammar.
- Before you begin, review the criteria in the Evaluation Guidelines that follow to help you clearly understand the expectations of the exercise.

Exercise Page 1, continued

Earth’s Life Story Layer Cake



Evaluation Guidelines

Element	1	2	3	Feedback
Content	Graphic organizer includes ideas from only one or two selections with some stated inaccurately.	Graphic organizer includes mostly accurate ideas from all four selections.	Graphic organizer includes an accurately stated scientific idea from each of the four selections.	
Relationship to layer cake metaphor	The statements and linking lines seem arbitrary and do not seem related to the layer cake metaphor.	Most but not all statements and linking lines show relationships to the metaphor of a layer cake reasonably.	All statements and linking lines show relationships to the metaphor of a layer cake reasonably.	
Design	Major improvements are needed in the design of the shape, lines, text, and arrangement to fill the page.	All but one of the following are well executed: shapes, text, color, and filling the page.	Page is attractively arranged; the text is easy to read; color is used effectively; graphic organizer fills the whole page well.	
Grammar and mechanics	Three or more errors are present in capitalization, punctuation, and spelling.	One or two errors are present in capitalization, punctuation, and spelling.	No errors are present in capitalization, punctuation, and spelling.	

Additional Feedback Notes:

Name: _____

Date: _____

Science Literacy Exercise Page 2

Use with Reading Collection 2

Roadmap for Reading

This week's reading collection focuses on patterns and causes and effects related to inheritance of traits in many species of living things.

"Collection 2: Genes, Species, and Change" consists of five selections.

- 1 It's All in the Genes
- 2 Hunting for Mutations
- 3 Variation Within Species
- 4 Convergence
- 5 Evo-Devo

As you read:

- Consider the general purpose of each part: is it a description, an explanation, a procedure, or an attempt to persuade?
- Look for main ideas of the selections and how they are supported by key details.
- Consider how each part of the reading relates to knowledge you gained from the previous part.

Written Response

Your writing exercise is to complete an outline that summarizes the readings in Collection 2.

- Complete the partial outline shown on the reverse side of this sheet.
- Fill in the missing information in the outline by writing short, complete sentences.
- Write main ideas at the upper level of the outline and supporting details at the lower level.
- Use wording that links how things are made to their functions.
- Use cause-and-effect language to explain main ideas and details.
- Check your grammar, punctuation, and spelling.

Exercise Page 2, continued

Genes, Species, and Change

- I. Genes, which are chunks of DNA molecules, are the cause of inherited traits.
 - A. Chromosomes inside the cell nucleus contain DNA.
 - B. _____
 - C. Gene therapy can change traits that cause diseases.
- II. It takes effort and teamwork to find the cause of an unusual trait.
 - A. First, the person's DNA is searched for mutations.
 - B. _____
 - C. _____
- III. _____
 - A. Individuals of the same species of nudibranch can be different colors.
 - B. The environment causes size and fur differences in a species of rabbit.
 - C. _____
 - D. _____
- IV. Species that are not closely related can have similar traits.
 - A. Ichthyosaurs and sharks have similar traits but are not closely related.
 - B. _____
- V. _____
 - A. Early embryos look almost the same.
 - B. _____

Name: _____

Date: _____

Science Literacy Exercise Page 3

Use with Reading Collection 3

Roadmap for Reading

This week's reading collection focuses on the evolution of species. The selections include excerpts from the most influential book on the subject. The explanations of evolution describe both natural and human causes of evolution.

"Collection 3: Selection and Survival" consists of five selections.

- 1 The Most Famous Writer Seldom Read
- 2 Darwinian Dictionary
- 3 Artificial Selection
- 4 Young Scientists Podcast
- 5 Pigotie Survival: A Classroom Game

As you read:

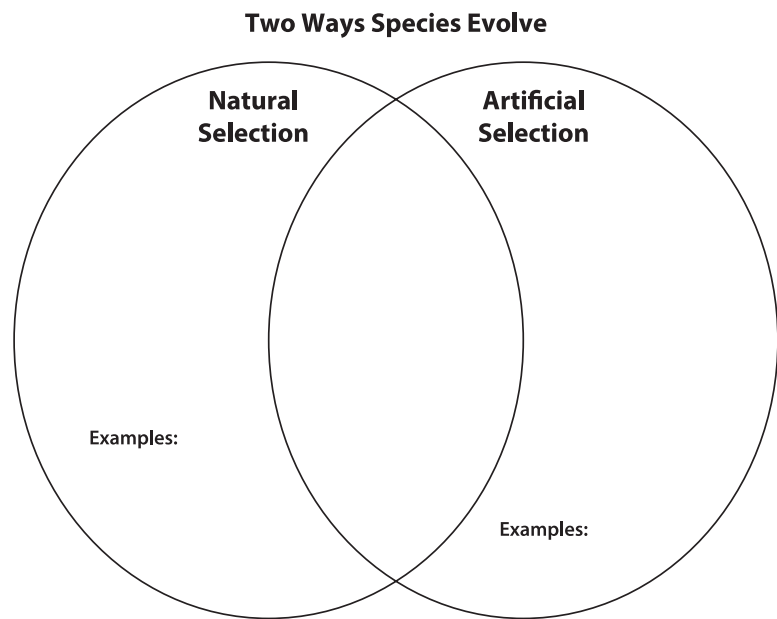
- Consider the general purpose of each part: is it a description, an explanation, a procedure, or an attempt to persuade?
- Use strategies to learn the meanings of unfamiliar science terms, such as looking for contextual clues or using an online dictionary.
- Consider how each part of the reading relates to knowledge you gained from the previous part.

Written Response

Your writing exercise is to make a Venn diagram to compare and contrast natural selection with artificial selection. Your source of information is Collection 3, but you may also refer to what you learned in class investigations.

- Copy the Venn diagram and labels shown on a separate sheet of paper; attach this page to the front of it when you turn it in.
- Write scientifically accurate facts about natural selection alone on the left side of the diagram. Write facts about artificial selection alone on the right side. Write facts that are true of both types of selection where the circles overlap.
- Add a title above your diagram.
- Before you begin, review the criteria in the Evaluation Guidelines that follow to help you clearly understand the expectations of the exercise.

Exercise Page 3, continued



Evaluation Guidelines

Element	1	2	3	Feedback
Content	Few or none of the scientific statements are supported by the text.	Most scientific statements are supported by the text.	All scientific statements are supported by the text.	
Organization of statements	Few statements are placed in the correct parts of the diagram, and the title is missing or inappropriate.	Most statements are placed in the correct parts of the diagram; the title is present and mostly accurate.	Statements of comparison/similarity are placed where the circles overlap; statements of contrast/differences are placed where the circles are not overlapping; the title is present and accurate.	
Number of quality statements	The diagram contains fewer than three quality statements.	The diagram contains at least one statement on the left, one on the right, and one at the intersection of the circles.	The diagram contains at least two statements on the left, two on the right, and two at the intersection of the circles.	
Grammar and mechanics	Six or more errors are present in punctuation, capitalization, and spelling.	Three to five errors are present in punctuation, capitalization, and spelling.	Fewer than three errors are present in punctuation, capitalization, and spelling.	

Additional Feedback Notes:

Name: _____

Date: _____

Science Literacy Exercise Page 4

Use with Reading Collection 4

Roadmap for Reading

This week's reading collection focuses on evolution, cloning, and humans. The selections include an essay on what it means to be a member of the human species. The theme of sudden versus gradual change is woven throughout.

"Collection 4: From Ancient to Modern Species" consists of four selections.

- 1 Settling a Friendly Debate
- 2 Extra Bones? Nope!
- 3 A Sheep Named Dolly
- 4 Unique Humanity

As you read:

- Consider the general purpose of each part: is it a description, an explanation, a procedure, or an attempt to persuade?
- Look for main ideas of the selections and how they are supported by key details.
- Consider how each part of the reading relates to knowledge you gained from the previous part.

Written Response

Your writing exercise is to complete a thoughtful and original paragraph that refers to sudden and/or gradual change over time.

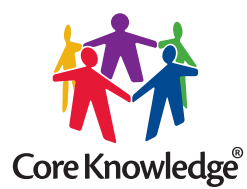
- Compose your paragraph on a separate sheet of paper; attach this page to the front of it when you turn it in.
- Choose one of the following topics:
 - Compare and contrast the meanings of the words *extinction* and *adaptation*.
 - Explain how a new species emerges.
 - Define *natural selection* and *artificial selection*, and explain the differences between them.
 - Respond to the Preface character's idea to use gene therapy to get taller.
 - Choose another related idea to respond to what you have read.
- Write a well-constructed paragraph, beginning with a strong topic sentence. Use details and examples from the reading selections in this unit in your paragraph's supporting sentences.
- Before you begin, review the criteria in the Evaluation Guidelines that follow to help you clearly understand the expectations of the exercise.

Exercise Page 4, continued

Evaluation Guidelines

Element	1	2	3	Feedback
Content	The paragraph contains an inadequate topic sentence, inaccurate use of scientific vocabulary, and few or no references to gradual versus sudden changes in organisms and species.	The paragraph contains an adequate topic sentence and minimal use of scientific vocabulary and is weak in understanding of gradual versus sudden changes in organisms and species.	The paragraph contains a strong topic sentence and accurate use of scientific vocabulary and shows understanding of gradual versus sudden changes in organisms and species.	
Supporting sentences (details)	The paragraph contains incomplete sentences or details irrelevant to the paragraph topic.	The paragraph contains complete sentences, but they are too few, lack in support from the reading, or have an unclear relationship with the topic sentence.	The paragraph contains at least six complete sentences, encompassing three major points from the readings that support the topic sentence.	
Organization and transitions	The paragraph contains statements with little clear relationship to the topic sentence or each other.	The paragraph contains key supporting details, but transitions are absent or choppy.	The paragraph contains ideas in an order that helps the topic make increasingly more sense.	
Grammar and mechanics	The paragraph contains six or more errors in punctuation, capitalization, and spelling.	The paragraph contains three to five errors in punctuation, capitalization, and spelling.	The paragraph contains fewer than three errors in punctuation, capitalization, and spelling.	

Additional Feedback Notes:



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