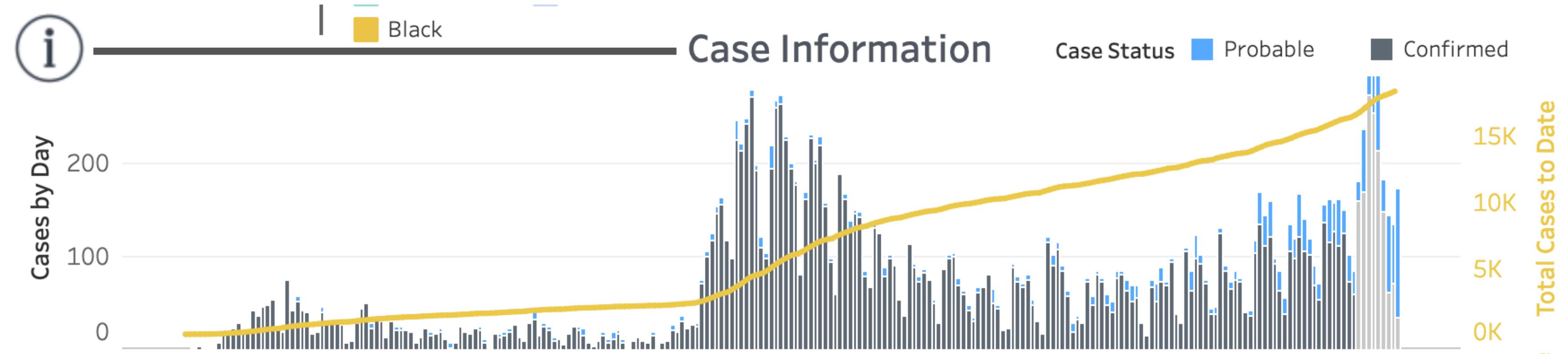
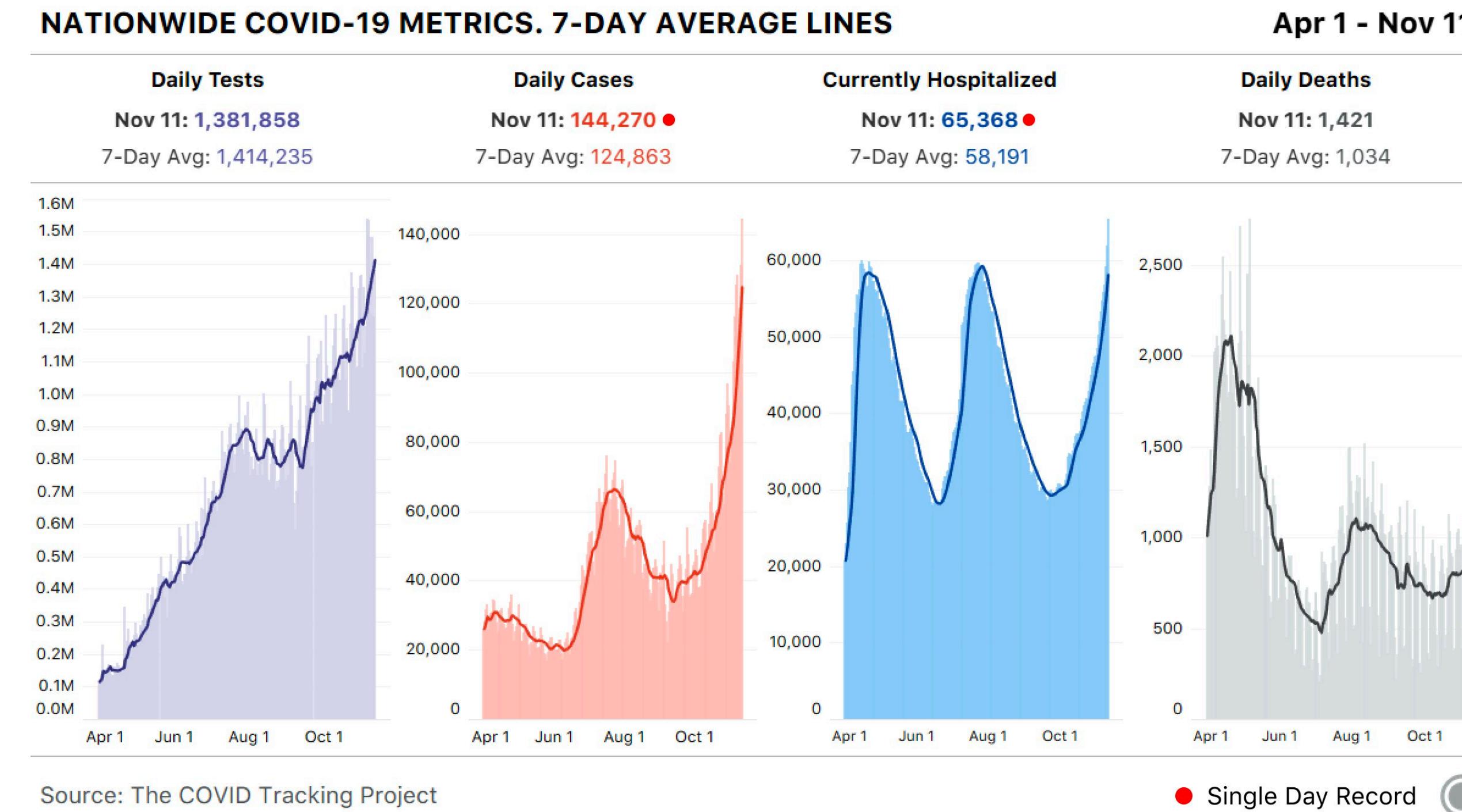


Unit 3: Learning from other people

3. Iterated learning

11/12/2020

A very quick warning to stay safe



Iterated learning

- 1. (Some) structure of language can be explained by two competing pressures: informativeness and simplicity**
- 2. Iterated learning is an experimental method for studying language evolution**
- 3. Iterated learning alone is not enough to give rise to language structure. You need communication**

The gavagai problem

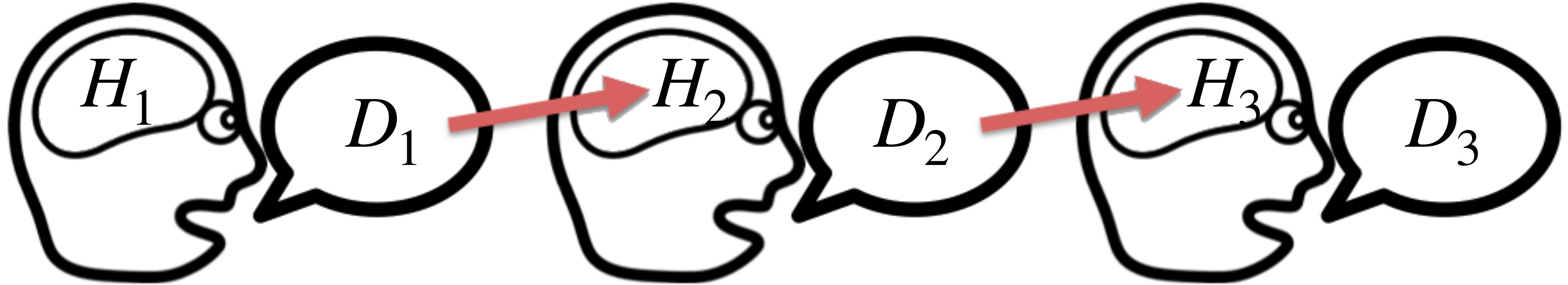


Quine (1960)

How does gavagai come to mean rabbit?



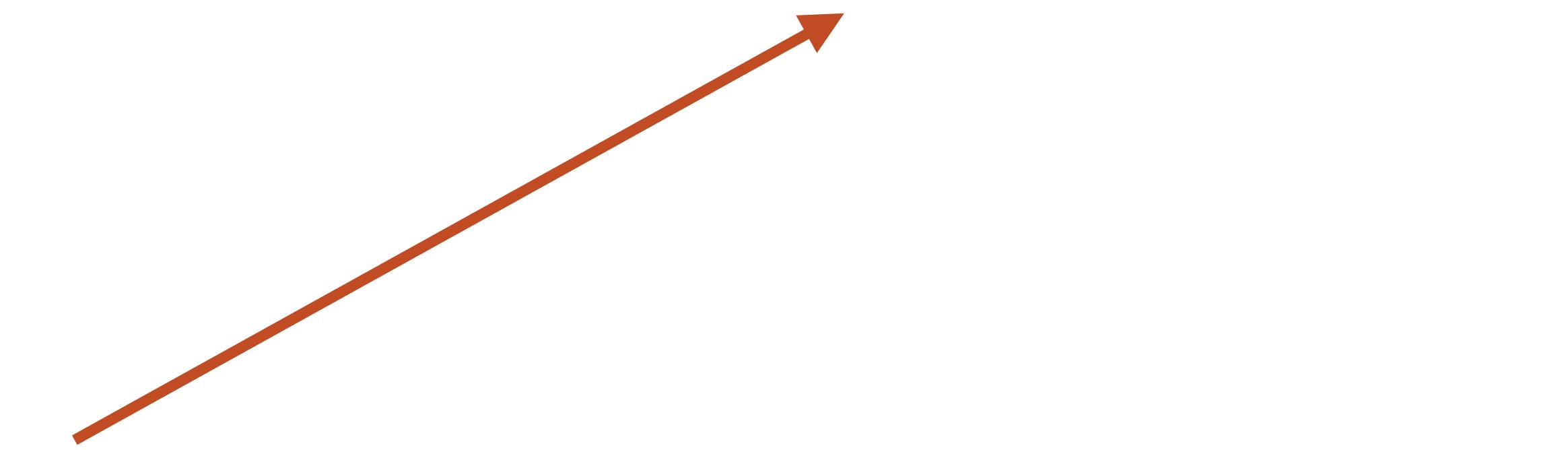
People learn the meaning of gavagai from other people



$$P(H_{i+1} | D_i) \propto P(D_i | H_i) P(H_i)$$

Pressures on the meanings of words

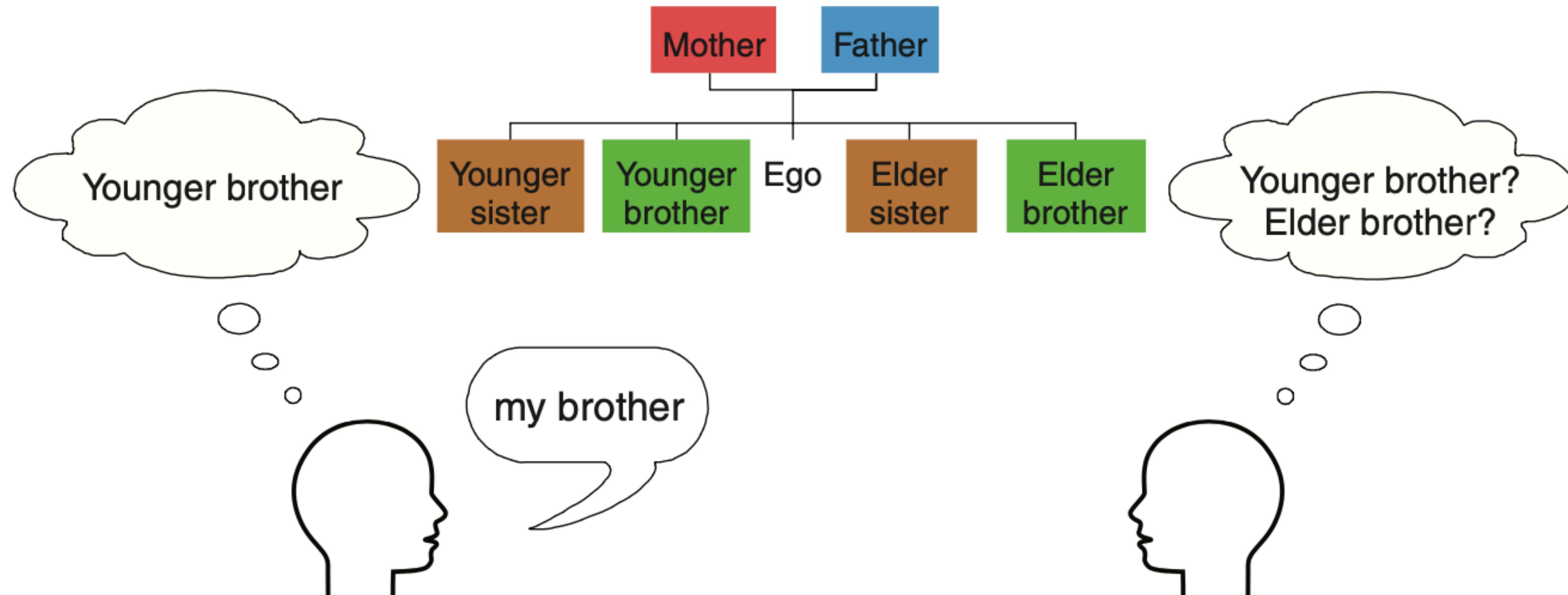
$$P(H_{i+1} | D_i) \propto P(D_i | H_i) P(H_i)$$



Informative:
Languages should be
useful for referring

Simple: Languages
should be easy to learn

The structure of kinship terms (Kemp & Regier, 2012)



Defining kinship systems

Primitives

FEMALE(·)

MALE(·)

PARENT(·, ·)

CHILD(·, ·)

OLDER(·, ·)

YOUNGER(·, ·)

SAMESEX(·, ·)

DIFFSEX(·, ·)

Rewrite rules

$C(x, y) \leftrightarrow A(x, y) \wedge B(x)$

$C(x, y) \leftrightarrow A(x, y) \wedge B(y)$

$C(x, y) \leftrightarrow A(x, y) \wedge B(x, y)$

$C(x, y) \leftrightarrow A(x, y) \vee B(x)$

$C(x, y) \leftrightarrow A(x, y) \vee B(y)$

$C(x, y) \leftrightarrow A(x, y) \vee B(x, y)$

$C(x, y) \leftrightarrow \exists z A(x, z) \wedge B(z, y)$

$C(x, y) \leftrightarrow A(y, x)$

$C(x, y) \leftrightarrow A^{\leftrightarrow}(x, y)$

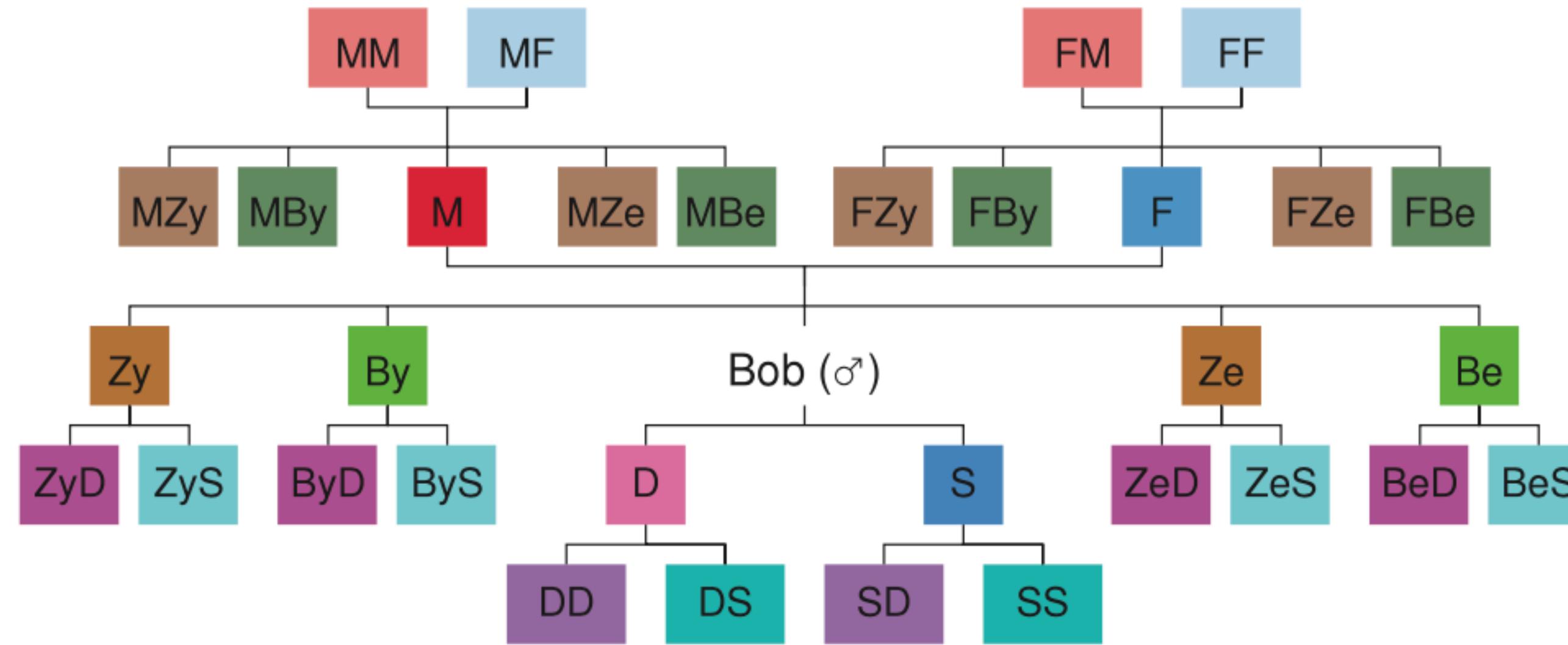
$C(x, y) \leftrightarrow A^{+}(x, y)$

Daughter

Grandmother

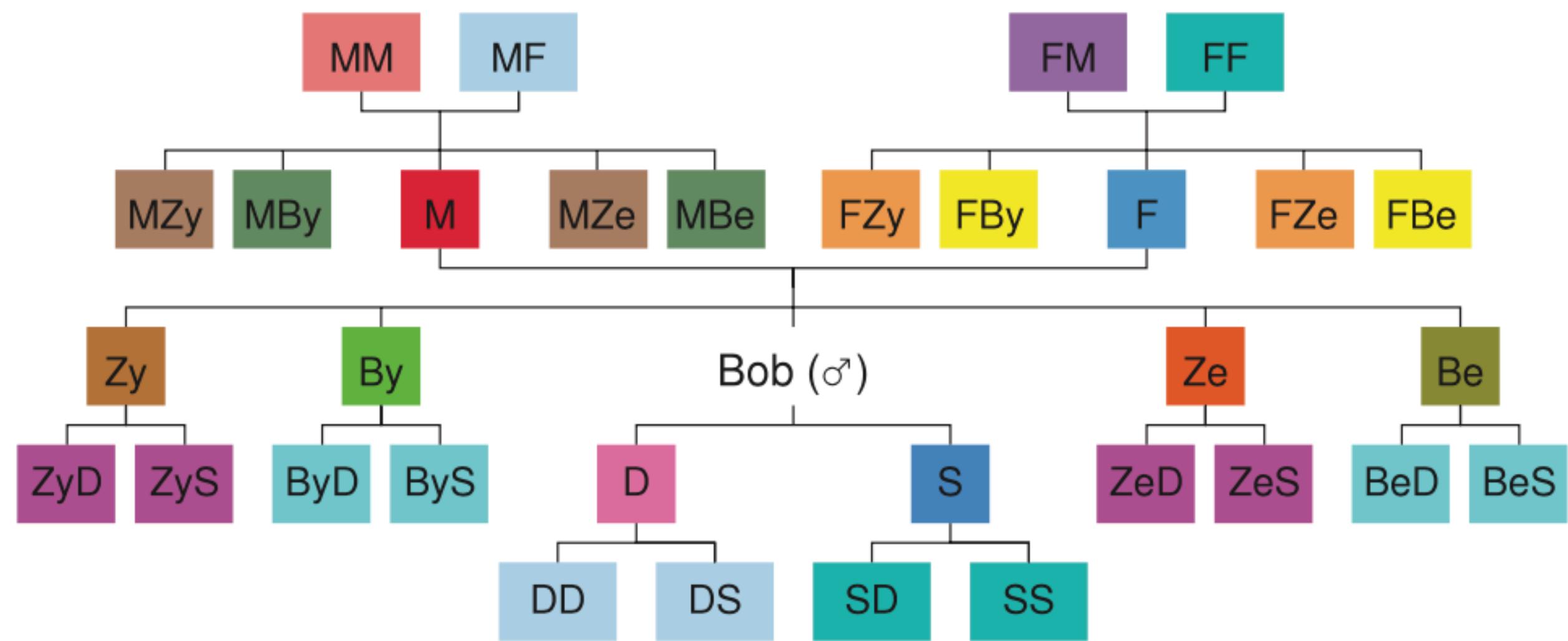
Uncle

The kinship structure of English



■	mother(x, y)	$\leftrightarrow \text{PARENT}(x, y) \wedge \text{FEMALE}(x)$
■	father(x, y)	$\leftrightarrow \text{PARENT}(x, y) \wedge \text{MALE}(x)$
■	daughter(x, y)	$\leftrightarrow \text{CHILD}(x, y) \wedge \text{FEMALE}(x)$
■	son(x, y)	$\leftrightarrow \text{CHILD}(x, y) \wedge \text{MALE}(x)$
■	sister(x, y)	$\leftrightarrow \exists z \text{ daughter}(x, z) \wedge \text{PARENT}(z, y)$
■	brother(x, y)	$\leftrightarrow \exists z \text{ son}(x, z) \wedge \text{PARENT}(z, y)$
	sibling(x, y)	$\leftrightarrow \exists z \text{ CHILD}(x, z) \wedge \text{PARENT}(z, y)$
■	aunt(x, y)	$\leftrightarrow \exists z \text{ sister}(x, z) \wedge \text{PARENT}(z, y)$
■	uncle(x, y)	$\leftrightarrow \exists z \text{ brother}(x, z) \wedge \text{PARENT}(z, y)$
■	niece(x, y)	$\leftrightarrow \exists z \text{ daughter}(x, z) \wedge \text{sibling}(z, y)$
■	nephew(x, y)	$\leftrightarrow \exists z \text{ son}(x, z) \wedge \text{sibling}(z, y)$
■	grandmother(x, y)	$\leftrightarrow \exists z \text{ mother}(x, z) \wedge \text{PARENT}(z, y)$
■	grandfather(x, y)	$\leftrightarrow \exists z \text{ father}(x, z) \wedge \text{PARENT}(z, y)$
■	granddaughter(x, y)	$\leftrightarrow \exists z \text{ daughter}(x, z) \wedge \text{CHILD}(z, y)$
■	grandson(x, y)	$\leftrightarrow \exists z \text{ son}(x, z) \wedge \text{CHILD}(z, y)$

The kinship structure of Northern Paiute



$\text{mother}(x, y)$	$\leftrightarrow \text{PARENT}(x, y) \wedge \text{FEMALE}(x)$
$\text{father}(x, y)$	$\leftrightarrow \text{PARENT}(x, y) \wedge \text{MALE}(x)$
$\text{daughter}(x, y)$	$\leftrightarrow \text{CHILD}(x, y) \wedge \text{FEMALE}(x)$
$\text{son}(x, y)$	$\leftrightarrow \text{CHILD}(x, y) \wedge \text{MALE}(x)$
$\text{sister}(x, y)$	$\leftrightarrow \exists z \text{ daughter}(x, z) \wedge \text{PARENT}(z, y)$
$\text{brother}(x, y)$	$\leftrightarrow \exists z \text{ son}(x, z) \wedge \text{PARENT}(z, y)$
$\text{youngersister}(x, y)$	$\leftrightarrow \text{sister}(x, y) \wedge \text{YOUNGER}(x, y)$
$\text{oldersister}(x, y)$	$\leftrightarrow \text{sister}(x, y) \wedge \text{OLDER}(x, y)$
$\text{youngerbros}(x, y)$	$\leftrightarrow \text{brother}(x, y) \wedge \text{YOUNGER}(x, y)$
$\text{olderbros}(x, y)$	$\leftrightarrow \text{brother}(x, y) \wedge \text{OLDER}(x, y)$
$\text{maternalauant}(x, y)$	$\leftrightarrow \exists z \text{ sister}(x, z) \wedge \text{mother}(z, y)$
$\text{maternaluncle}(x, y)$	$\leftrightarrow \exists z \text{ brother}(x, z) \wedge \text{mother}(z, y)$
$\text{paternalauant}(x, y)$	$\leftrightarrow \exists z \text{ sister}(x, z) \wedge \text{father}(z, y)$
$\text{paternaluncle}(x, y)$	$\leftrightarrow \exists z \text{ brother}(x, z) \wedge \text{father}(z, y)$
$\text{mansisterchild}(x, y)$	$\leftrightarrow \text{maternaluncle}(y, x)$
$\text{manbrotherchild}(x, y)$	$\leftrightarrow \text{paternaluncle}(y, x)$
$\text{maternalgrandmother}(x, y)$	$\leftrightarrow \exists z \text{ mother}(x, z) \wedge \text{mother}(z, y)$
$\text{maternalgrandfather}(x, y)$	$\leftrightarrow \exists z \text{ father}(x, z) \wedge \text{mother}(z, y)$
$\text{paternalgrandmother}(x, y)$	$\leftrightarrow \exists z \text{ mother}(x, z) \wedge \text{father}(z, y)$
$\text{paternalgrandfather}(x, y)$	$\leftrightarrow \exists z \text{ father}(x, z) \wedge \text{father}(z, y)$
$\text{selfreciprocal1}(x, y)$	$\leftrightarrow \text{maternalgrandmother}^{\leftrightarrow}(x, y)$
$\text{selfreciprocal2}(x, y)$	$\leftrightarrow \text{maternalgrandfather}^{\leftrightarrow}(x, y)$
$\text{selfreciprocal3}(x, y)$	$\leftrightarrow \text{paternalgrandmother}^{\leftrightarrow}(x, y)$
$\text{selfreciprocal4}(x, y)$	$\leftrightarrow \text{paternalgrandfather}^{\leftrightarrow}(x, y)$

How (and why) are these systems different?

	mother(x, y)	$\leftrightarrow \text{PARENT}(x, y) \wedge \text{FEMALE}(x)$
	father(x, y)	$\leftrightarrow \text{PARENT}(x, y) \wedge \text{MALE}(x)$
	daughter(x, y)	$\leftrightarrow \text{CHILD}(x, y) \wedge \text{FEMALE}(x)$
	son(x, y)	$\leftrightarrow \text{CHILD}(x, y) \wedge \text{MALE}(x)$
	sister(x, y)	$\leftrightarrow \exists z \text{ daughter}(x, z) \wedge \text{PARENT}(z, y)$
	brother(x, y)	$\leftrightarrow \exists z \text{ son}(x, z) \wedge \text{PARENT}(z, y)$
	sibling(x, y)	$\leftrightarrow \exists z \text{ CHILD}(x, z) \wedge \text{PARENT}(z, y)$
	aunt(x, y)	$\leftrightarrow \exists z \text{ sister}(x, z) \wedge \text{PARENT}(z, y)$
	uncle(x, y)	$\leftrightarrow \exists z \text{ brother}(x, z) \wedge \text{PARENT}(z, y)$
	niece(x, y)	$\leftrightarrow \exists z \text{ daughter}(x, z) \wedge \text{sibling}(z, y)$
	nephew(x, y)	$\leftrightarrow \exists z \text{ son}(x, z) \wedge \text{sibling}(z, y)$
	grandmother(x, y)	$\leftrightarrow \exists z \text{ mother}(x, z) \wedge \text{PARENT}(z, y)$
	grandfather(x, y)	$\leftrightarrow \exists z \text{ father}(x, z) \wedge \text{PARENT}(z, y)$
	granddaughter(x, y)	$\leftrightarrow \exists z \text{ daughter}(x, z) \wedge \text{CHILD}(z, y)$
	grandson(x, y)	$\leftrightarrow \exists z \text{ son}(x, z) \wedge \text{CHILD}(z, y)$

	mother(x, y)	$\leftrightarrow \text{PARENT}(x, y) \wedge \text{FEMALE}(x)$
	father(x, y)	$\leftrightarrow \text{PARENT}(x, y) \wedge \text{MALE}(x)$
	daughter(x, y)	$\leftrightarrow \text{CHILD}(x, y) \wedge \text{FEMALE}(x)$
	son(x, y)	$\leftrightarrow \text{CHILD}(x, y) \wedge \text{MALE}(x)$
	sister(x, y)	$\leftrightarrow \exists z \text{ daughter}(x, z) \wedge \text{PARENT}(z, y)$
	brother(x, y)	$\leftrightarrow \exists z \text{ son}(x, z) \wedge \text{PARENT}(z, y)$
	youngersister(x, y)	$\leftrightarrow \text{sister}(x, y) \wedge \text{YOUNGER}(x, y)$
	oldersister(x, y)	$\leftrightarrow \text{sister}(x, y) \wedge \text{OLDER}(x, y)$
	youngbrother(x, y)	$\leftrightarrow \text{brother}(x, y) \wedge \text{YOUNGER}(x, y)$
	olderbrother(x, y)	$\leftrightarrow \text{brother}(x, y) \wedge \text{OLDER}(x, y)$
	maternalauant(x, y)	$\leftrightarrow \exists z \text{ sister}(x, z) \wedge \text{mother}(z, y)$
	maternaluncle(x, y)	$\leftrightarrow \exists z \text{ brother}(x, z) \wedge \text{mother}(z, y)$
	paternalauant(x, y)	$\leftrightarrow \exists z \text{ sister}(x, z) \wedge \text{father}(z, y)$
	paternaluncle(x, y)	$\leftrightarrow \exists z \text{ brother}(x, z) \wedge \text{father}(z, y)$
	mansisterchild(x, y)	$\leftrightarrow \text{maternaluncle}(y, x)$
	manbrotherchild(x, y)	$\leftrightarrow \text{paternaluncle}(y, x)$
	maternalgrandmother(x, y)	$\leftrightarrow \exists z \text{ mother}(x, z) \wedge \text{mother}(z, y)$
	maternalgrandfather(x, y)	$\leftrightarrow \exists z \text{ father}(x, z) \wedge \text{mother}(z, y)$
	paternalgrandmother(x, y)	$\leftrightarrow \exists z \text{ mother}(x, z) \wedge \text{father}(z, y)$
	paternalgrandfather(x, y)	$\leftrightarrow \exists z \text{ father}(x, z) \wedge \text{father}(z, y)$
	selfreciprocal1(x, y)	$\leftrightarrow \text{maternalgrandmother}^{\leftrightarrow}(x, y)$
	selfreciprocal2(x, y)	$\leftrightarrow \text{maternalgrandfather}^{\leftrightarrow}(x, y)$
	selfreciprocal3(x, y)	$\leftrightarrow \text{paternalgrandmother}^{\leftrightarrow}(x, y)$
	selfreciprocal4(x, y)	$\leftrightarrow \text{paternalgrandfather}^{\leftrightarrow}(x, y)$

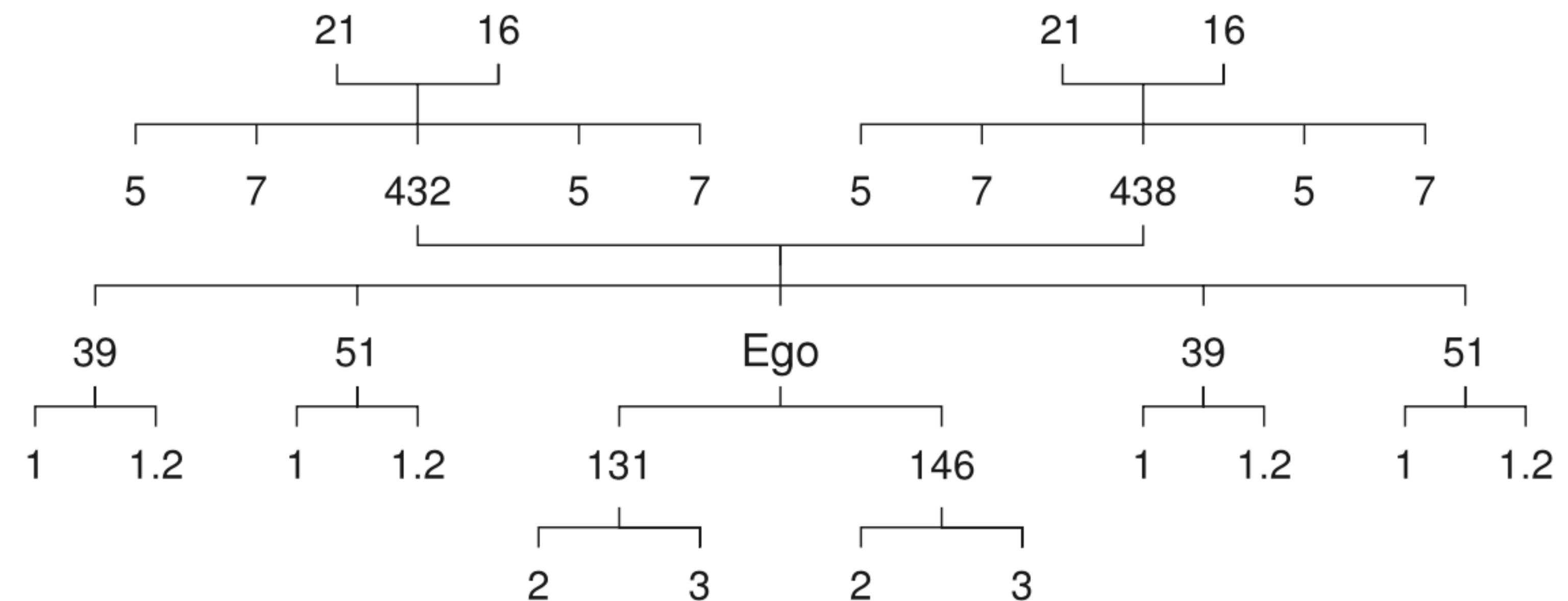
Two competing tradeoffs: Informativeness and simplicity

Informativeness

The cost of referring is proportional to the ambiguity of reference (e.g. how many people could be your “uncle”)

$$c_i = \frac{p_i}{\sum_{z_j=z_i} p_j}$$

$$C = \sum_{i=1}^{24} p_i c_i$$



Two competing tradeoffs: Informativeness and simplicity

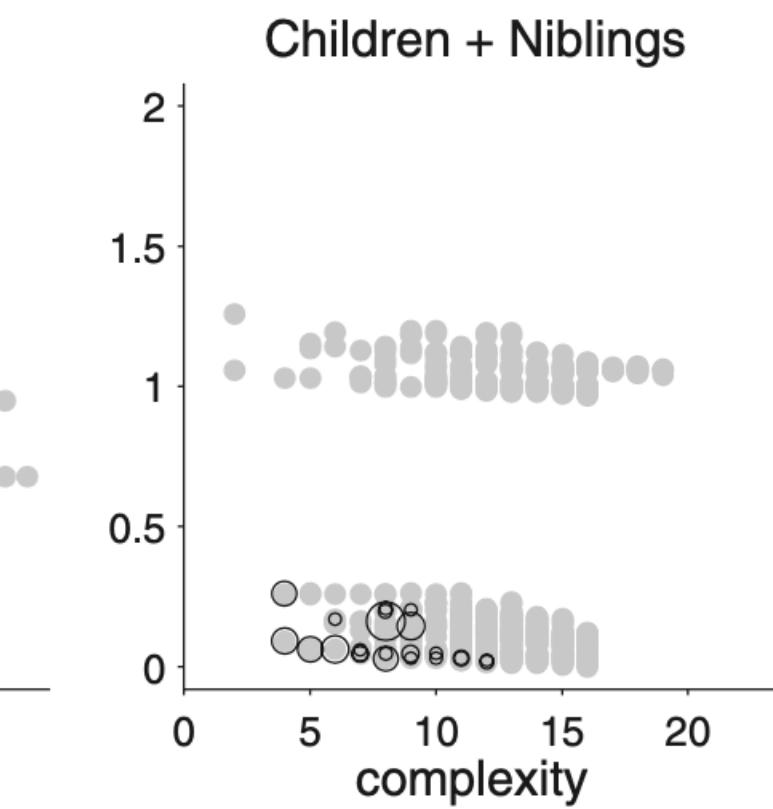
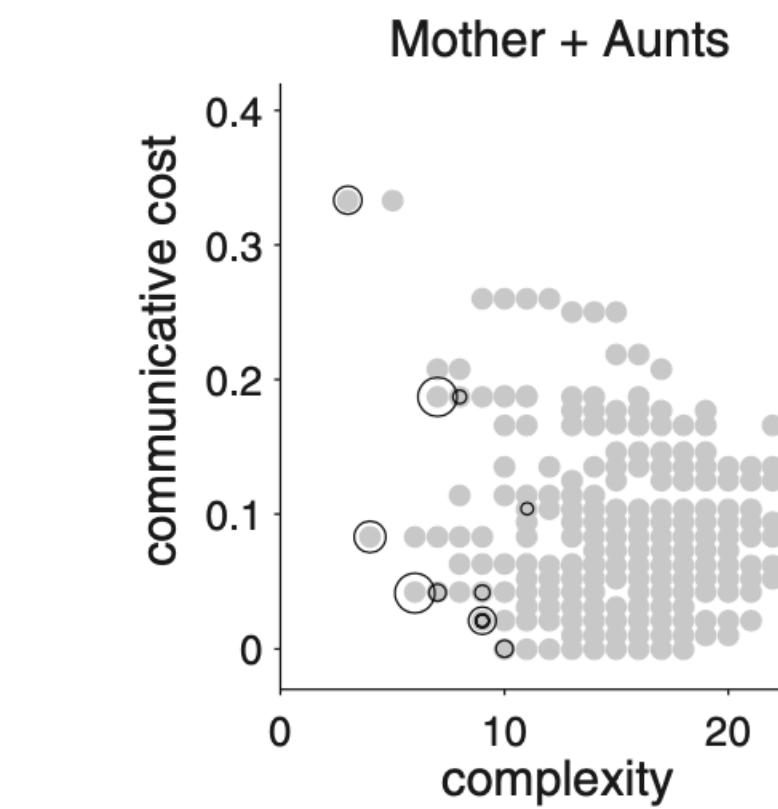
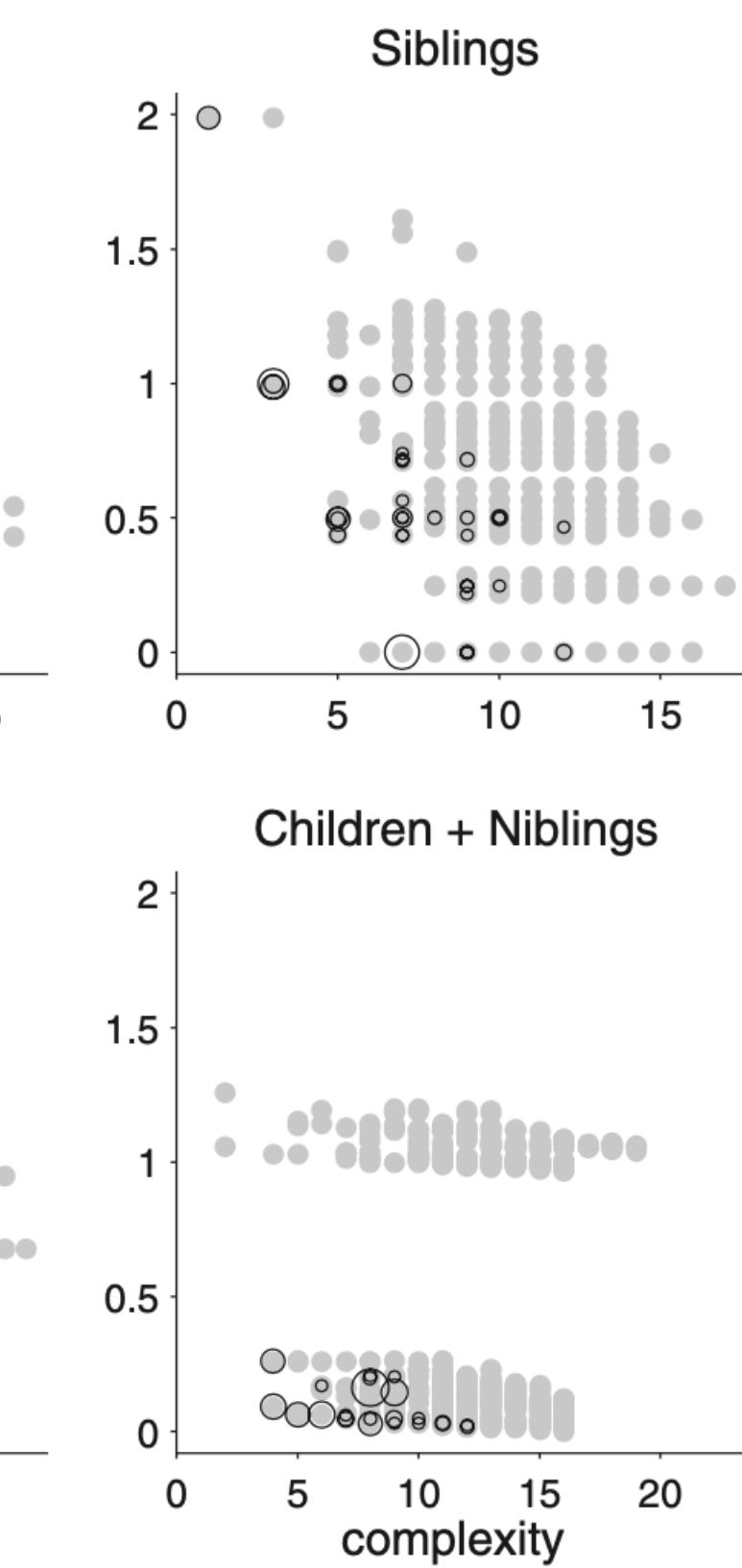
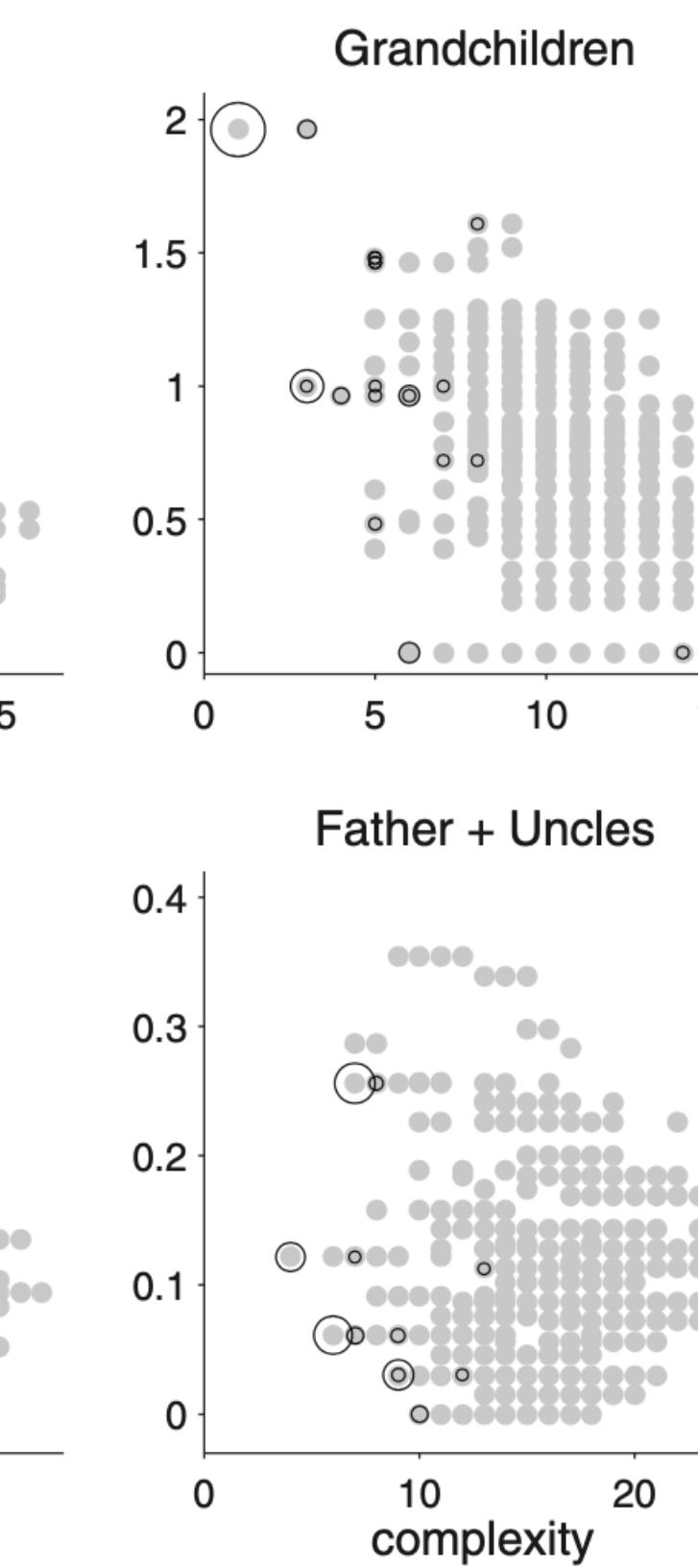
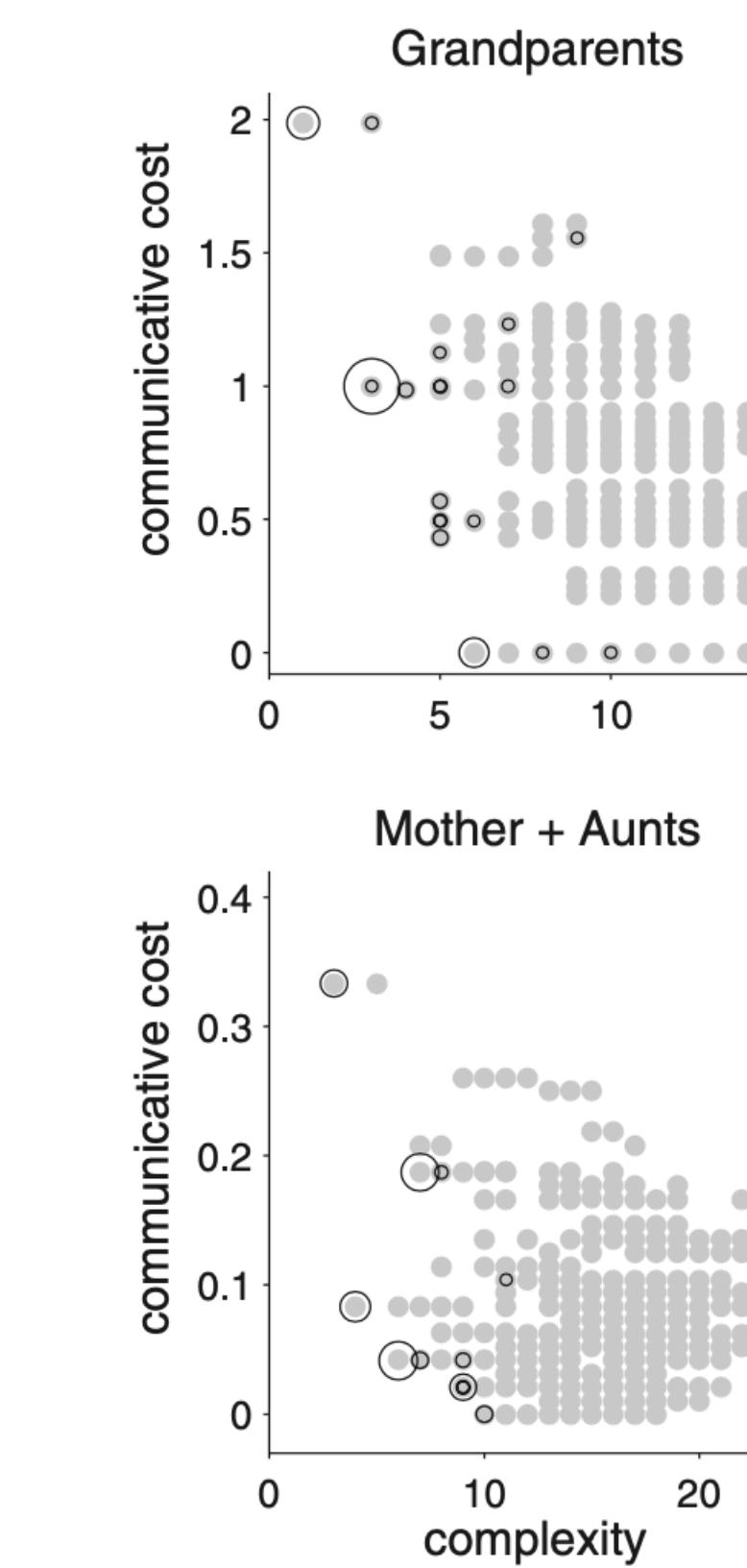
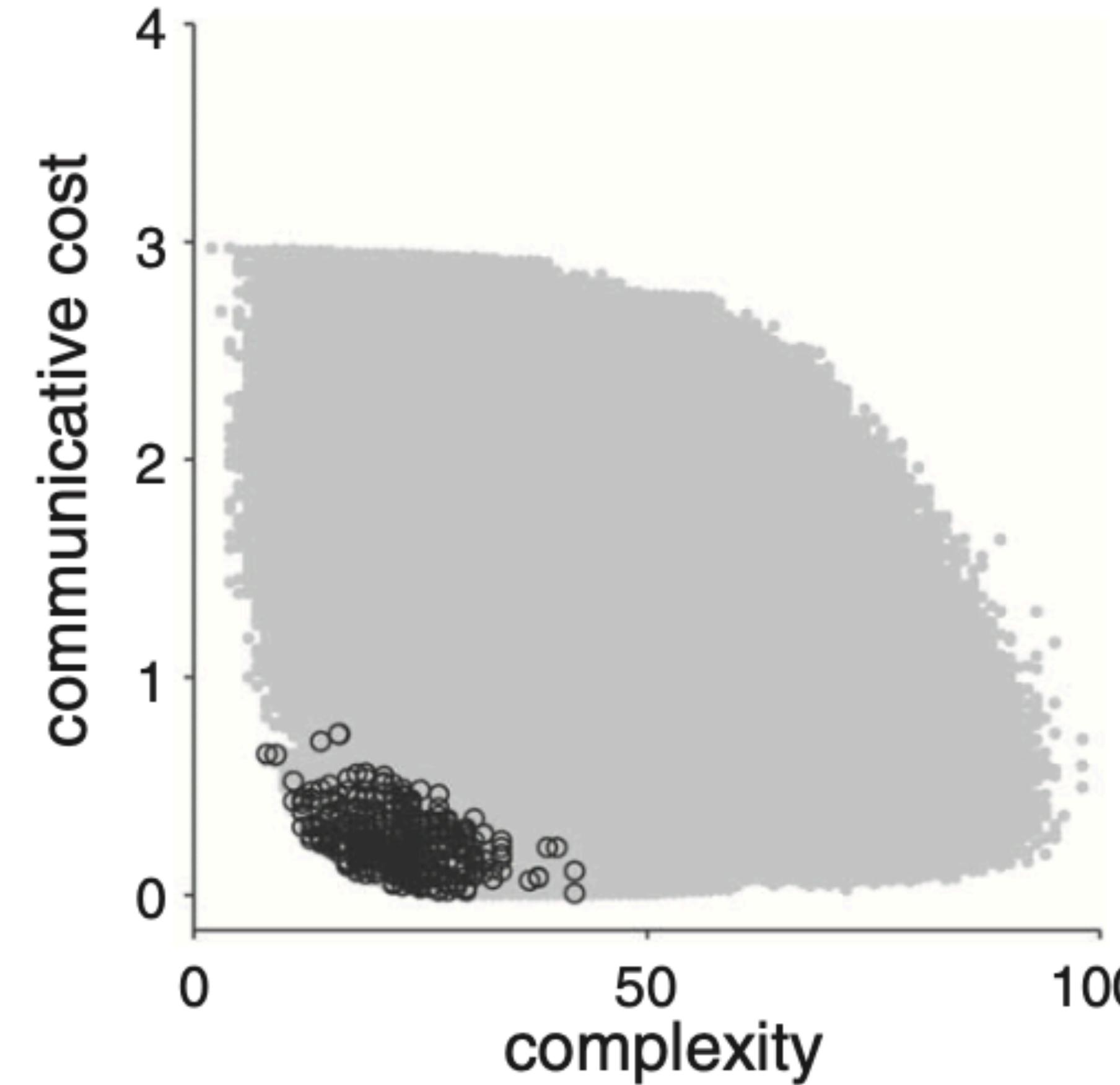
Simplicity

The cost of learning a language is proportional to how many rules it has

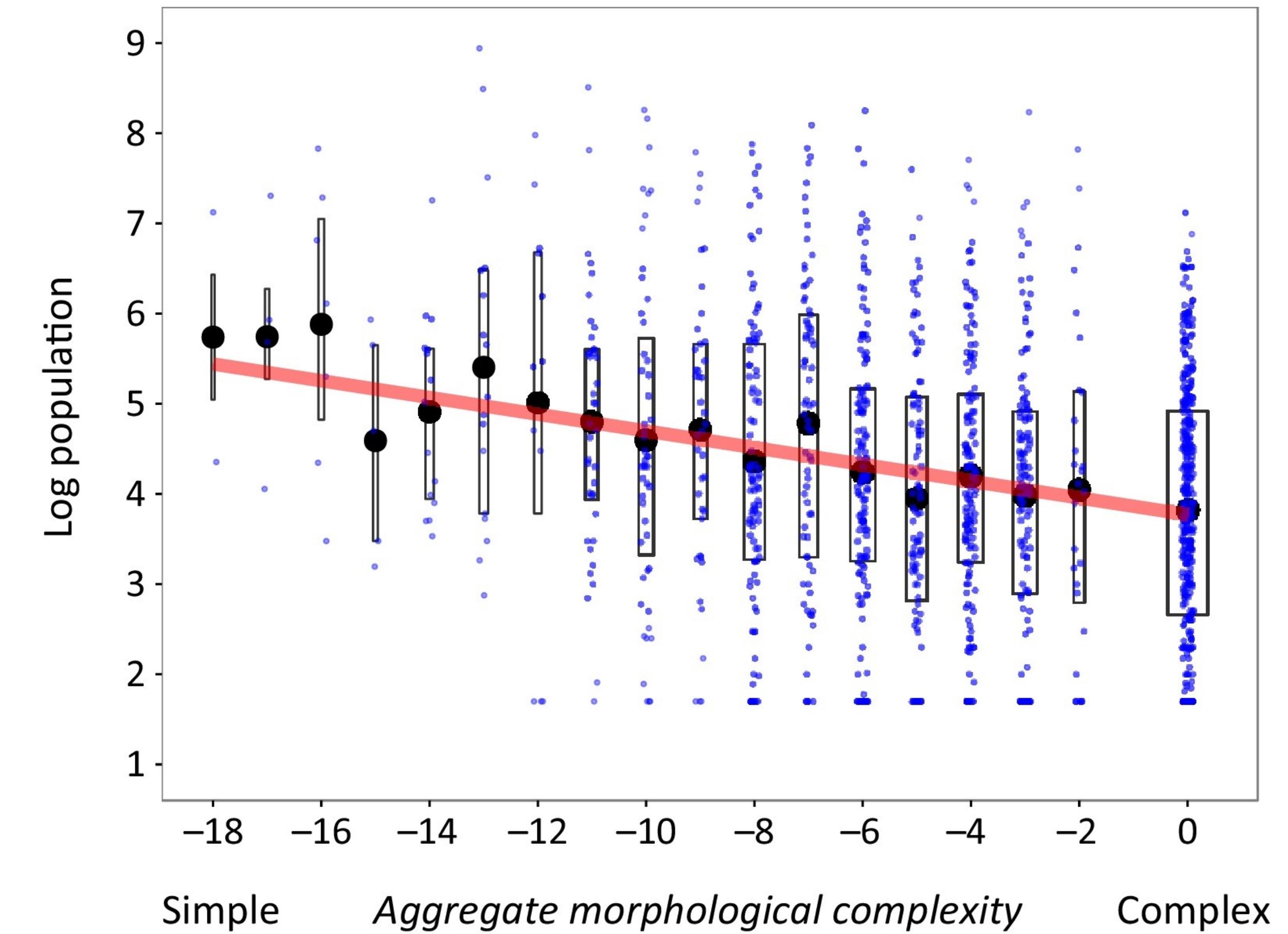
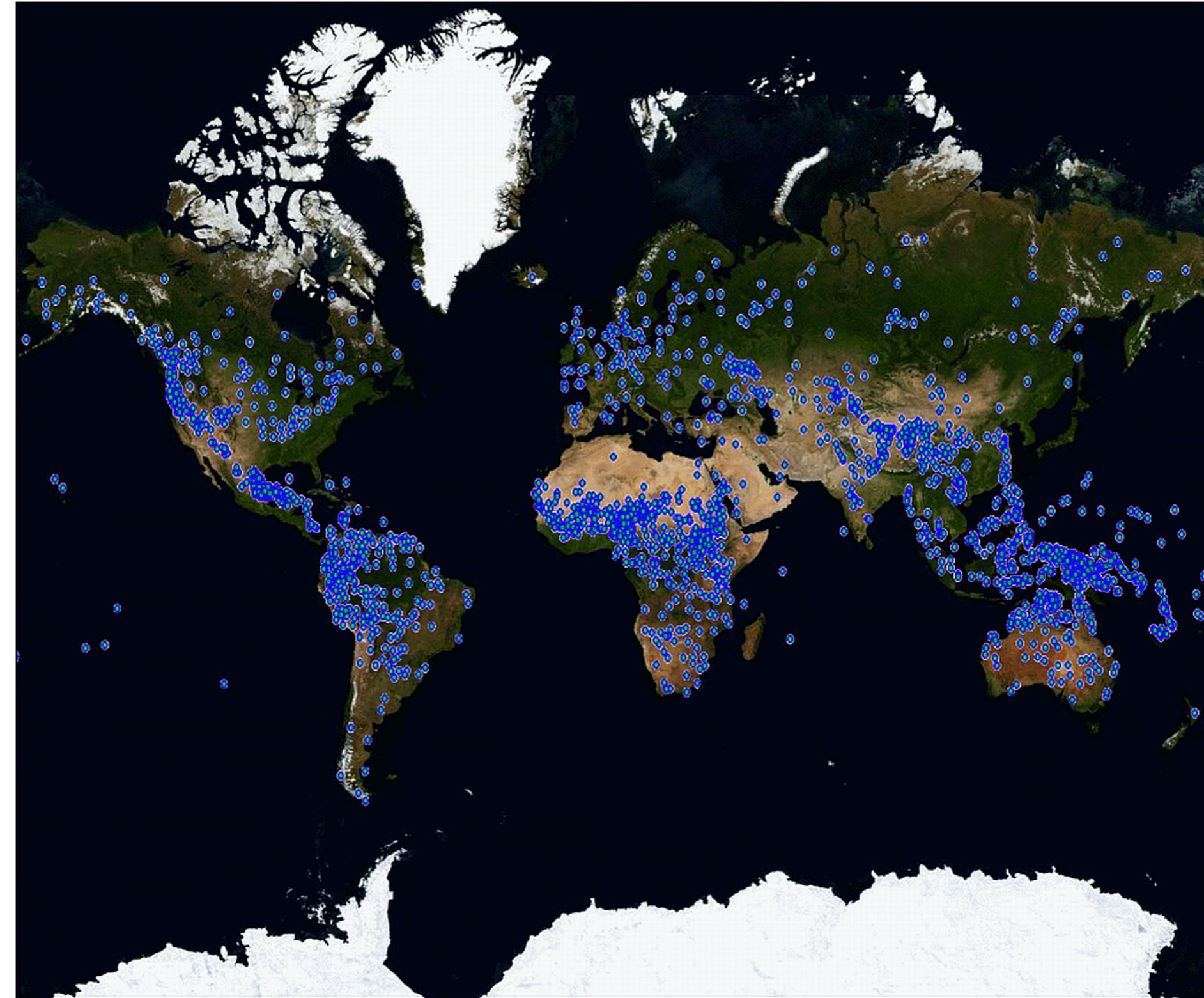
mother(x, y)	$\leftrightarrow \text{PARENT}(x, y) \wedge \text{FEMALE}(x)$
father(x, y)	$\leftrightarrow \text{PARENT}(x, y) \wedge \text{MALE}(x)$
daughter(x, y)	$\leftrightarrow \text{CHILD}(x, y) \wedge \text{FEMALE}(x)$
son(x, y)	$\leftrightarrow \text{CHILD}(x, y) \wedge \text{MALE}(x)$
sister(x, y)	$\leftrightarrow \exists z \text{ daughter}(x, z) \wedge \text{PARENT}(z, y)$
brother(x, y)	$\leftrightarrow \exists z \text{ son}(x, z) \wedge \text{PARENT}(z, y)$
sibling(x, y)	$\leftrightarrow \exists z \text{ CHILD}(x, z) \wedge \text{PARENT}(z, y)$
aunt(x, y)	$\leftrightarrow \exists z \text{ sister}(x, z) \wedge \text{PARENT}(z, y)$
uncle(x, y)	$\leftrightarrow \exists z \text{ brother}(x, z) \wedge \text{PARENT}(z, y)$
niece(x, y)	$\leftrightarrow \exists z \text{ daughter}(x, z) \wedge \text{sibling}(z, y)$
nephew(x, y)	$\leftrightarrow \exists z \text{ son}(x, z) \wedge \text{sibling}(z, y)$
grandmother(x, y)	$\leftrightarrow \exists z \text{ mother}(x, z) \wedge \text{PARENT}(z, y)$
grandfather(x, y)	$\leftrightarrow \exists z \text{ father}(x, z) \wedge \text{PARENT}(z, y)$
granddaughter(x, y)	$\leftrightarrow \exists z \text{ daughter}(x, z) \wedge \text{CHILD}(z, y)$
grandson(x, y)	$\leftrightarrow \exists z \text{ son}(x, z) \wedge \text{CHILD}(z, y)$

mother(x, y)	$\leftrightarrow \text{PARENT}(x, y) \wedge \text{FEMALE}(x)$
father(x, y)	$\leftrightarrow \text{PARENT}(x, y) \wedge \text{MALE}(x)$
daughter(x, y)	$\leftrightarrow \text{CHILD}(x, y) \wedge \text{FEMALE}(x)$
son(x, y)	$\leftrightarrow \text{CHILD}(x, y) \wedge \text{MALE}(x)$
sister(x, y)	$\leftrightarrow \exists z \text{ daughter}(x, z) \wedge \text{PARENT}(z, y)$
brother(x, y)	$\leftrightarrow \exists z \text{ son}(x, z) \wedge \text{PARENT}(z, y)$
youngersister(x, y)	$\leftrightarrow \text{sister}(x, y) \wedge \text{YOUNGER}(x, y)$
oldersister(x, y)	$\leftrightarrow \text{sister}(x, y) \wedge \text{OLDER}(x, y)$
youngerbrother(x, y)	$\leftrightarrow \text{brother}(x, y) \wedge \text{YOUNGER}(x, y)$
olderbrother(x, y)	$\leftrightarrow \text{brother}(x, y) \wedge \text{OLDER}(x, y)$
maternalauant(x, y)	$\leftrightarrow \exists z \text{ sister}(x, z) \wedge \text{mother}(z, y)$
maternaluncle(x, y)	$\leftrightarrow \exists z \text{ brother}(x, z) \wedge \text{mother}(z, y)$
paternalauant(x, y)	$\leftrightarrow \exists z \text{ sister}(x, z) \wedge \text{father}(z, y)$
paternaluncle(x, y)	$\leftrightarrow \exists z \text{ brother}(x, z) \wedge \text{father}(z, y)$
mansisterchild(x, y)	$\leftrightarrow \text{maternaluncle}(y, x)$
manbrotherchild(x, y)	$\leftrightarrow \text{paternaluncle}(y, x)$
maternalgrandmother(x, y)	$\leftrightarrow \exists z \text{ mother}(x, z) \wedge \text{mother}(z, y)$
maternalgrandfather(x, y)	$\leftrightarrow \exists z \text{ father}(x, z) \wedge \text{mother}(z, y)$
paternalgrandmother(x, y)	$\leftrightarrow \exists z \text{ mother}(x, z) \wedge \text{father}(z, y)$
paternalgrandfather(x, y)	$\leftrightarrow \exists z \text{ father}(x, z) \wedge \text{father}(z, y)$
selfreciprocal1(x, y)	$\leftrightarrow \text{maternalgrandmother}^{\leftrightarrow}(x, y)$
selfreciprocal2(x, y)	$\leftrightarrow \text{maternalgrandfather}^{\leftrightarrow}(x, y)$
selfreciprocal3(x, y)	$\leftrightarrow \text{paternalgrandmother}^{\leftrightarrow}(x, y)$
selfreciprocal4(x, y)	$\leftrightarrow \text{paternalgrandfather}^{\leftrightarrow}(x, y)$

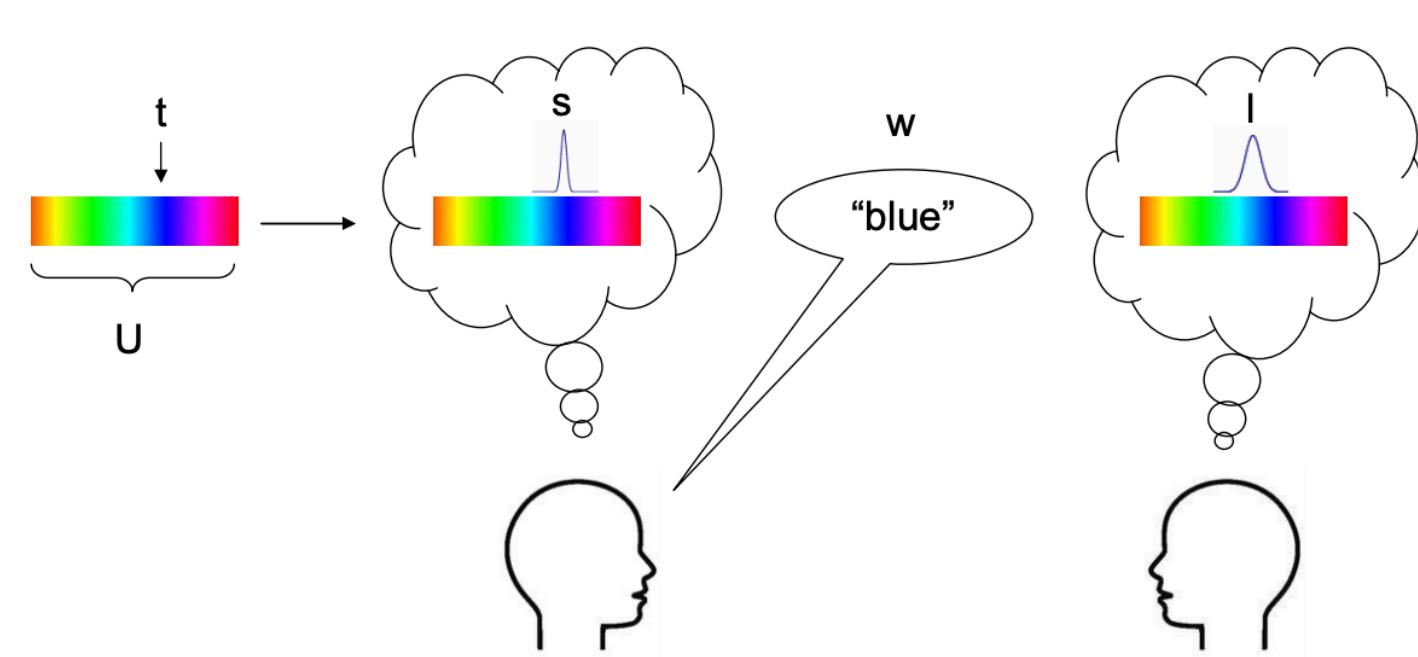
The world's kinship systems are near optimal!



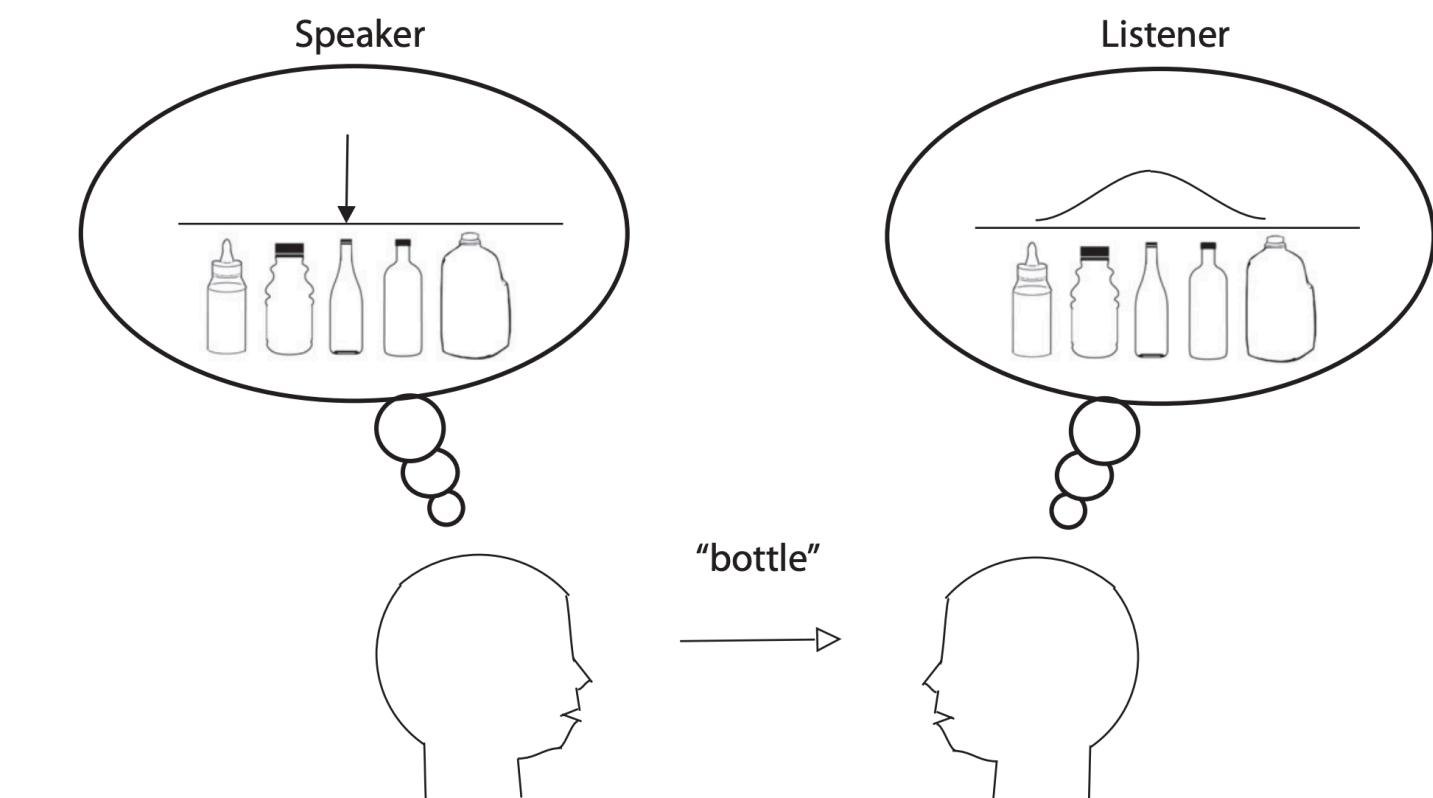
Population size predicts tradeoff (Dale & Lupyán, 2010)



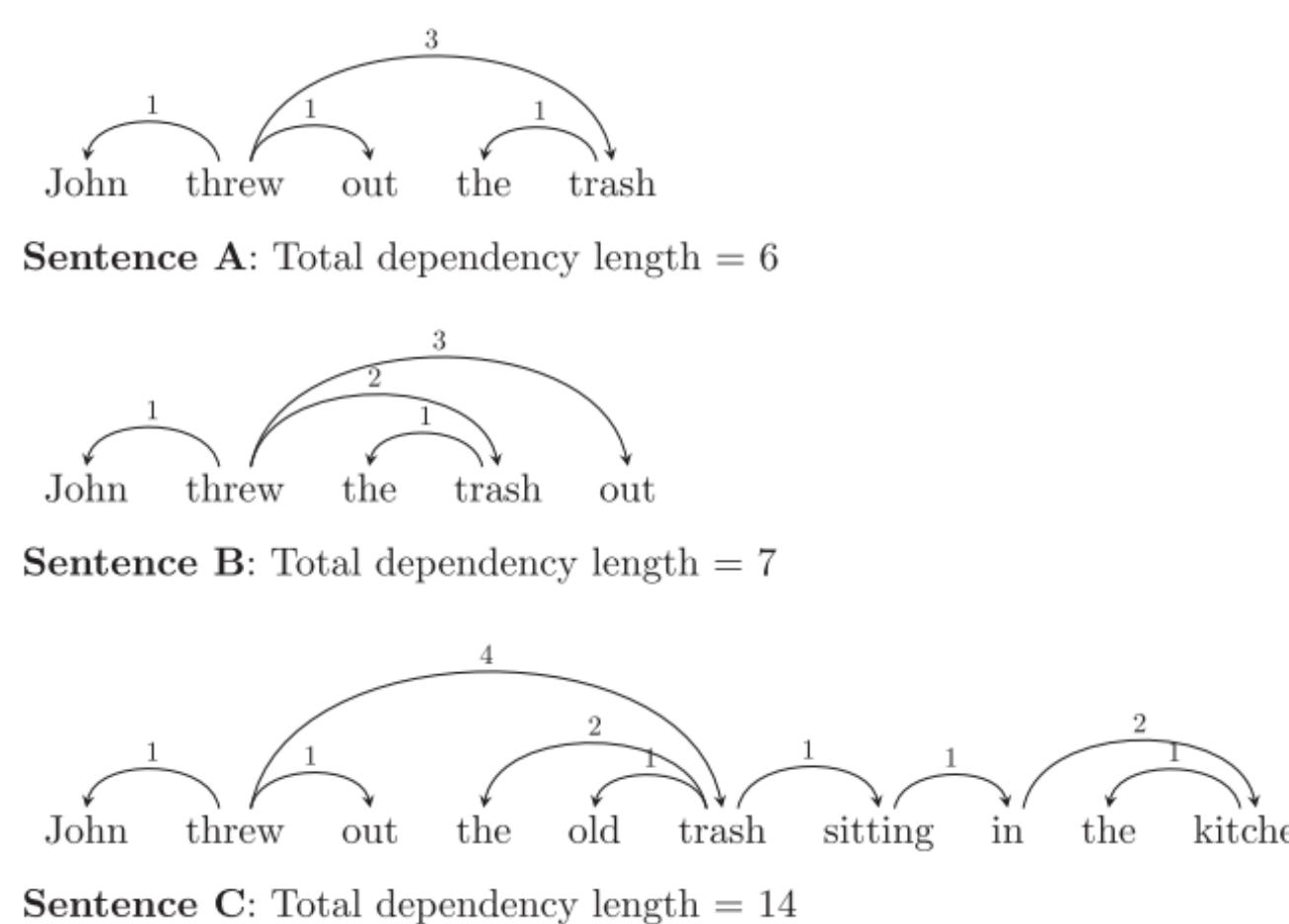
Other domains appear to operate under similar pressures



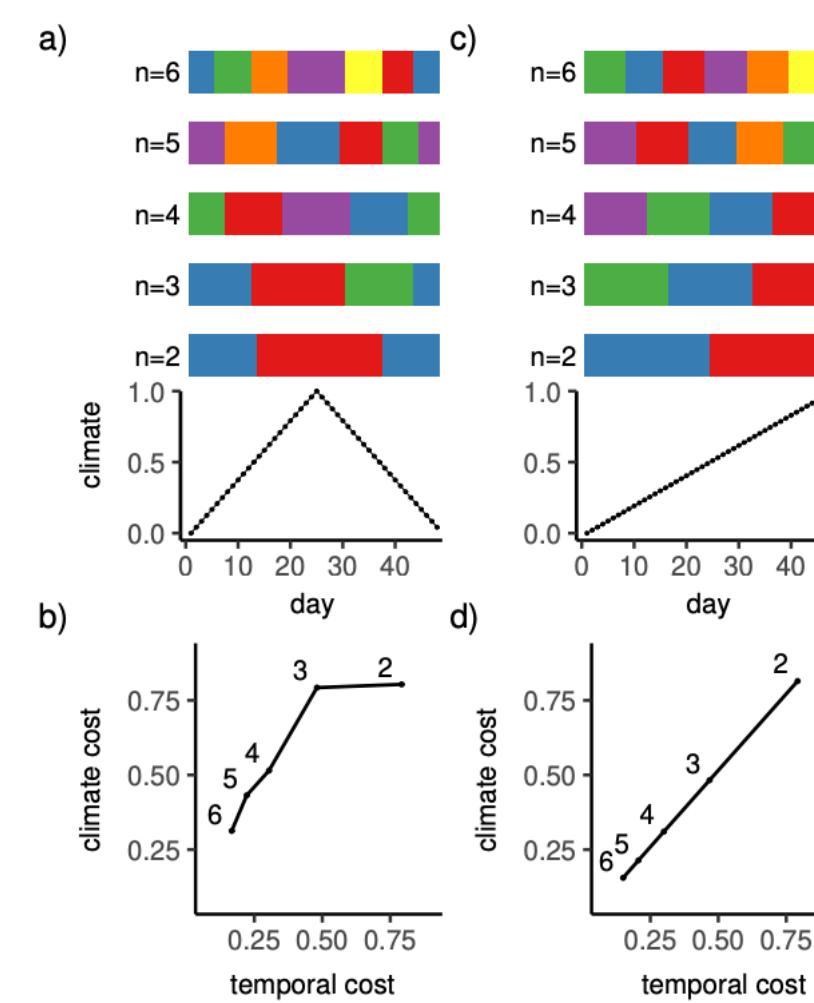
Regier et al. (2007)



Xu, Regier, & Malt (2016)



Futtrell et al. (2015)



Kemp et al. (2019)

Can we test this in the lab?



The iterated learning paradigm (Kirby, Cornish, & Smith 2008)

You come into the lab, and learn

:

You are shown the picture again,
and asked what it is called.

Sometimes, you make an **error**

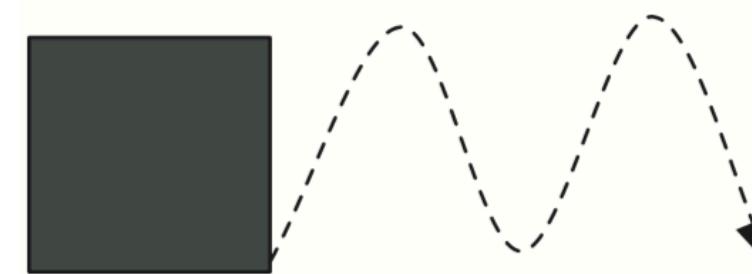
:

Your responses become the
learning stimuli for the
next participant

kihemiwi



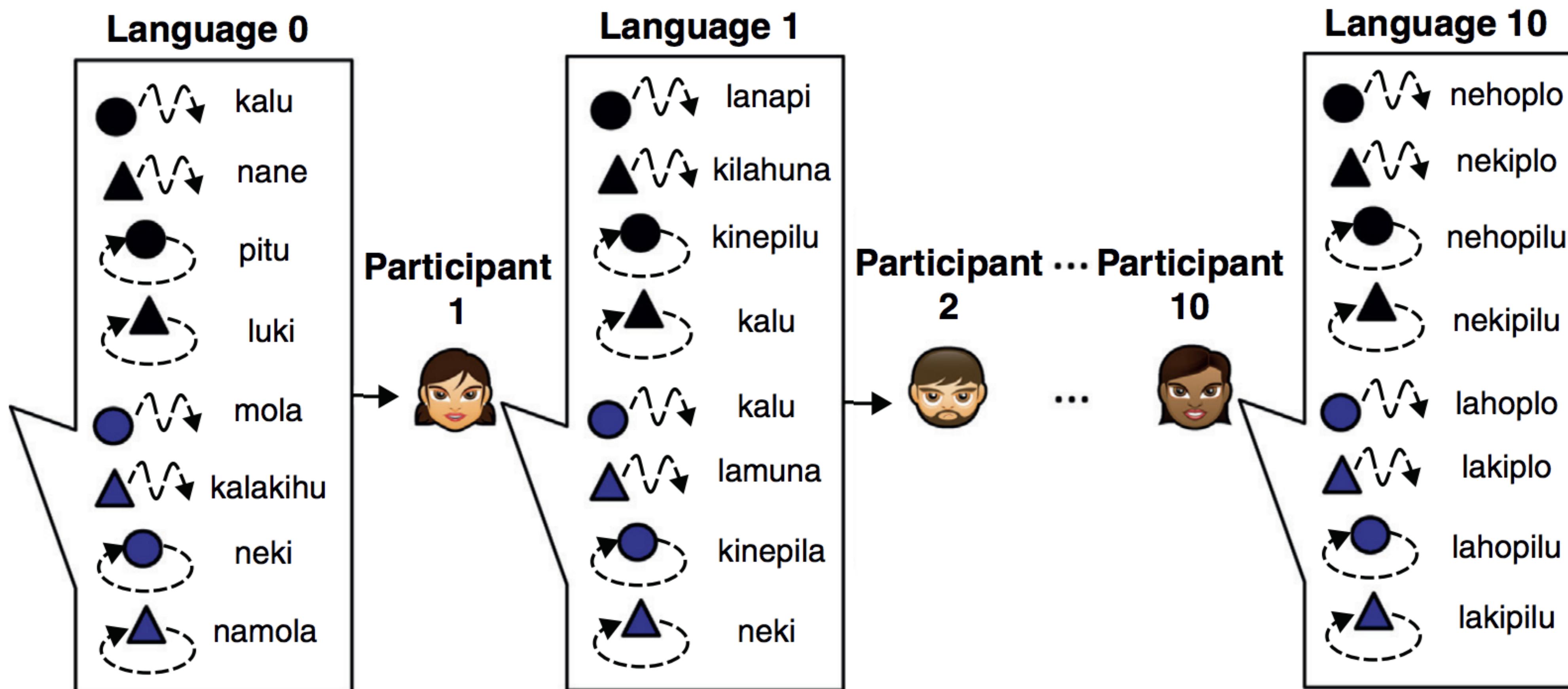
kihemo



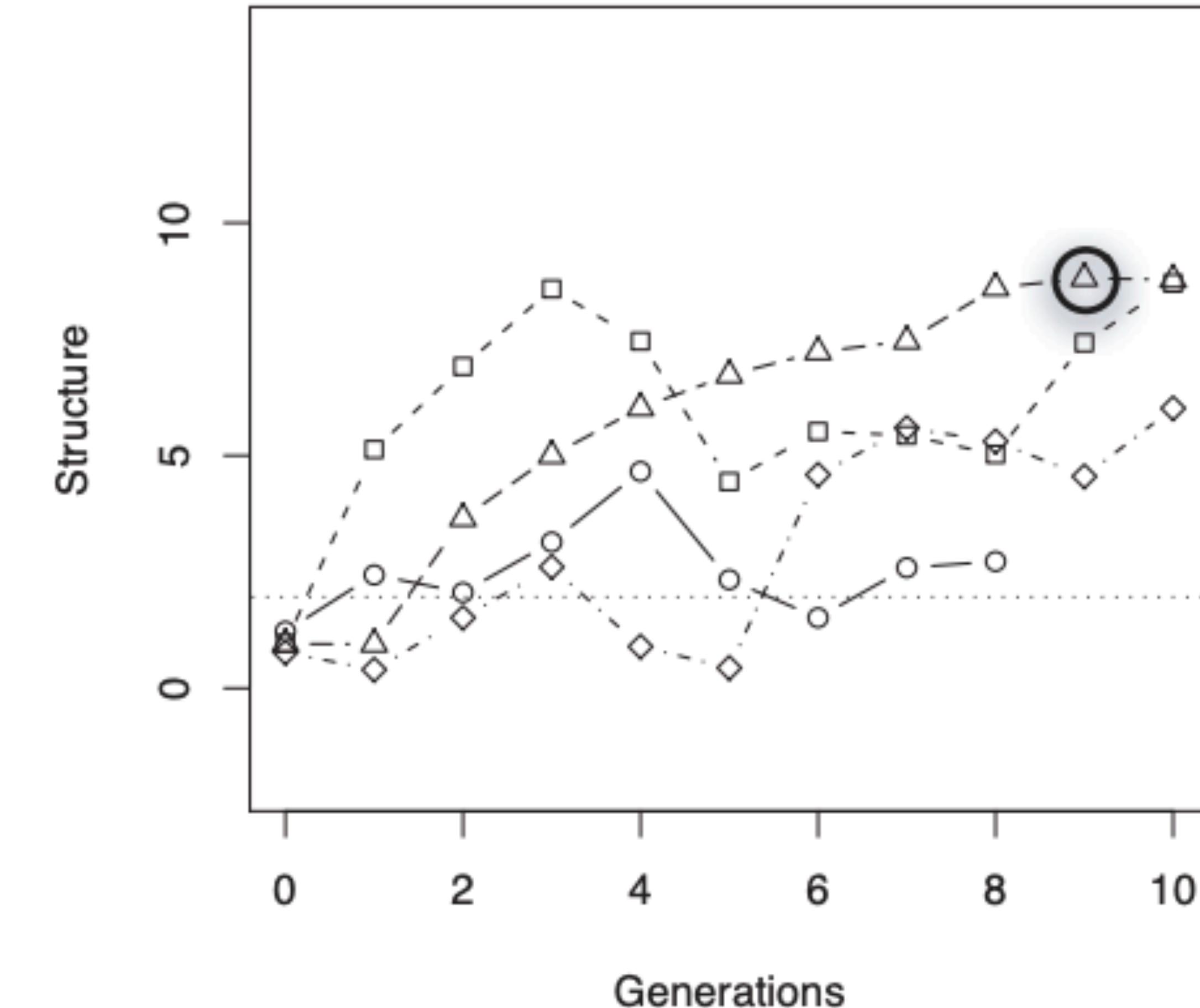
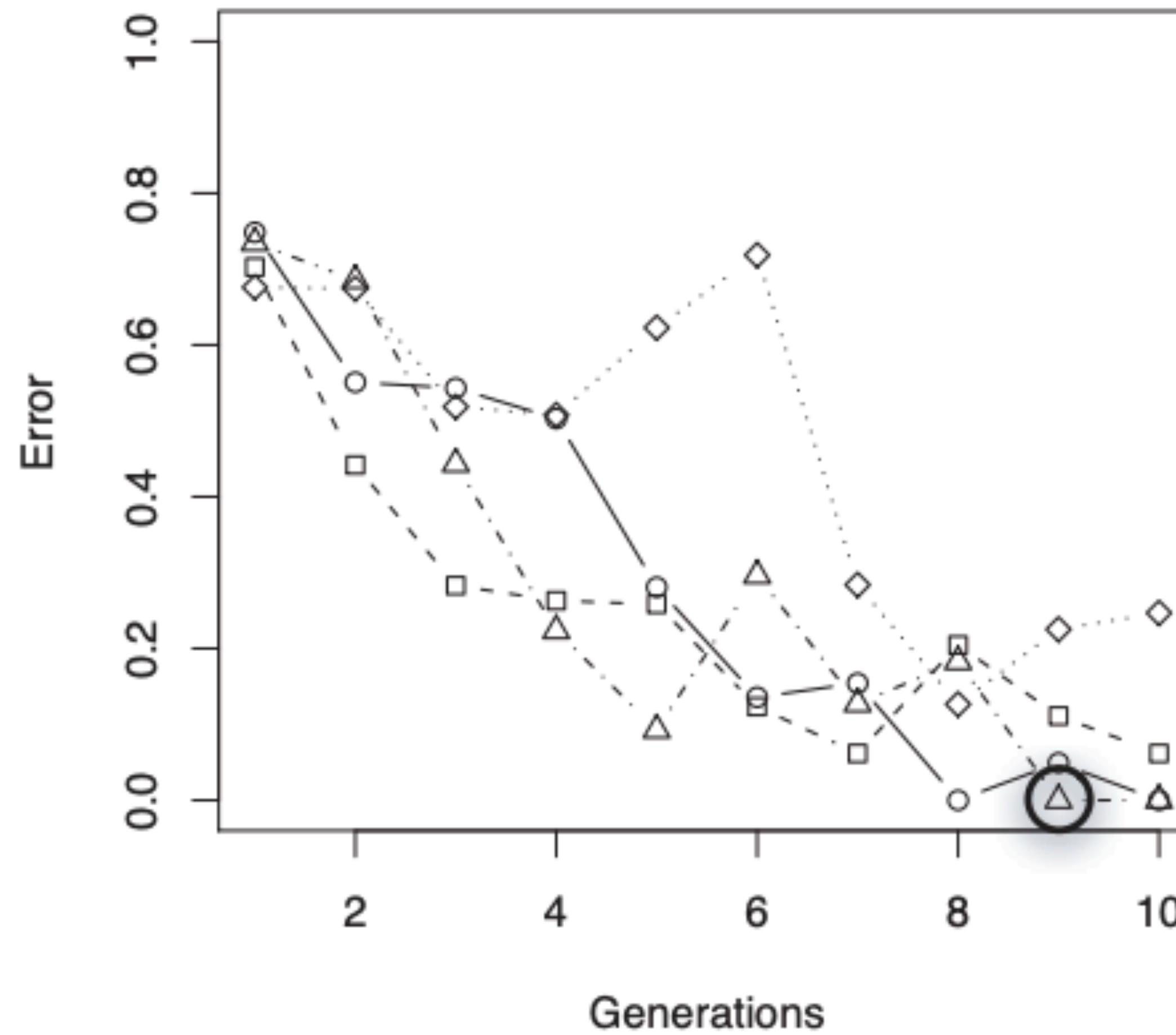
kihemo



The iterated learning paradigm (Kirby, Cornish, & Smith 2008)



Languages change over generations



After iterated learning



Table 1. Number of distinct words by generation in the first experiment

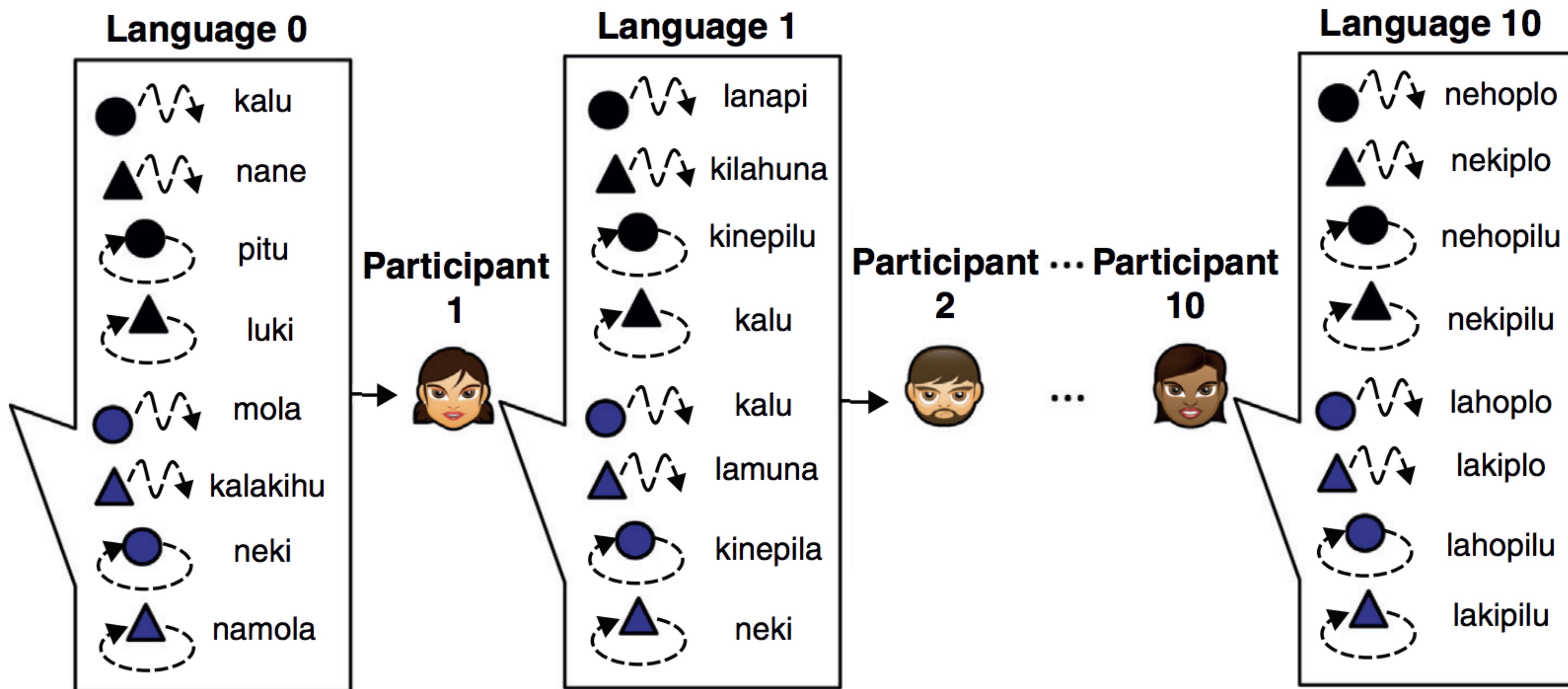
Generation	0	1	2	3	4	5	6	7	8	9	10
○ Chain 1	27	17	9	6	5	4	4	2	2	2	2
□ Chain 2	27	17	15	8	7	6	6	6	5	5	4
△ Chain 3	27	24	8	6	6	5	6	5	5	5	5
◊ Chain 4	27	23	9	10	9	11	7	5	5	4	4

Why do these languages degenerate?

Can we test this in the lab?



Removing ambiguous words



After removing ambiguous words

	n-ere-ki	I-ere-ki	renana
-----→	n-ehe-ki	I-aho-ki	r-ene-ki
	n-eke-ki	I-ake-ki	r-ahe-ki
	n-ere-plo	I-aneplo	r-e-plo
↖ ↘ ↙	n-eho-plo	I-aho-plo	r-eho-plo
	n-eki-plo	I-aki-plo	r-aho-plo
	n-e-pilu	I-anepilu	r-e-pilu
↗ ↙ ↘ ↛	n-eho-pilu	I-aho-pilu	r-eho-pilu
	n-eki-pilu	I-aki-pilu	r-aho-pilu

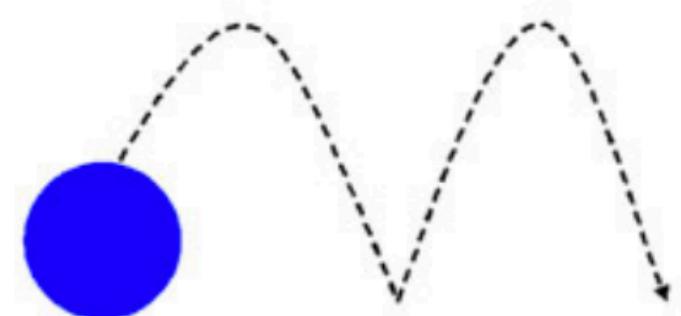


Table 2. Number of distinct words by generation in the second experiment

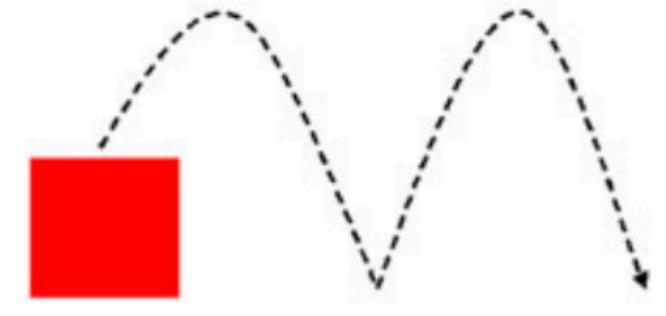
Generation	0	1	2	3	4	5	6	7	8	9	10
○ Chain 1	27	23	22	17	21	21	17	21	25	13	16
□ Chain 2	27	26	13	10	10	16	16	12	12	13	12
△ Chain 3	27	11	16	14	12	17	14	16	20	19	12
◊ Chain 4	27	19	19	17	19	17	22	23	21	27	23

Testing referential constraints directly (Silvey, Kirby, & Smith, 2015)

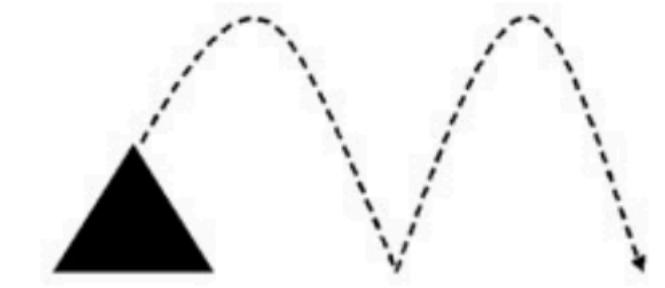
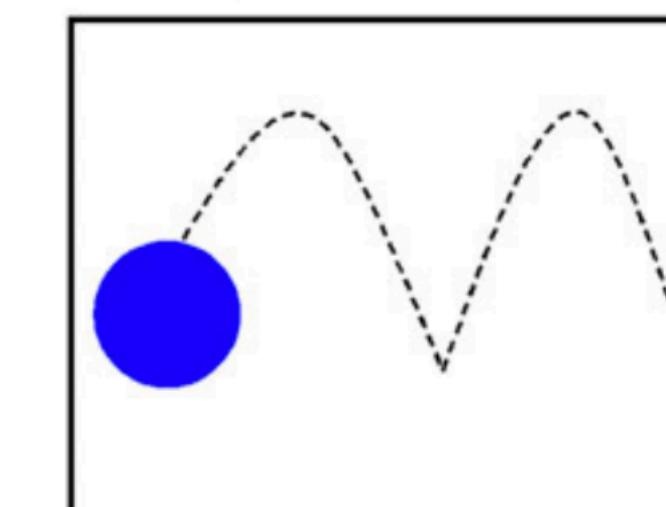
Training



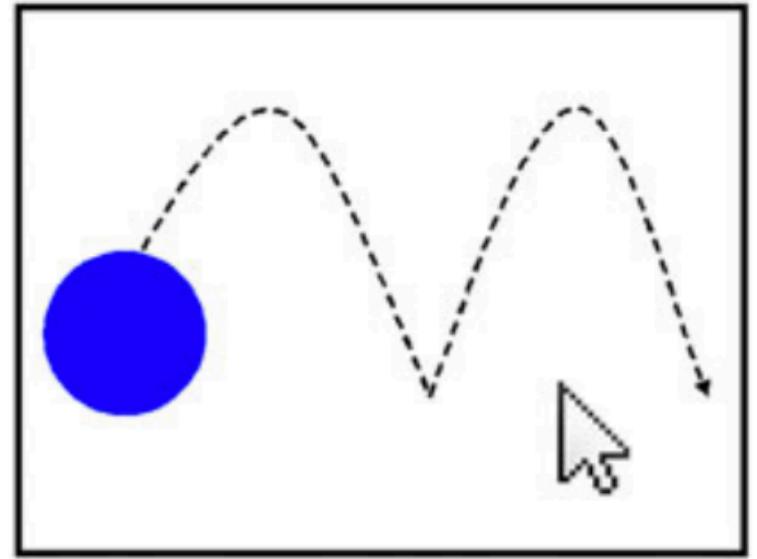
hobika



Test



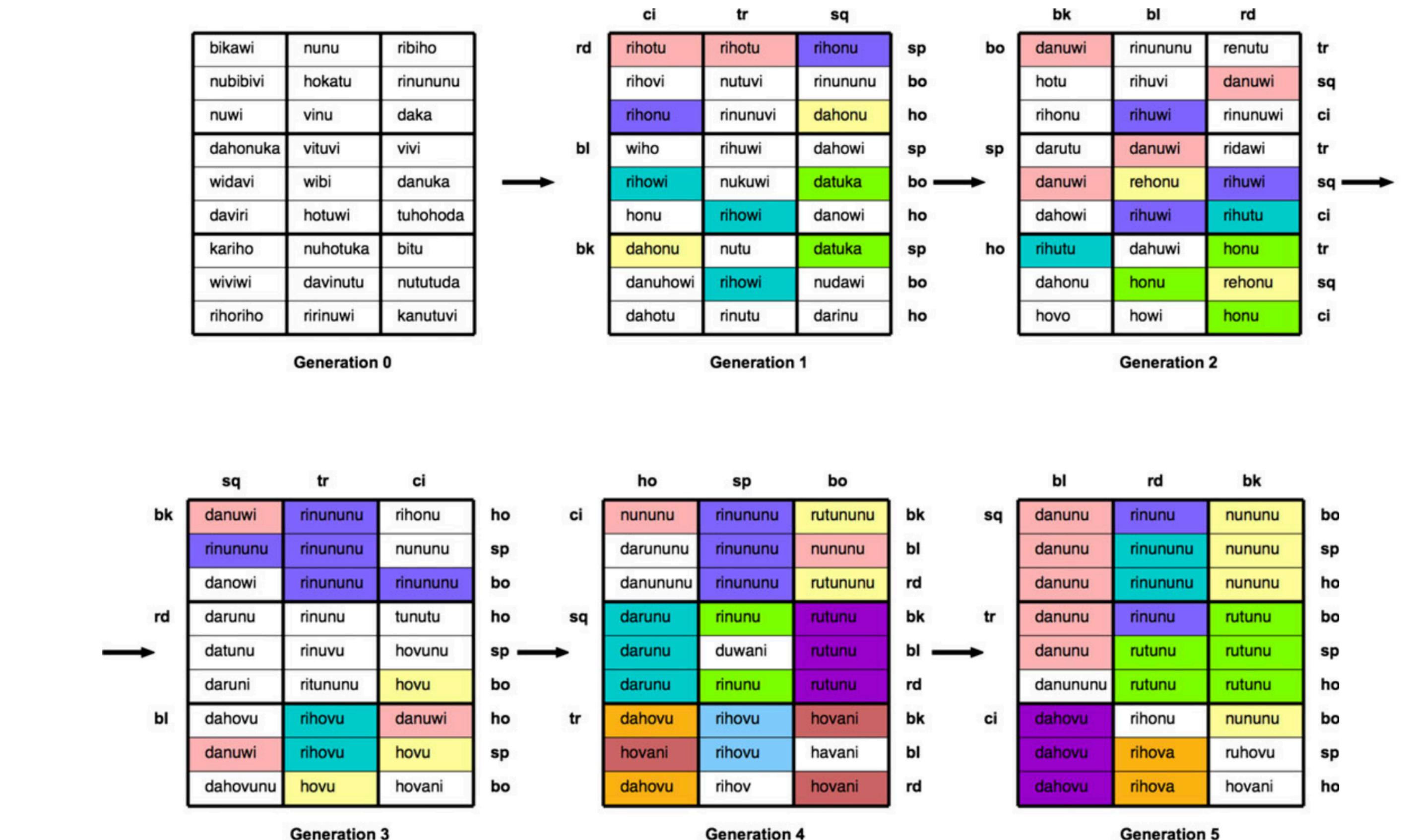
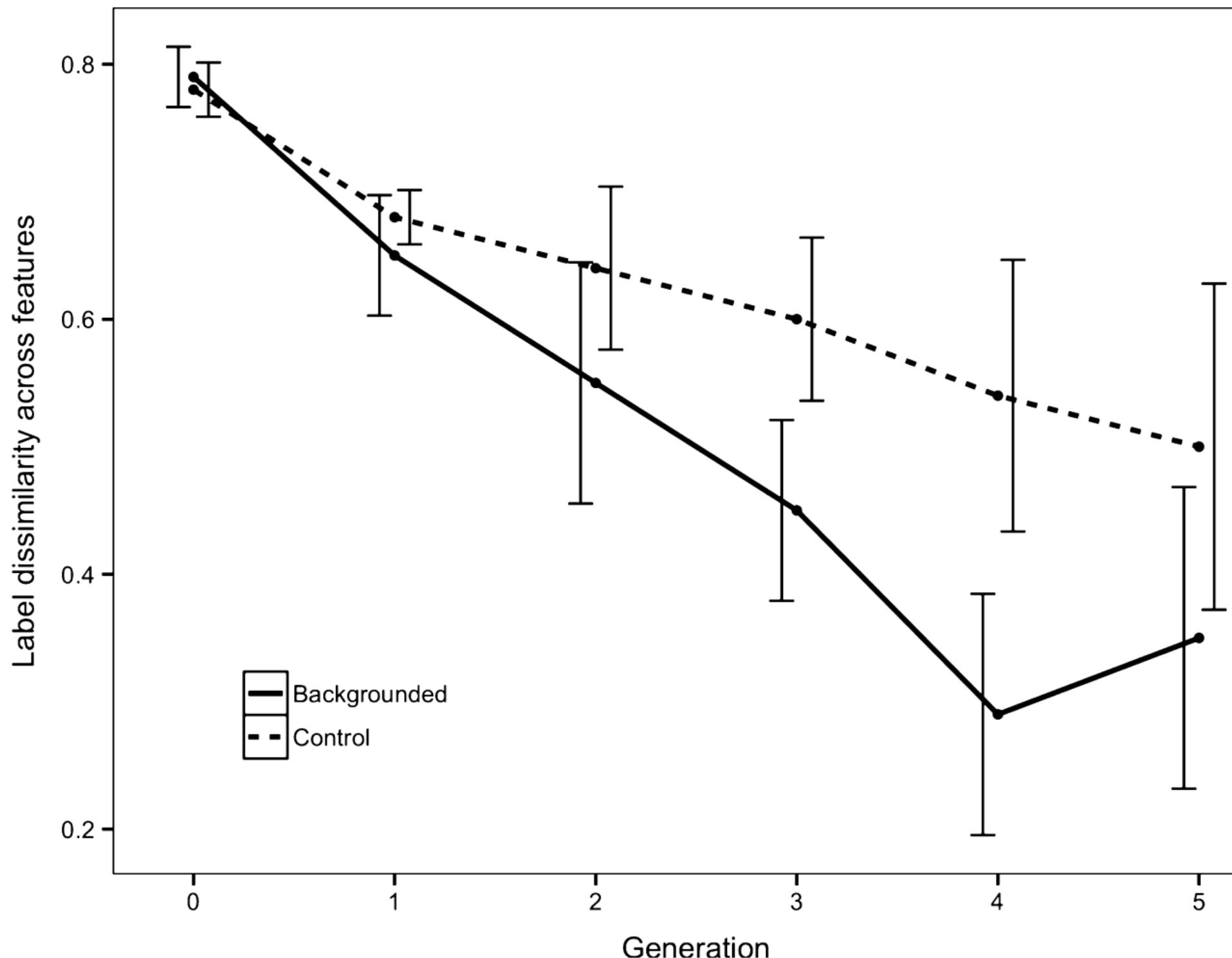
Correct



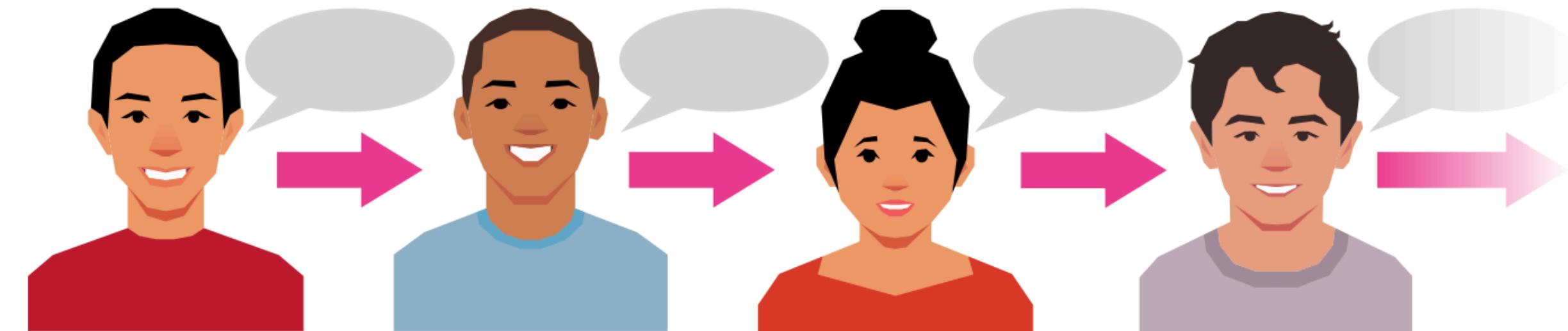
hobika



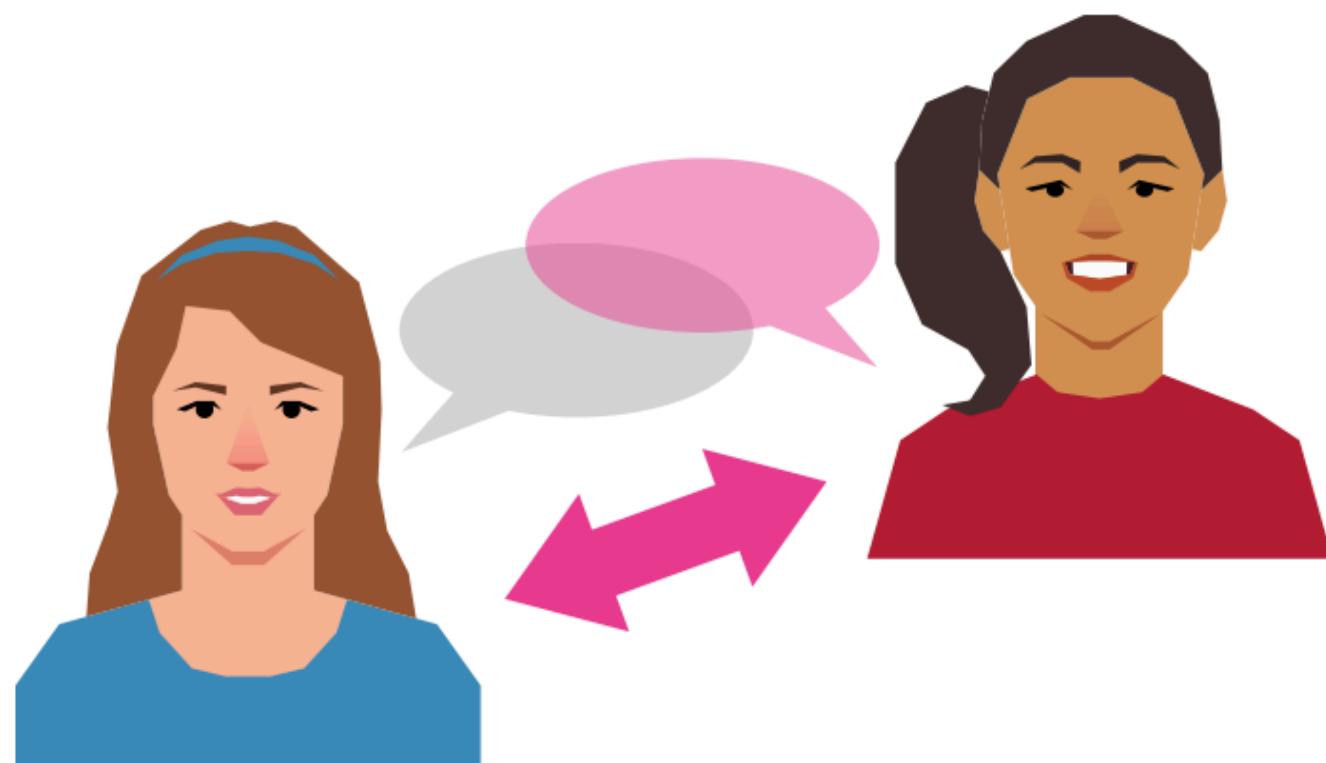
The meaning of the backgrounded dimension is not preserved



Learning vs communication

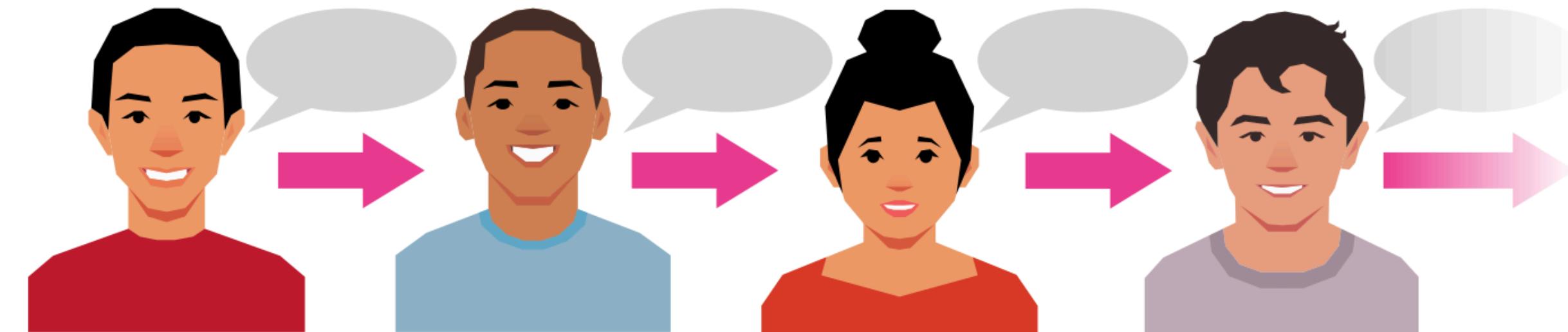


Iterated learning

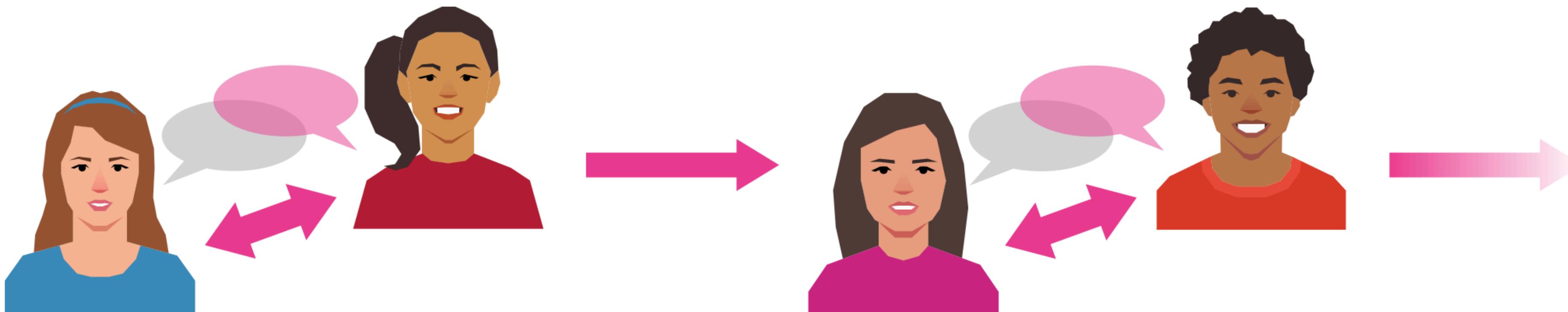


Communication

Learning vs communication

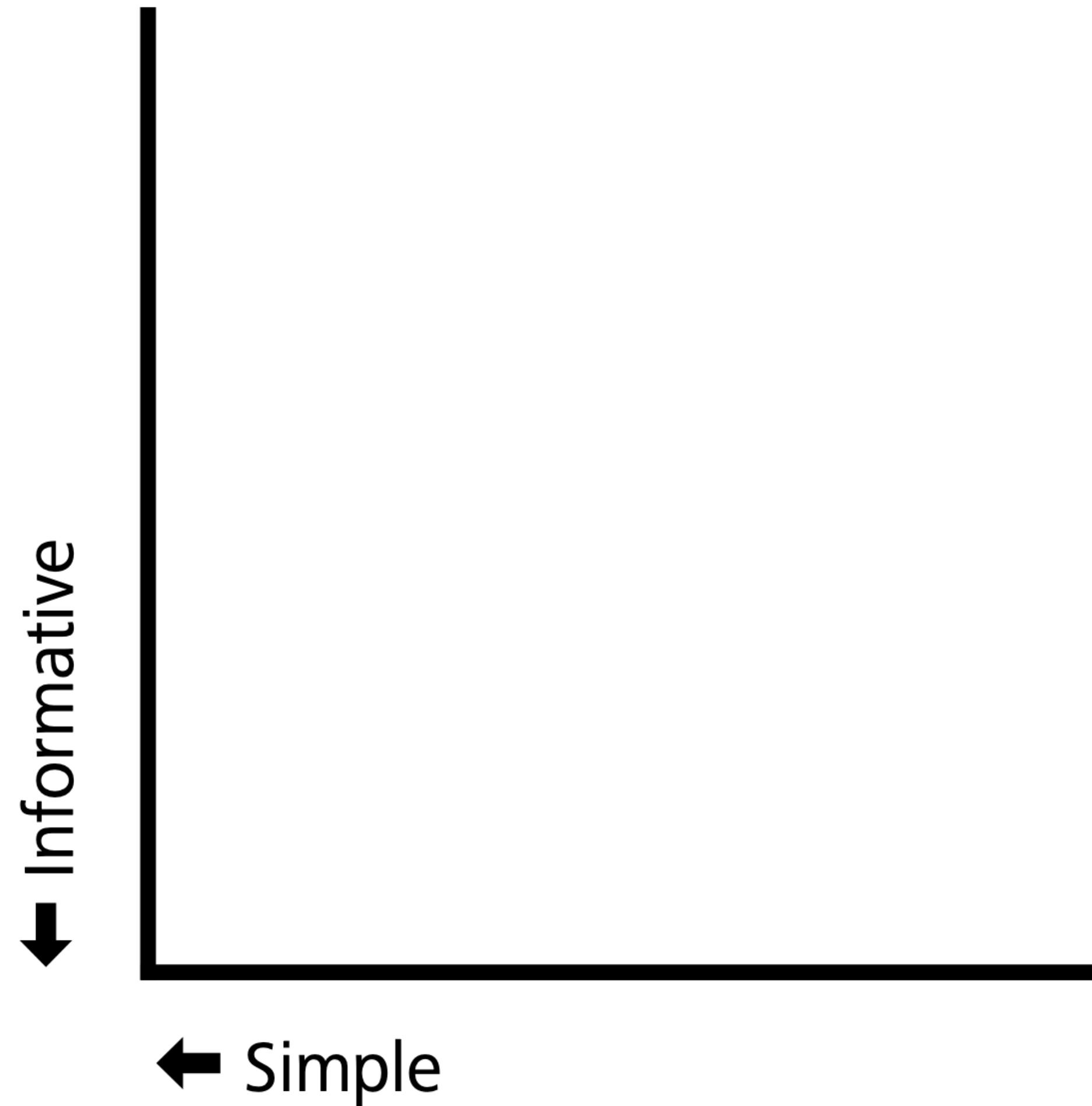


Iterated learning

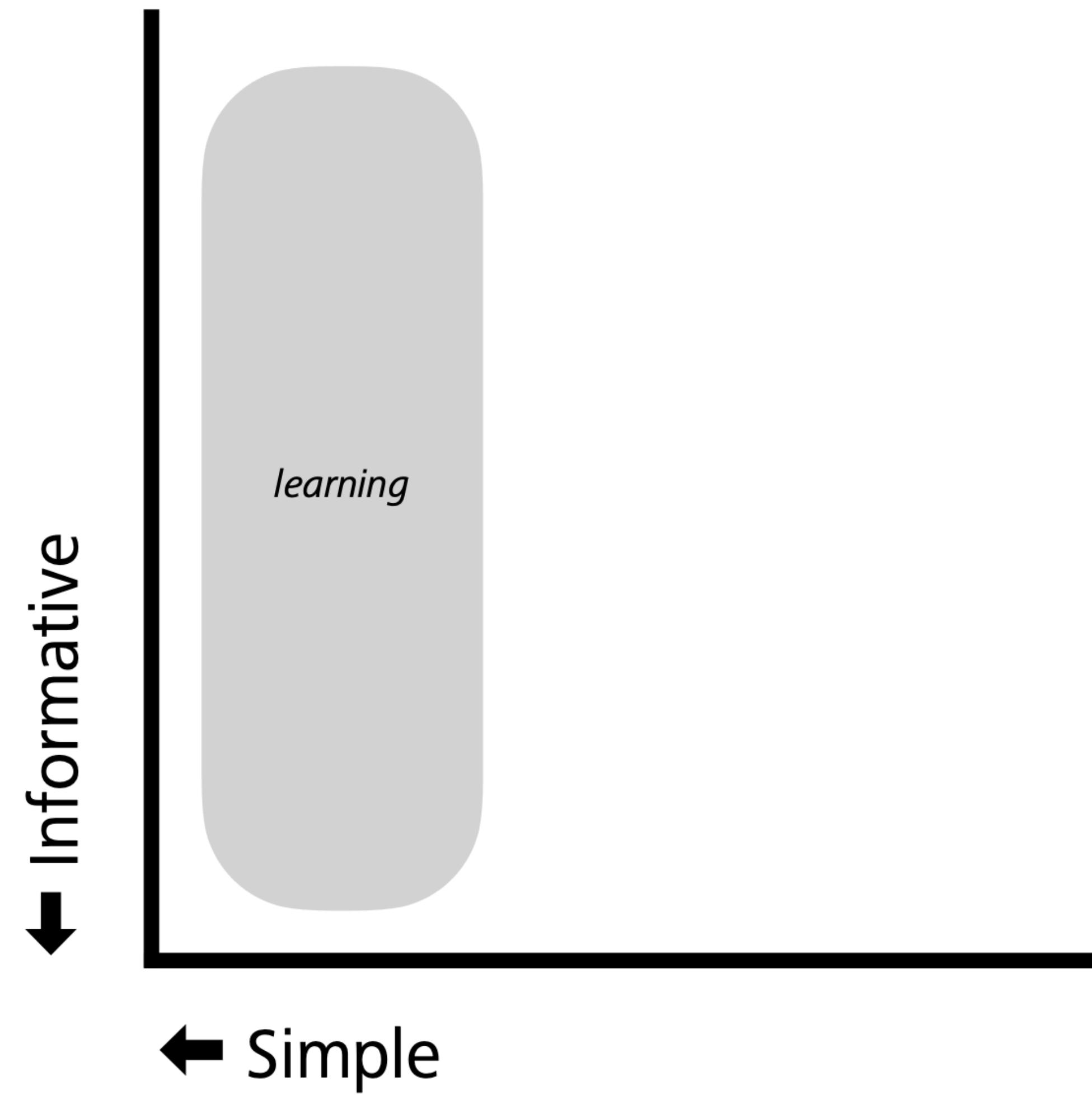


Iterated learning & Communication

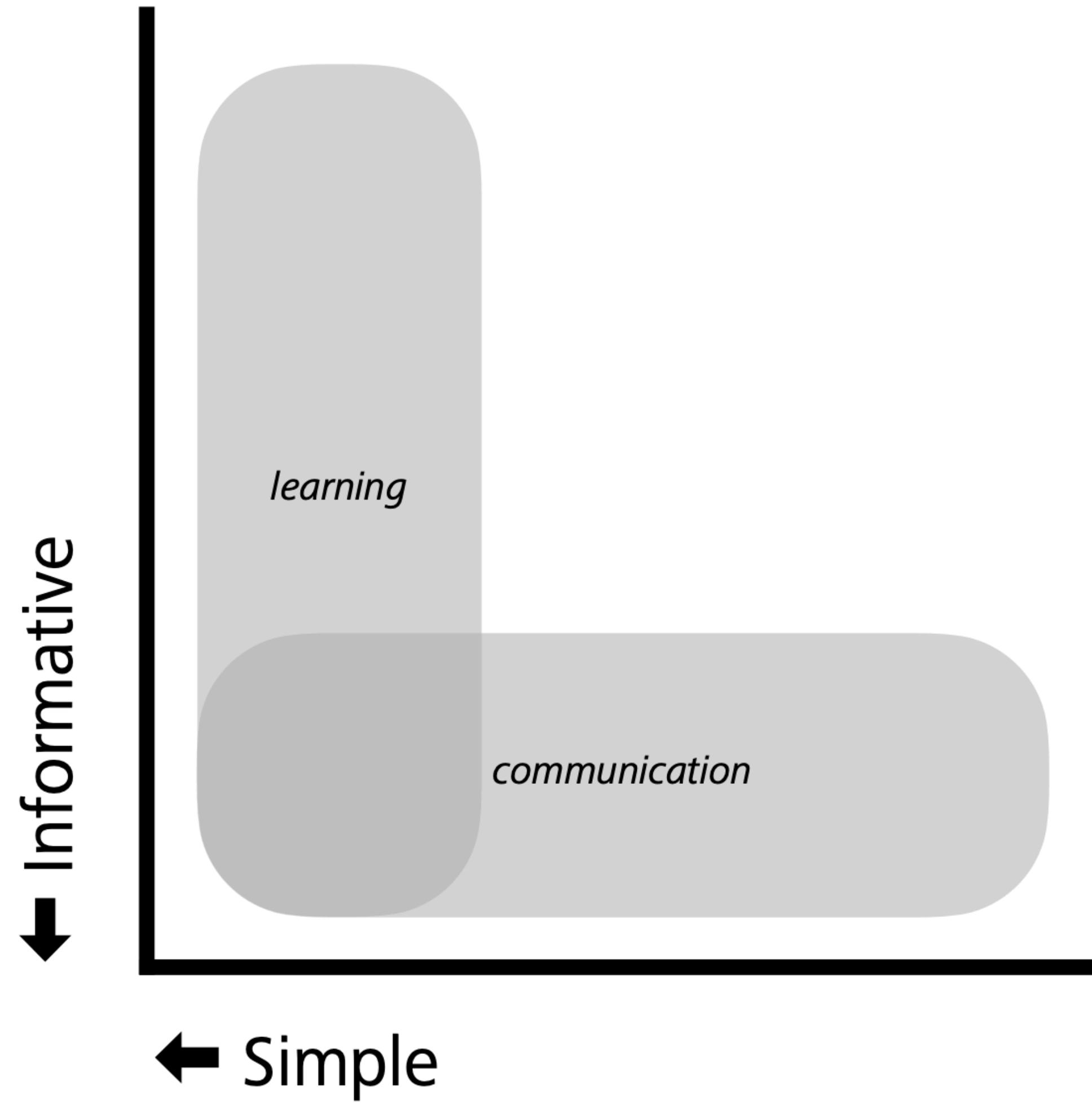
Learning and communication pressures



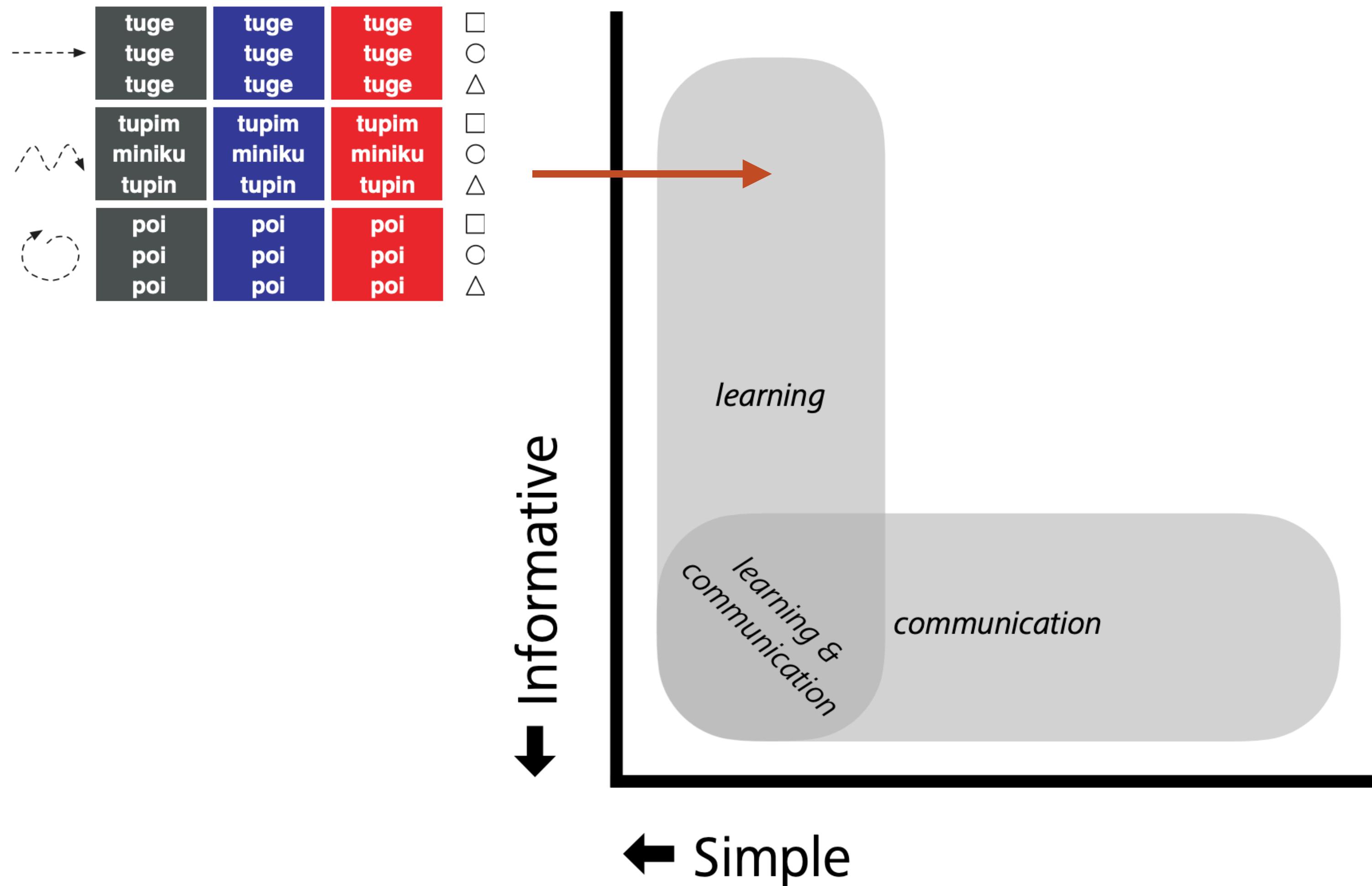
Learning and communication pressures



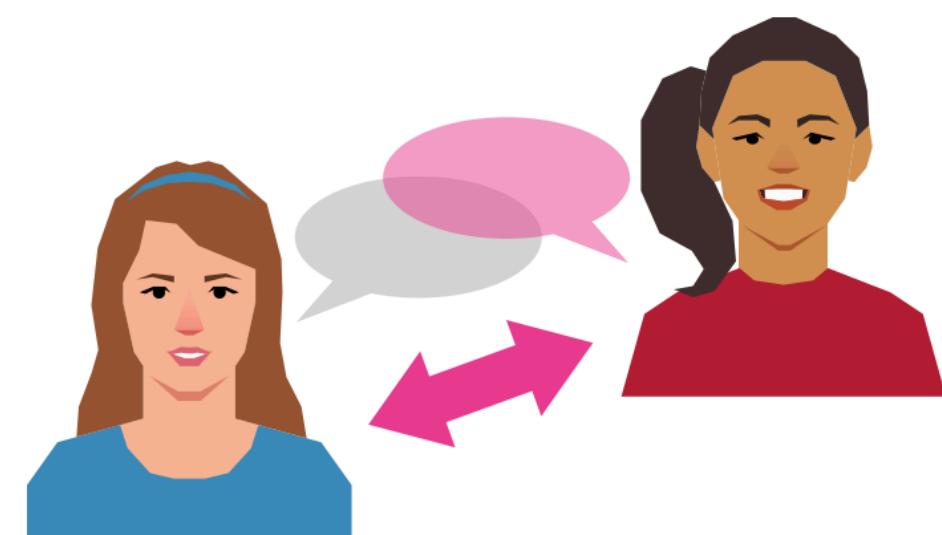
Learning and communication pressures



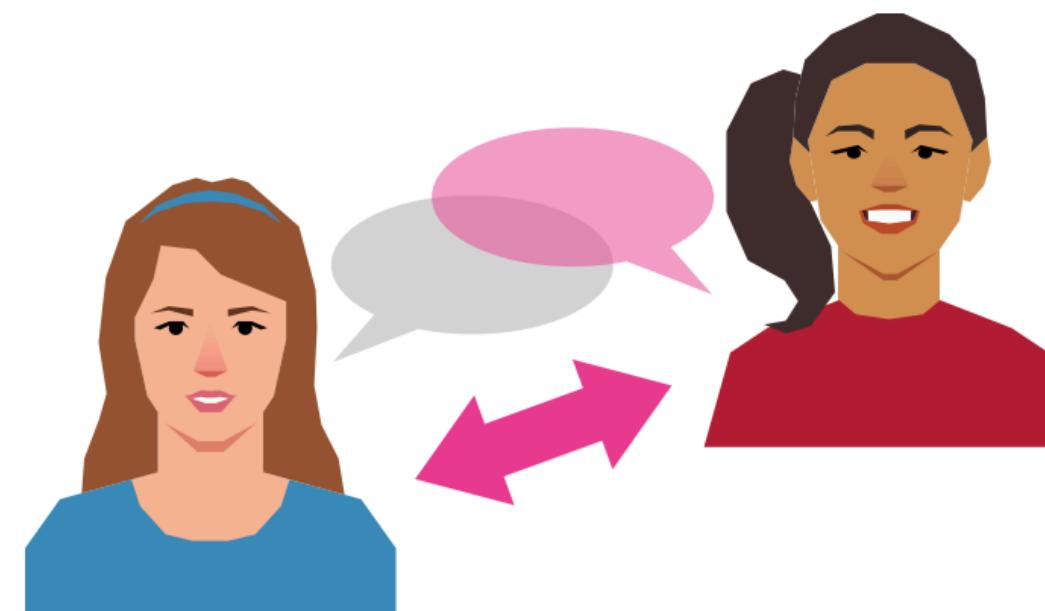
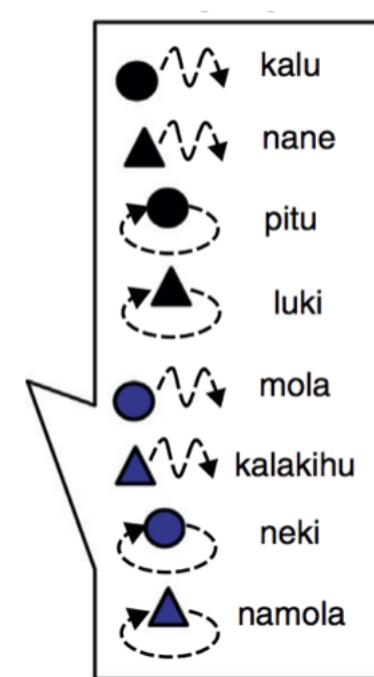
Learning and communication pressures



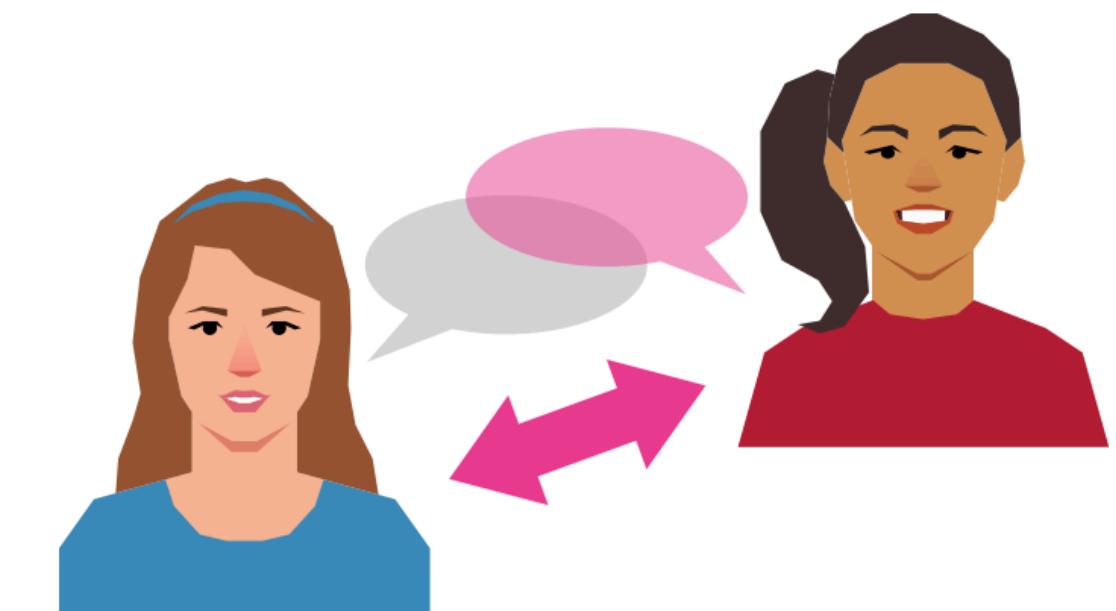
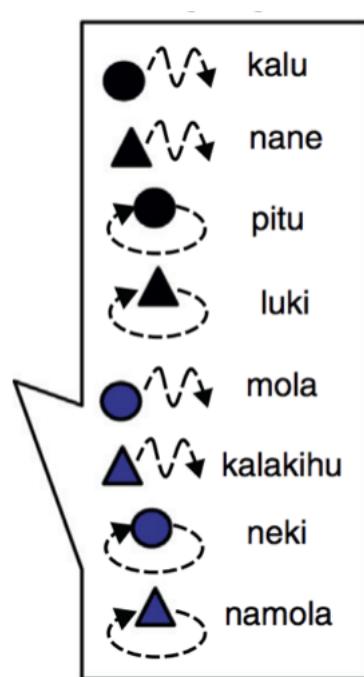
Testing the effect of communication (Kirby, Tamariz, Cornish, & Smith, 2015)



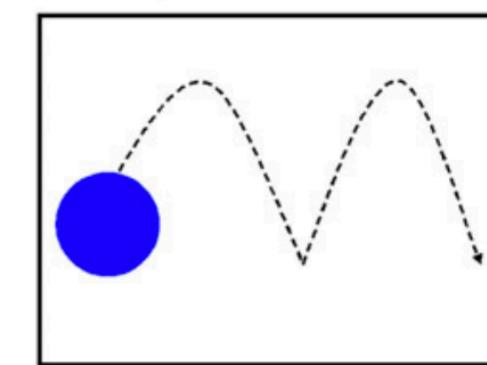
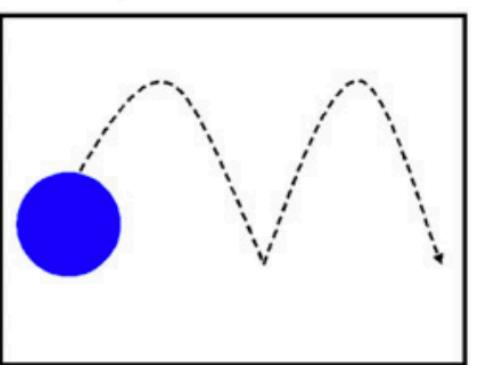
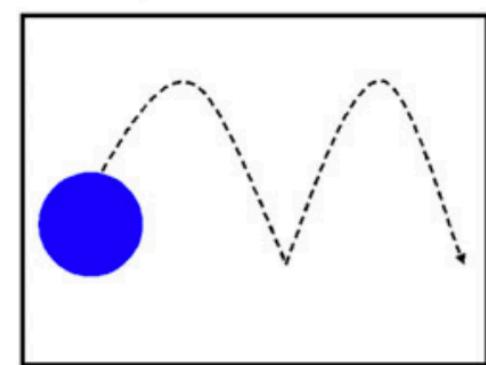
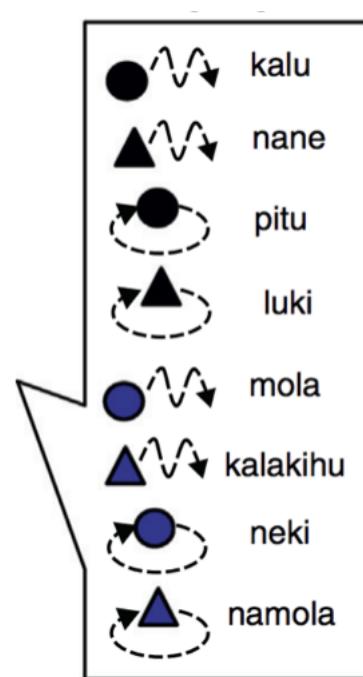
Communication



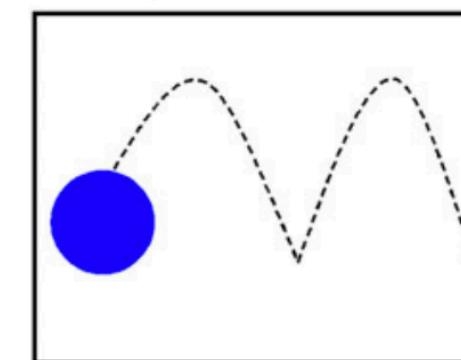
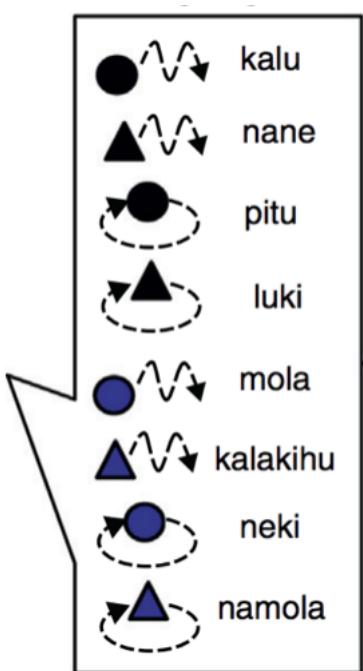
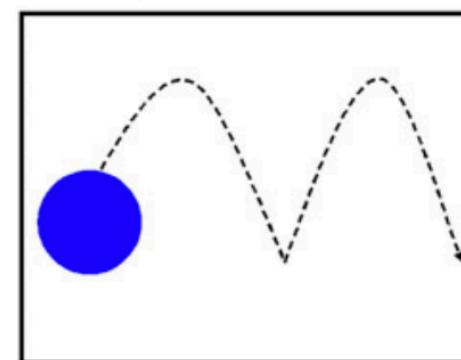
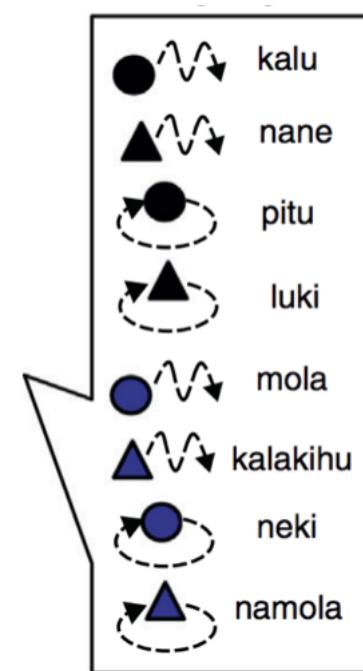
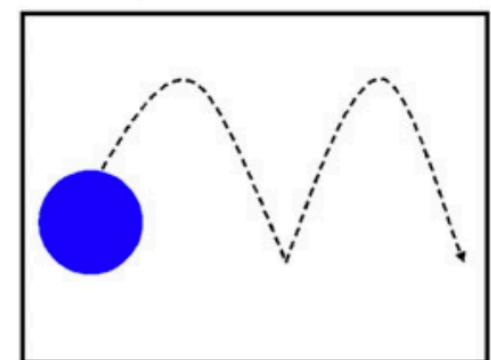
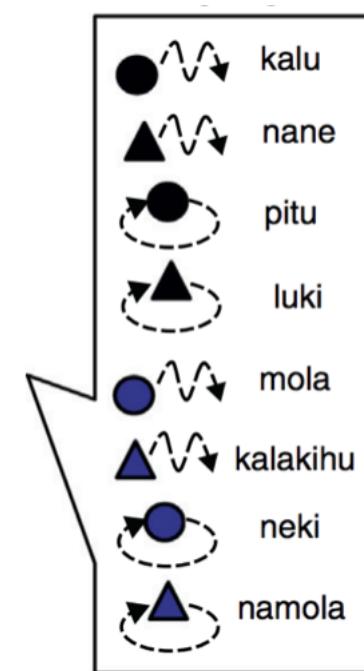
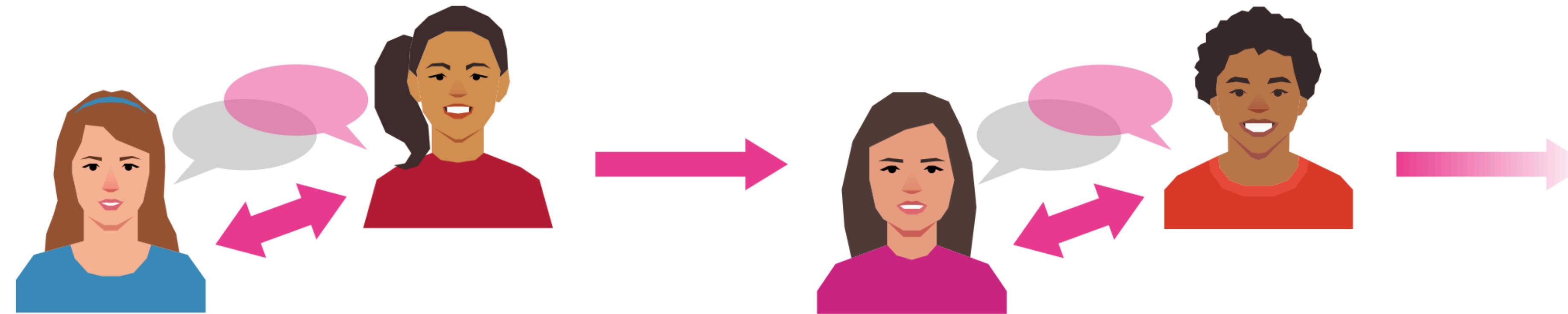
Communication



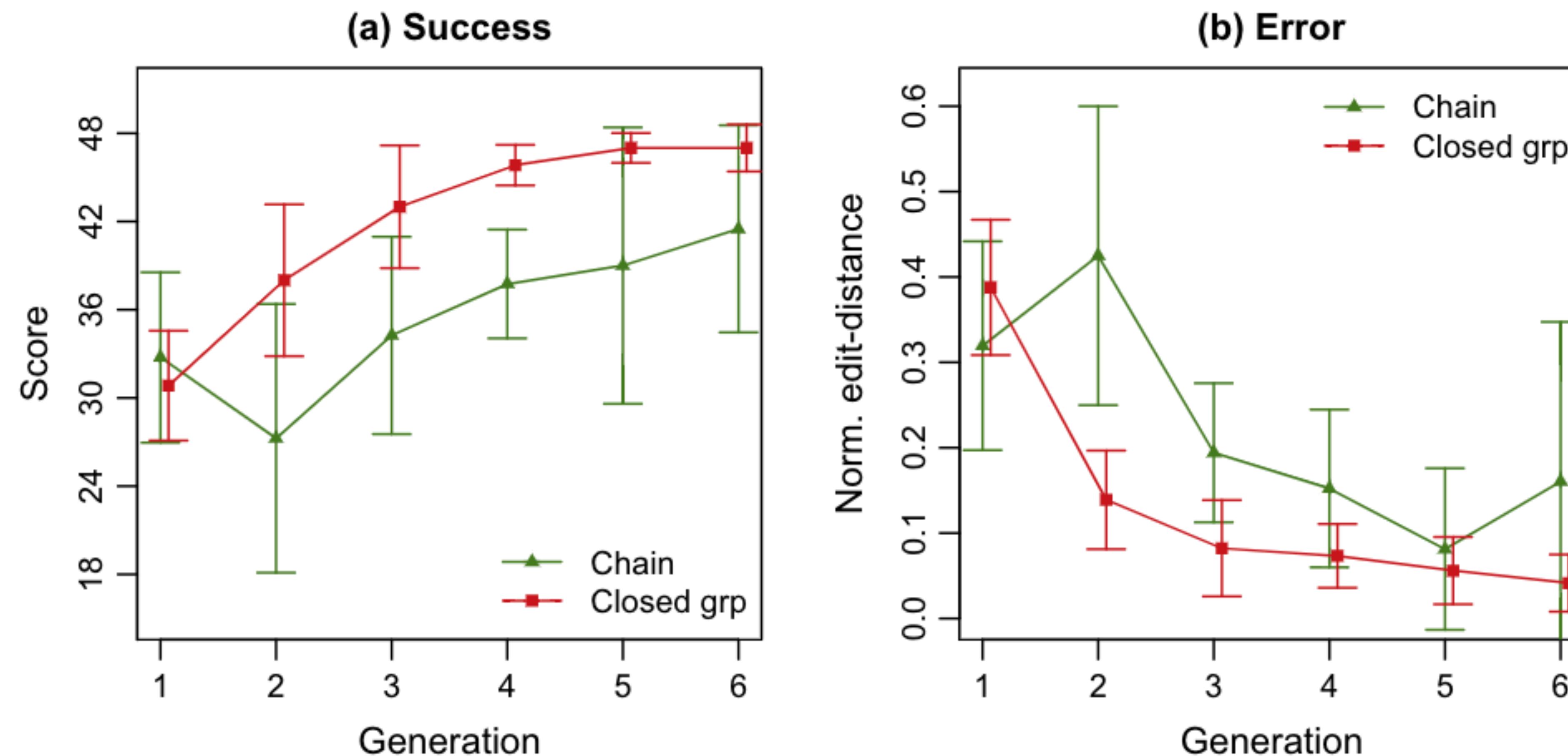
Communication



Testing the effect of iterated learning and communication

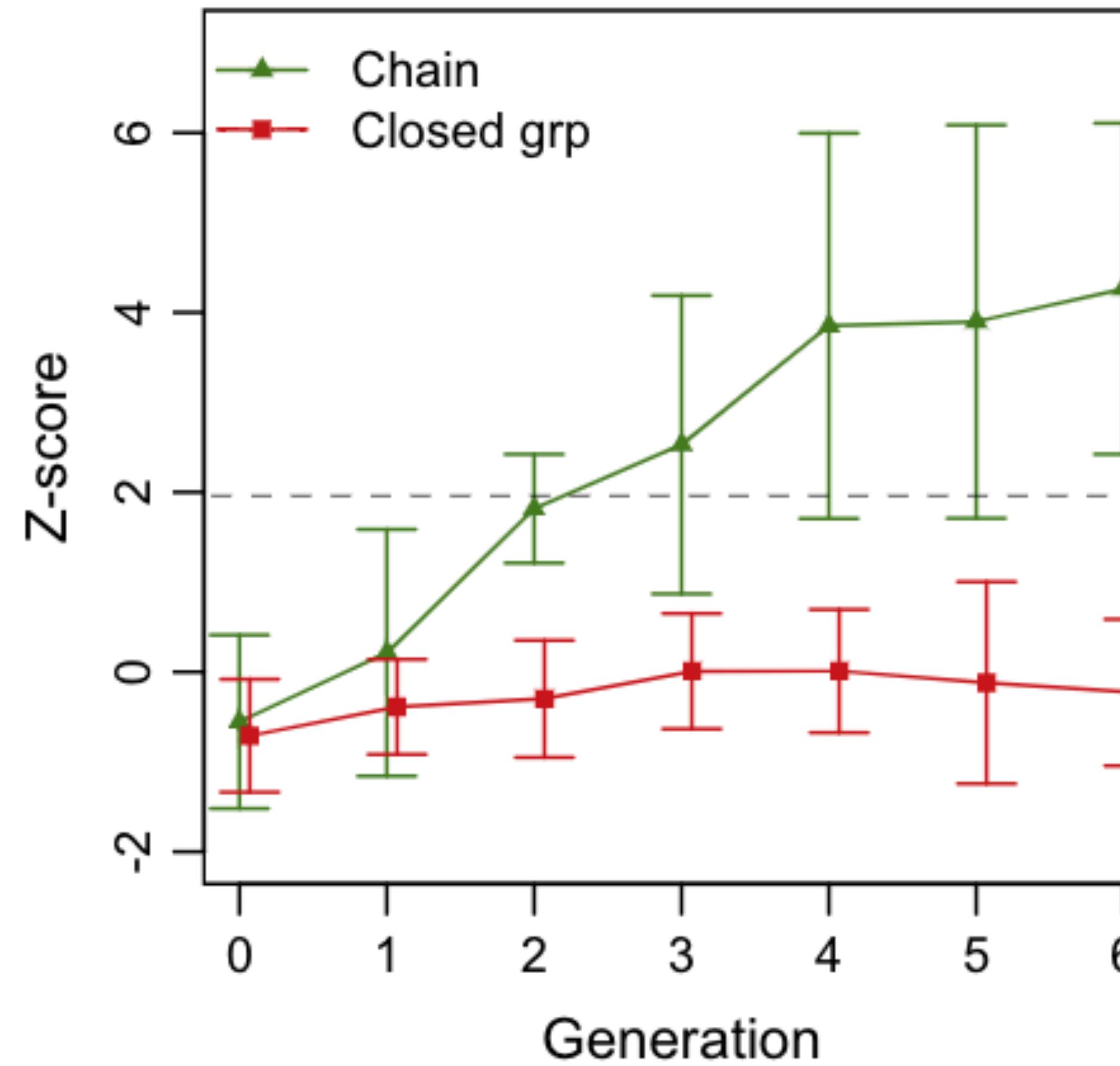


Testing the effect of iterated learning and communication

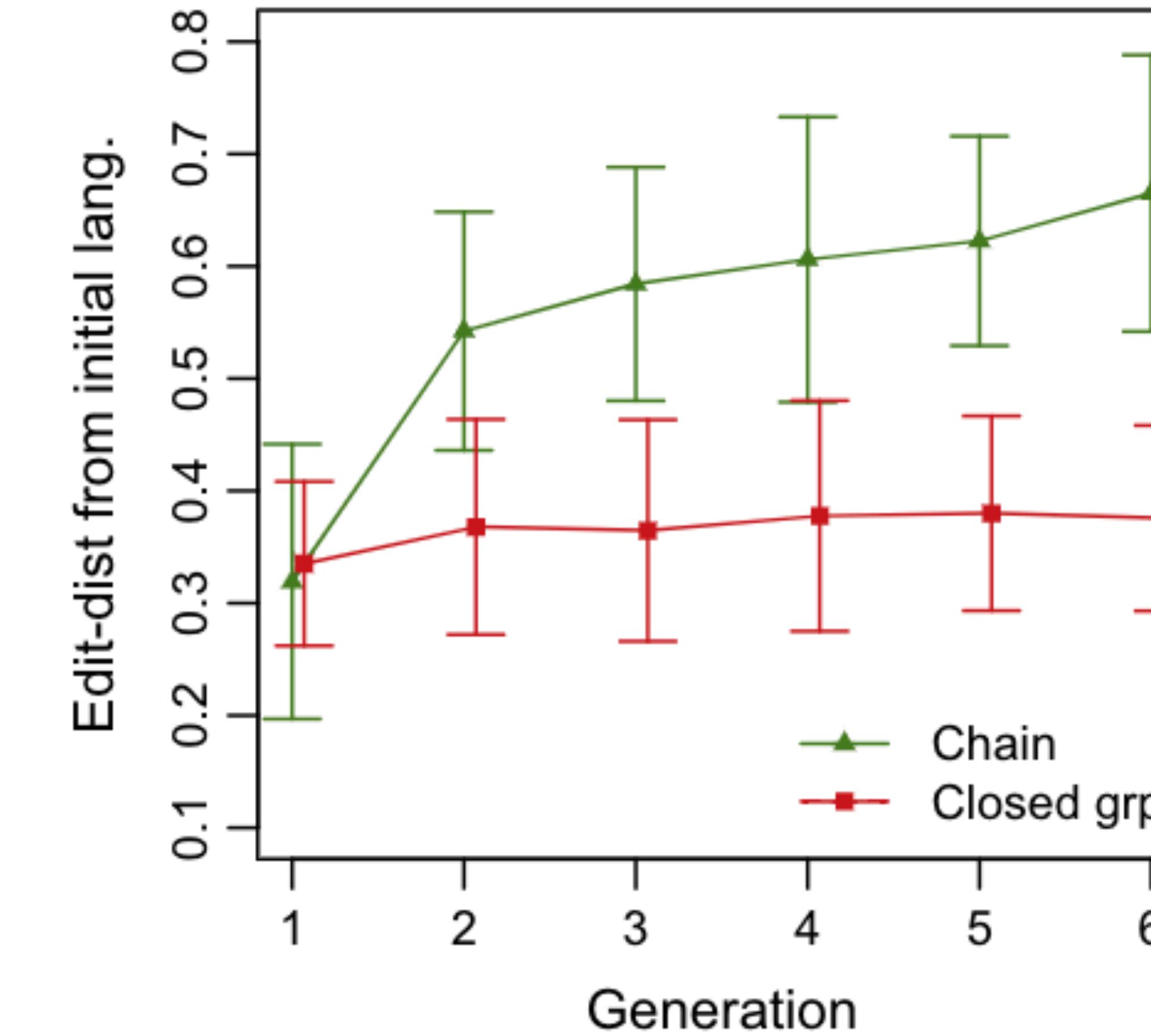


Testing the effect of iterated learning and communication

(c) Structure

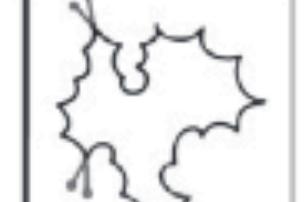


(d) Change from init. lang.

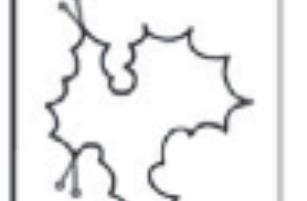


What kind of structure emerges?

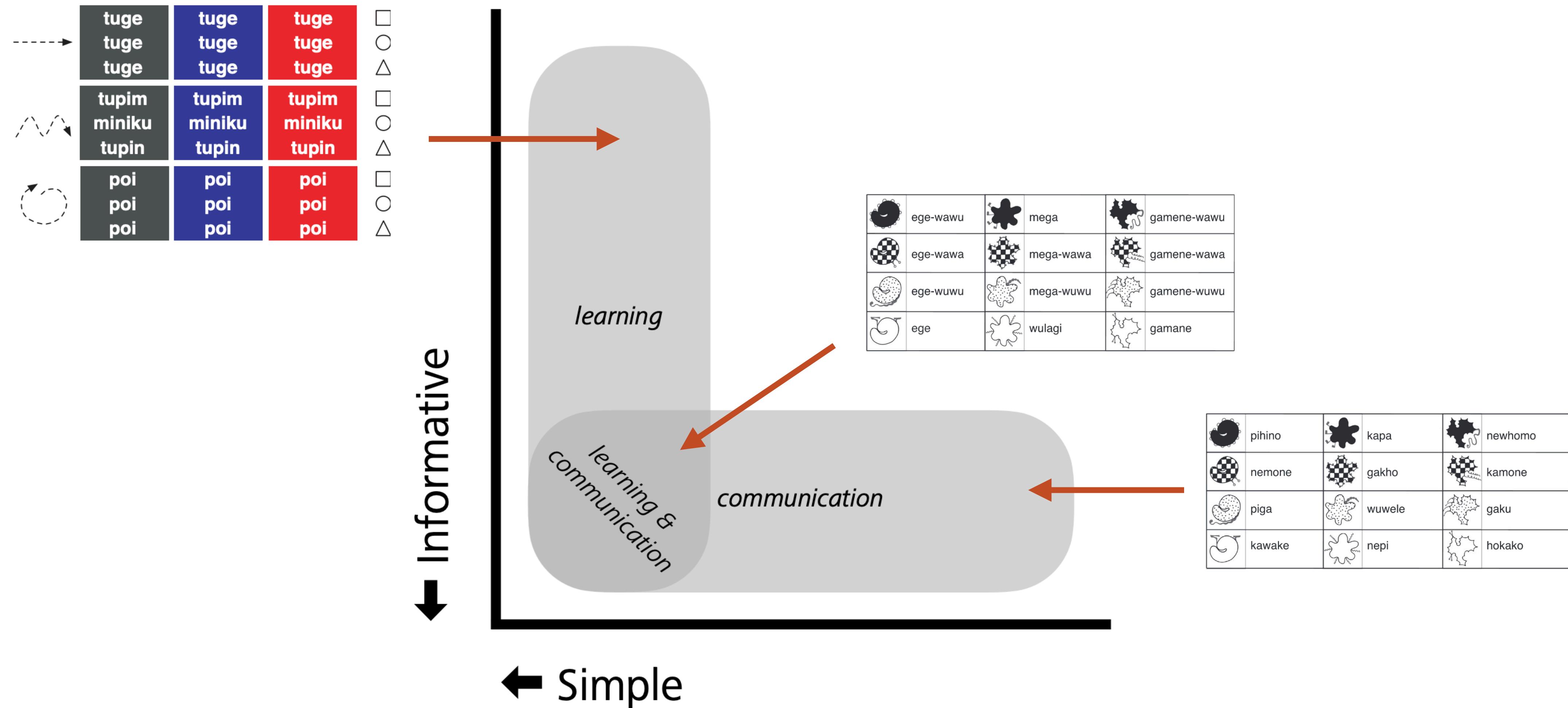
Closed group

	pihino		kapa		newhomo
	nemone		gakho		kamone
	piga		wuwele		gaku
	kawake		nepi		hokako

Chain

	ege-wawu		mega		gamene-wawu
	ege-wawa		mega-wawa		gamene-wawa
	ege-wuwu		mega-wuwu		gamene-wuwu
	ege		wulagi		gamane

Learning and communication pressures



Iterated learning

- 1. (Some) structure of language can be explained by two competing pressures: informativeness and simplicity**
- 2. Iterated learning is an experimental method for studying language evolution**
- 3. Iterated learning alone is not enough to give rise to language structure. You need communication**