Evolutionary Psychology

www.epjournal.net – 2010. 8(2): 205-228

Original Article

Understanding of Evolution May Be Improved by Thinking about People

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Abstract: The theory of evolution is poorly understood in the population at large, even by those with some science education. The recurrent misunderstandings can be partly attributed to failure to distinguish between processes which individual organisms undergo and those which populations undergo. They may be so pervasive because we usually explain evolutionary ideas with examples from non-human animals, and our everyday cognition about animals does not track individuals as distinct from the species to which they belong. By contrast, everyday cognition about other people tracks unique individuals as well as general properties of humans. In Study 1, I present experimental evidence that categorization by species occurs more strongly for non-human animals than for other people in 50 British university students. In Study 2, I show, in the same population, that framing evolutionary scenarios in terms of people produces fewer conceptual errors than when logically identical scenarios are framed terms of non-human animals. I conclude that public understanding of evolution might be improved if we began instruction by considering the organisms which are most familiar to us.

Keywords: evolution, social cognition, human-animal interactions, education

Introduction

Although the theory of evolution by natural selection is overwhelmingly accepted as true by biologists, the general public is not so convinced, with only around 30% of Britons, for example, endorsing the belief that the theory of evolution is definitely true (Miller, Scott, and Okamoto, 2006). Perhaps more troublingly, research suggests that there is very widespread misunderstanding of the mechanisms which drive evolutionary change (Bishop and Anderson, 1990; Demastes, Settlage, and Good, 1995; Gregory, 2009; Hallden, 1988; Shtulman, 2006). This is true amongst those who accept evolution as much as those who reject it, and even true in science students and among biology teachers (Brumby, 1984; Nehm, Kim, and Sheppard, 2009). Misunderstanding is only modestly reduced by formal instruction in many studies (Gregory and Ellis, 2009; Jensen and Finley, 1995; Nehm and Reilly, 2007). The misunderstandings are diverse, but there is a set that appears to recur across different populations (Bishop and Anderson, 1990; Gregory, 2009; Shtulman, 2006). For example, people conceive of species as entities which have distinct moments of birth and death (and hence ages), and which have needs, and strategies to further them. Evolutionary change is seen as a response to these needs. Mutation and inheritance are thought of goal-directed, so mutations arise and/or are passed on because they are beneficial. The distinction between the statistical change in the composition of populations which actually characterizes evolution, and ontogenetic changes within particular individuals, tends not to be clearly made. Thus, people conflate the proportion of moths in a population which are dark increasing over time with individual moths becoming darker as they age, and people assume that if an individual acquires a character something in its lifetime, that character thereby becomes a property of the species in general ("soft inheritance": Gregory, 2009). Individuals are widely assumed to do things "for the good of the species".

Central to these incorrect understandings is an under-appreciation of within-species variation and its consequences (Hallden, 1988). Students tend to argue that all members of a species must be basically the same (Gregory, 2009), and when asked to choose cartoons of evolutionary processes, select those in which at any one point in time, all individuals have the same phenotype (Shtulman, 2006). Shtulman and Schulz have recently shown that students who appreciate the extent of individual-level variability are more likely to have a correct mechanistic grasp of natural selection (Shtulman and Schulz, 2008). They suggest variation is under-appreciated because our habitual cognition about non-human animals tracks properties mainly at the species level. This may be pragmatically useful (deer are good to eat, tigers are dangerous; these species-level properties are more important to us than individual variation), but leads to error when applied to evolution, where the differences between individuals, and the heterogeneity in what befalls individuals over their lifetimes, are the central engines of the process.

To be precise, then, the hypothesis is that, for non-human animals, cognitive representations are maintained only or mainly at the type level, and not maintained, or maintained only weakly, at the individual level. This accords with a wealth of developmental and cross-cultural research on folk biology, which shows that the type is a cross-culturally recurrent, ontogenetically early, and inferentially privileged level of representation when reasoning about the natural world (Medin and Atran, 2004). Note that "types" here refers to folk species, that is, taxa which have a single ordinary-language name (referred to as "generic species" by Atran et al. 2001). These sometimes correspond to biological species (as in the case, say, of lions), but there are many cases where the folk species encompasses a genus of closely related biological species (e.g., bears), and some cases where two folk species turn out to be the same biological species (e.g., dogs and wolves).

The conceptual primacy of the type in cognition about non-human living things is, *ex hypothesi*, responsible for the intuition that all members of a species must be the same, and could also be responsible for many of the other confusions. The ideas that species have ages, birth dates, interests and needs, would arise from mis-assigning properties which should belong to individuals to the representation of the type. The idea that phenotypic characteristics acquired by a single moth during its lifetime automatically become species-wide heritable characters would stem from updating a type record when it should be an individual record which should have changed. Individual moths would be judged to change during their lifetime because their individual trajectories (staying the same color) are not represented as distinct from the trajectory of the population as a whole (getting darker). The idea that mutation and inheritance are directed might arise from thinking of them as purposive behavior on the part of the type, which again relates to assigning to the species properties which are proper to the individual. Thus, it seems plausible that many of the misunderstandings would stem from a central one, that is, cognitively representing non-human animals only or predominantly as instances of a type.

Of course, the insight that understanding Darwinian theory correctly requires the shift to thinking about populations of individuals, rather than species, as being of central importance, is not a novel one. Ernst Mayr argued that it is exactly the importance attached to individual variation and uniqueness which makes Darwinian population thinking different from the transformationalist, species-based evolutionary frameworks which preceded it (Mayr, 1982), and the emphasis laid on individuals, rather than types, marks a difference between the writings of Darwin and Wallace (Kutschera, 2003). Darwin devotes the two opening chapters of *The Origin* to discussing variation, and the difficulty of finding the boundaries of species and varieties. From the current perspective, one can see these chapters as an attempt to loosen the hold of thinking about animals and plants as mere instances of types on the reader, in preparation for the argument which is to come.

However, there is a cognitive domain already available where we do habitually track and represent properties of individuals, and that is cognition about other people. Human folk psychology operates on different cognitive principles from folk biology, without the conceptual primacy of the type (Atran et al. 2001; Medin and Atran 2004). Our social cognitive abilities, having evolved precisely to facilitate appropriate choices of coalition partners, friends and people to avoid (Dunbar, 1993, 1998; Humphrey, 1976), are exquisitely tuned to the fact that individuals have unique properties which lead to differential outcomes. There is comparative evidence from other primates that cognition about conspecifics involves the tracking of individuals, whereas that about allospecifics is more strongly based on classification by species (Humphrey, 1974). If this is true of humans, too, then it would follow that people might make fewer of the characteristic misunderstandings described above if they were thinking of the entities involved in the evolutionary process as other people, rather than members of other species.

This article, then, investigates the hypothesis that making students think about people gives them better intuitions about how evolution works than making them think about non-human animals. In Study 1, I created a novel experimental paradigm for assessing whether the tendency to categorize by type is stronger for non-human animals than for humans amongst members of my study population (British university students). In Study 2, I tested my main hypothesis more directly by presenting logically identical evolutionary scenarios framed either in terms of people or in terms of a non-human mammal, and testing participants' intuitions about how evolutionary change would occur.

Study 1: Introduction

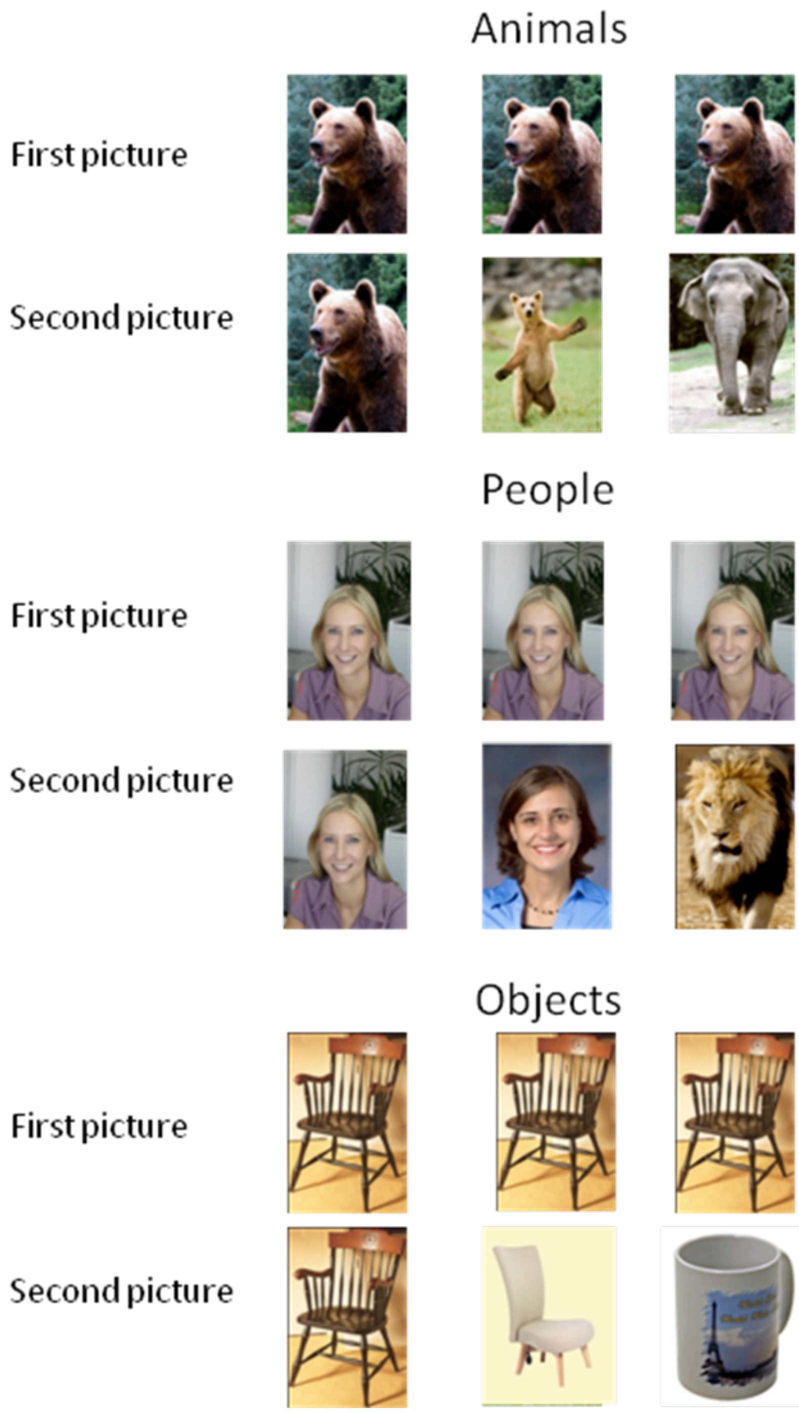
Study 1 sought to establish whether representation by type does indeed occur more strongly and immediately for non-human animals than for humans. I aimed to create a relatively implicit paradigm for demonstrating this, since my aim is to show that people understand evolution badly for deeper reasons than merely having heard it explained by people who also understand it badly, and because the persistence and pervasiveness of the characteristic misunderstandings suggest that categorization of animals at the type level might be a highly automatic, low-level process. In the experimental setup, participants saw two pictures separated by a five-second delay, and had to judge whether the second picture was the exact same picture as the first. The pictures depicted people, animals or inanimate objects. The critical comparison was between a condition where the second picture was different from the first and showed an entity belonging to a different type (the different-type condition), and a condition where the second photograph was different from the first, but depicted another entity of the same type (the different-picture condition; see Figure 1 for example stimuli). I reasoned that categorizing the first picture by type would make the different-picture condition more difficult than the different-type condition, since the categorical judgment that the second picture was the same type of thing would interfere with the production of the correct response, which is that the picture is a different one, producing slower reaction times. This kind of interference effect on response latencies and accuracies is often used in experimental paradigms within cognitive psychology, as in the famous Stroop effect (Stroop, 1935). Thus, if the hypothesis that categorization by type occurs more strongly for non-human animals than for humans is correct, then we should predict a greater decrement in performance in the different-picture versus the different-type conditions for pictures of non-human animals than for pictures of humans.

Study 1: Materials and Methods

Materials

Color digital images were obtained of animals (bears, deer, elephants, lions, tigers, dolphins), everyday objects (hammers, shoes, chairs, knives, spoons, mugs), or people (non-famous adult women in head and shoulders frame). Multiple images of the same type were chosen so as to maximize perceptual distinctiveness, with the animals in different poses, and the objects in different orientations. Images were displayed in the center of the screen of a desktop computer occupying a standard size of one quarter of the display area. The experiment was administered using E-Prime 2.0 (PST, 2007).

Figure 1. Example stimulus pairs for Study 1, for each of the three domains (animals, objects, people).



Note: The left-hand column represents what would be seen in the "same" condition, the middle column the "different-picture" condition, and the right-hand column the "different-type" condition.

Procedure

In each trial, a fixation cross appeared center screen, followed by the first picture, which was displayed for 1 second. This was followed by a series of colorful Mondrian-type block displays which changed every second and lasted five seconds overall. The second (target) picture then appeared, and the participant had to judge whether it was the same picture as the first, or a different one, using the computer keyboard. There were 6 trials for each combination of domain (animals, objects, people) and trial type (same, different-picture, different-type), giving 6*9 = 54 trials in total. The trials were presented in a different random order for each participant.

Participants

Subjects were 50 first-year BSc Psychology students from Newcastle University, the same population as surveyed in Study 2. Course credit was awarded for participation. The study was approved by the Newcastle University psychology ethics committee, and all participants gave their informed consent.

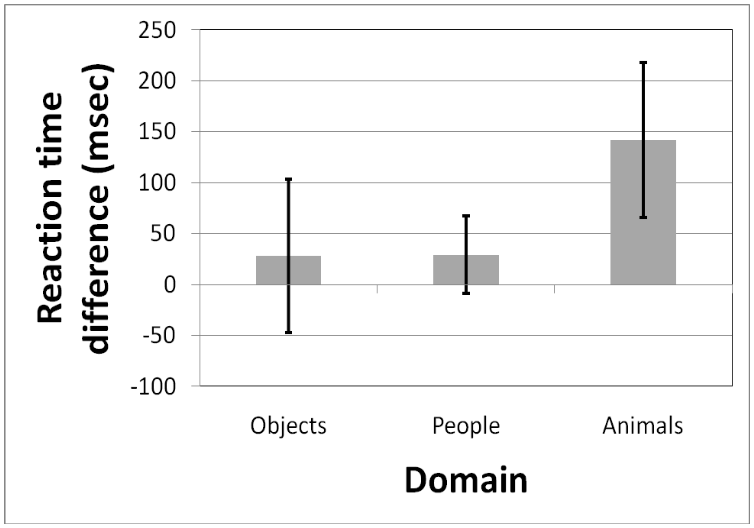
Study 1: Results

Table 1. Mean (and standard deviation) of reaction times (msecs) for the Study 1 task for each combination of domain and trial-type.

	Animals	Objects	People
Same	937 (324)	935 (366)	863 (338)
Different-picture	987 (337)	889 (238)	805 (232)
Different-type	846 (212)	861 (252)	776 (189)

Accuracies on the task were generally high (means 5.50 to 5.98 out of a possible 6 for all 9 of the trial type-domain combinations. Table 1 shows the mean reaction times (msec) for each combination of domain and trial type. Participants were faster overall for pictures of people than for animals or objects (repeated measures ANOVA: $F_{(2,98)} = 18.41$, $p < 0.05$). To test the main hypothesis, I used a repeated-measures ANOVA comparing the reaction times on the different-picture and different-type trials across the three domains. There were significant main effects of domain ($F_{(2,98)} = 16.01$, $p < 0.05$) and trial type ($F_{(1,49)} = 10.31$, $p < 0.05$), and a significant interaction between trial type ($F_{(2,98)} = 4.45$, $p < 0.05$). This was driven by participants being slowed up to a greater extent by the different-picture relative to the different-type trials in the animal domain than the other two domains. To visualize this, I calculated a within-subject difference score of the mean reaction time in the different-picture condition minus the mean reaction time in the different-type condition, for each domain. For the animal domain, but not the other two domains, this difference score differs significantly from zero (Figure 2).

Figure 2. Mean slowing of reaction time in the different-picture condition relative to the different-type condition, for the three domains. Only for animals is the mean slowing significantly greater than zero.



Study 1: Discussion

Study 1 shows that judging a second picture to be a different one from a first is more difficult, as evidenced by longer reaction times, when the second picture depicts an animal of the same species as the first. No equivalent effects are found for humans or for inanimate objects. This suggests that categorization by type occurs very powerfully for non-human animals, and this interferes with participants' ability to give different types of response than those based on category membership. One possible objection to this conclusion is that the low-level perceptual similarity of the animal images is simply greater for the different-picture than the different-type conditions. I did attempt to mitigate this problem, by choosing different pictures of the same species in different poses, such that the body outline in the second picture was often much more different in the different-picture than the different-type conditions (see Figure 1). Moreover, the different pictures of humans had high levels of basic perceptual similarity, because they all involved women in head and shoulders frame facing the camera. Nonetheless, people were no slower to judge that two of these images of women were different than they were to judge that an image of a woman and an image of an elephant were different. Thus it seems plausible that there are genuine differences in the strength and immediacy of categorization by type between the domain of non-human animals, and that of people.

Study 2: Introduction

Study 1 suggested that there are indeed differences between the human and non-human domains in the strength of automatic classification by type, in this population of university students. This makes it plausible that thinking about non-human animals will lead to more typological-thinking errors in evolutionary reasoning than thinking about the same processes happening to people, as suggested in the general introduction. To test this hypothesis directly, I prepared a questionnaire containing a description of an evolutionary scenario where a population moves from one environment to another, and there is an adaptive evolutionary response. Multiple choice questions then probed for misunderstandings of the mechanisms driving the evolutionary change, and also directly for what intuitions the participants had about the extent of intra-population variation. In the animal version, the populations were of fossas, a Madagascan carnivore unfamiliar to most students, and in the human version, Malagasy people, an unfamiliar but conspecific population. The two questionnaires were otherwise identical.

Though there have been many previous studies of understanding of evolution in student populations (Bishop and Anderson, 1990; Brumby, 1984; Demastes et al., 1995; Gregory, 2009; Hallden, 1988; Nehm et al., 2009; Shtulman, 2006; Shtulman and Schulz 2008), no standard method for assessing understanding has emerged. Many studies use open-ended responses and categorize misunderstandings retrospectively, whilst others do not ask sufficiently precise questions to characterize students' cognition precisely. Shtulman (2006) provides the most useful instrument, and it is one that presents the students with concrete examples of different species to express their intuitions about. However, Shtulman's instrument does not cover the full range of misunderstandings which have been described as common in the literature (see Gregory 2009), or those which have recurred in my experience as an instructor of evolution. I thus set out to create a new instrument which would (a) be capable of being presented either as concerning humans or a non-human animal, with relatively few changes required between the two versions; (b) assess the extent to which respondents assume there will be intra-species variation (cf. Schtulman and Schulz 2008); (c) specifically probe for the presence of misunderstandings which have been mentioned in the literature (e.g., Gregory 2009) and been most prevalent in my own teaching experience (for a list of these, see *Materials* below), and (d) be assessed by multiple choice to provide unambiguous and quick assessment of a large class of students. Students in the first week of instruction in a module on evolution (n = 123) were then randomly assigned to complete either the human or animal version of this questionnaire.

Study 2: Materials and Methods

Materials

The questionnaires (see Appendix) ask the reader to imagine they are a Martian come to earth (specifically, to Madagascar) to study a particular population (animal version, of fossas, human version, of Malagasy people). It sets up a scenario where the population lives in an open sandy environment and has fur (hair) color suitable for this environment, namely light-colored. However, the reader is told that at some previous time, the population lived in a dense forest, and at that time members mainly had dark fur (hair). Thus, there has been an episode of evolutionary adaptation to a novel environment.

The reader is asked to consider in detail the period during which the population was changing from having mainly dark fur (hair) to mainly light fur (hair). The first four questions (section A) assess the extent to which readers assume that the phenotypic characteristics of one member of the population will be the same for all others. Ten subsequent questions (section B) then probe the reader's intuitions about how the process of adaptive evolution occurred. These questions were designed to reveal the presence of ten key misunderstandings (see Study 2 introduction above). The misunderstandings are as listed below (listed by associated question number; see questionnaires themselves for details of wording).

5. *Individual change.* The idea that during an episode of adaptive evolution, individuals change their phenotype over the course of their lifetimes, in the direction of the long-term population-level change.
6. *Biased heredity*. The idea that during an episode of adaptive evolution, offspring are on average phenotypically different from their parents in the direction of the long-term population level change.
7. *Directed mutation*. The idea that mutations with a particular phenotypic effect are more likely in environments where that effect is beneficial than in environments where it is not.
8. *No variation*. The idea that any particular point in time, all members of the population have the same phenotype, which is identical to the current average phenotype of the population.
9. *Species need.* The statement of the impetus for evolutionary change in terms of a species' need, versus in terms of changes on the composition of the population.
10. *Extinction versus adaptation*. The idea that environmental change causes current species to disappear and new species to be born, versus the view that environmental change produces adaptation without necessarily producing speciation.
11. *Species competition*. The idea that the competition most relevant to adaptive evolution is between species rather than between members of the same population.
12. *Good of the species*. The expectation that behaviors which are for the good of the species will be prevalent rather than those which maximize inclusive fitness.
13. *Soft inheritance*. The idea that if one individual learns to swim, swimming ability thereby becomes a species-wide characteristic.
14. *Species birth*. The idea that successive chronospecies change into one another by an abrupt saltation rather than gradual change.

A subsequent section (section C) provides questions about the reader's prior study and acceptance of evolution, and their interest in and experience with animals.

Procedure

The questionnaire was completed during the first class of an undergraduate module on evolution and genetics. Students worked on their own without discussion. Equal piles of the two versions of the questionnaire were placed at the corners of the lecture theater, and by chance, more students took the animal version (n = 70) than the human version (n = 53). Responses to the section A questions were used to give a uniformity score (M 3.86, SD 0.34). This represents the extent to which the respondent assumes that a second individual from the study population will have the same phenotypic characteristics as have been observed for a first individual. Responses to section B were used to create a misunderstandings score, which was the number of the characteristic misunderstandings listed in the Materials section which the respondent had endorsed (out of 10; M 3.84, SD

1.67). In addition, I compared the frequency of misunderstanding responses to each of the section B questions across the two versions.

Participants

Students (n = 123) were non-biology majors who were completing an evolution and genetics module compulsorily as part of a psychology degree program (the overwhelming majority), or as an option within a major unrelated to biology (e.g., English literature). The psychology students were in their first year at university. As the class contained students with varying degrees of prior study of biology, I recorded whether the respondent had studied A-level (high school) biology or not, and control for this in the analysis of misunderstandings. Students were informed that the questionnaire was not a compulsory part of the class and would not be assessed. The study was approved by the Newcastle University psychology ethics committee, and all participants consented to participate.

Study 2: Results

The uniformity score (the extent to which a second individual from the population was assumed to have the same phenotypic characteristics as a first) was slightly but significantly higher for the animal than the human version (t_{121}=2.01, $p < 0.05$). There were no significant correlations between the misunderstandings score and students' degree of acceptance of evolution (r = -0.17, *ns*; though there was rather little variation in acceptance), or their perception of their understanding of evolution (r = -0.07, *ns*). Nor were respondent's liking or exposure to animals correlated with their misunderstanding scores (r = -0.01, *ns*). However, receiving the human version of the questionnaire was associated with lower misunderstandings scores than receiving the animal version ($F_{(1,118)}$ = 5.83, $p < 0.05$), whilst having studied A-level (high school) biology made no difference ($F_{(1,118)}$ = 3.06, *ns*; Figure 3). The version by prior study interaction was not significant ($F_{(1,118)}$ = 2.85, *ns*).

Table 2 breaks down the proportion of students endorsing the "misunderstanding" response for each of the questions in section B of the questionnaire, by questionnaire version. As the table shows, the effect of questionnaire version was by no means uniform across the questions. Having the animal version increased the prevalence of the error response with odds ratios greater than 2 for questions B10, B13 and B14, and with odds ratios between 1.5 and 2 for questions B5, B11 and B12. The odds ratios for questions B6, B7 and B8 were close to 1, whilst that for question B9 tended in the opposite direction.

Figure 3. Mean number of misunderstandings in Study 2, by version of the questionnaire, and whether the subject had studied A-level (high school) biology. Error bars represent 95% confidence intervals.

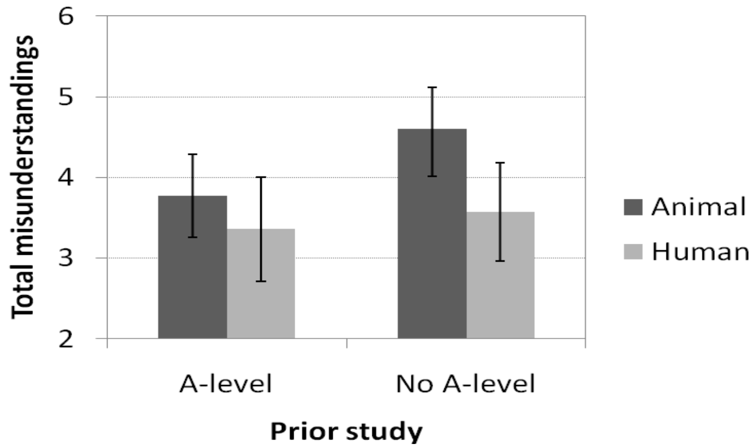


Table 2. Numbers (percentages) of students with each version of the questionnaire choosing the "misunderstanding" response, Study 2, and the odds ratio for making the error in the animal versus human version.

Misunderstanding	Animal version (n = 70)	Human version (n = 53)	Overall (n = 123)	Odds ratio
B5. Individual change	13 (18.6)	7 (13.2)	20 (16.3)	1.50
B6. Biased heredity	53 (75.7)	41 (77.4)	94 (76.4)	0.91
B7. Directed mutation	40 (57.1)	33 (62.3)	73 (59.3)	0.81
B8. No variation	38 (54.3)	27 (50.9)	65 (52.8)	1.14
B9. Species need	31 (44.3)	30 (56.6)	61 (49.6)	0.61
B10. Extinction > adaptation	25 (36.2)	11 (20.8)	36 (29.5)	2.17*
B11. Species competition	34 (48.6)	20 (37.7)	54 (43.9)	1.56
B12. Good of the species	17 (24.3)	9 (17.0)	26 (21.1)	1.57
B13. Soft inheritance	31 (44.3)	6 (11.3)	37 (30.1)	6.23*
B14. Species birth	6 (8.6)	0 (0)	6 (4.9)	X*

Notes: *x:* odds ratio is indefinitely large; * difference in frequencies significant at $p < 0.05$ by one-tailed χ^2 test.

Discussion: Study 2 and General Discussion

The questions on uniformity in Study 2 showed that merely making people think about humans rather than other animals evokes a greater appreciation that individuals vary. Moreover, the overall prevalence of misunderstanding responses to the questions on evolutionary processes was lower on the human than the animal version of the questionnaire. This difference was driven by respondents with the human version being much less likely to think of species as things with abrupt moments of birth and death, or of characteristics being acquired by one individual during life thereby automatically becoming species-wide species-typical characteristics, when thinking about humans. In addition, with the human version, respondents tended to think that adaptive change could occur within the same species, whereas in the animal version, they were more likely to respond that when the environment changes, a species goes extinct, and a novel species adapted to the novel conditions comes along. There were also trends towards a greater clarity that population change does not require individuals to change during their lifetimes, and a reduced tendency to endorse the good of the species as the maximand of evolution, or competition between species as its central driver, in the human version. All of these shifts make sense on the hypothesis that, cognitive representations of individuals as distinct from species-types are more easily accessible for humans than for non-human animals.

However, although these results are encouraging, other misunderstandings such as the idea that mutation and heredity are non-randomly related to utility, or that evolutionary problems are best thought of as driven by the needs of species, showed no evidence of being reduced by using the human version of the questionnaire. Thus, we can take this evidence as suggestive that *some* of the most common misunderstandings of evolution, specifically those which stem from an under-appreciation of intra-species variation, can be reduced in frequency by thinking in terms of people, but not make the stronger claim that merely thinking about people abolishes all misunderstandings of the Darwinian process.

These findings are of interest for two different reasons. First, they support the claim, developed elsewhere using quite different kinds of evidence, that there are different domain-specific cognitive propensities at work when we think about non-human animals rather than people (Atran et al. 2001; Medin and Atran 2004). These differences plausibly make functional sense, since in most interactions with non-human animals, the species-typical features are consequential to us, and the individual variation relatively unimportant, whereas in dealings with other people, exactly the opposite is true. The current study sheds no light on the origins of these domain differences. Thinking mainly in terms of species-types could simply reflect the relative lack of involvement of my urbanized study population with allospecifics (although there was no correlation in this study between misunderstandings and self-rated involvement with animals). However, the cross-cultural and developmental evidence rather tends to support the view that tracking animals predominantly at the species level is a reliably-developing cognitive strategy not easily overcome by experience (Medin and Atran 2004).

Second, and more directly related to my initial objectives, the results might help educators to devise better strategies for the teaching of evolution. Educators have established that thinking about animals at the species-type level is a barrier to correct understanding (Shtulman and Schulz, 2008), and also noted that using human examples in the teaching of evolution is popular with students (Wilson, 2005). However, to my knowledge, this is the first study to show experimentally that understanding might be improved specifically by using humans as the focus. Admittedly, some caveats are in order. First, the differences in the level of misunderstanding between the two questionnaire versions were modest, and did not apply to all types of misunderstanding. However, the students had received no instruction in evolution in either condition. The mere evocation of thinking about people already improved cognition about the process in some respects. Thus, well-designed instruction that introduced key concepts through examples concerning humans could be a dramatic improvement on existing pedagogical strategies. Second, the study has provided no evidence that a better understanding of evolution derived through thinking about humans can then be transferred to thinking about evolution more generally. That is, Study 2 did not show that the students receiving the human version went on to think better about evolution when they subsequently thought about animals (or indeed, plants, bacteria and archaea).

However, these limitations noted, the results are at least suggestive that thinking about humans might be a good starting point for developing good intuitions about how evolution works. My own practice as a teacher of evolution has been to introduce concepts through non-human examples, and then, in subsequent chapters or lectures, show the force of the argument that this must be true of humans too. I have, perhaps, being getting matters back to front. Perhaps a better approach would be to think about the variation in phenotype of the people around us, and the consequences of this for their lives, and then show the force of the argument that this must be true of other species as well. This is a slightly paradoxical strategy, in that surveys show people are more ready to accept that evolution is a true account of how other species came to be than it is of the origin of humans (Miller et al., 2006). However, this human exceptionalism may arise exactly because they have an incorrect, species-level cognitive model of evolution, derived from non-human examples, which they then resist applying to humans, who are so obviously unique individuals. Using human examples might thus ameliorate the situation with regards to both the understanding of evolution by natural selection, and the acceptance of the acceptance of its relevance to our lives.

Acknowledgements: I am grateful to my students who participated in this study, and provided assistance with data coding, and to an audience at Behavior, Evolution and Culture (UCLA), who were a helpful first audience.

Received 10 March 2010; Revision submitted 29 April 2010; Accepted 11 May 2010

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Appendix

This appendix contains the full questionnaires used in Study 2.

Questionnaire: Animal version

Thinking about evolution

Please imagine you are a Martian biologist who has come to earth to study an animal called the *fossa*, which only lives in a remote corner of Madagascar. It lives by hunting birds and small mammals. It used to live in dense forest, but hundreds of years ago the forest was cut down, and it now lives on open sandy plains. Fossas have either black or white coats. Back in the days when there was dense forest where they lived, almost all fossas had black coats. This gave them good camouflage in the forest. Nowadays almost all fossas have white coats. This gives them good camouflage on the open sandy plains where they now live. Now please answer the following questions as best you can given this information about the fossa. If you are not sure, or can't tell from the information given, please follow your hunches and guess, but do answer one way or the other.

Section one

Imagine you come upon the first fossa you have ever seen. You study its behaviour. You observe that it is most active very early in the morning, has a sleep in the afternoon, sharpens its claws on the trunks of small trees, and knows how to get honey out of a beehive by burrowing a hole in the hive wall. Now, imagine that a few weeks later you encounter another fossa, a few miles down the road. Please rate your degree of belief in the following statements:

1. The second fossa will also be most active in the morning.

Definitely untrue	Probably untrue	Impossible to say	Probably true	Definitely true

2. The second fossa will also have a sleep during the afternoon.

Definitely untrue	Probably untrue	Impossible to say	Probably true	Definitely true

3. The second fossa will also sharpen its claws on the trunks of small trees.

Definitely untrue	Probably untrue	Impossible to say	Probably true	Definitely true

4. The second fossa will also know how to get honey from a beehive by burrowing a hole in the hive wall.

Definitely untrue	Probably untrue	Impossible to say	Probably true	Definitely true

Section two

The fact that fossas nowadays are almost all white, which is the best colour to be for the open plains, whereas they used to be almost all black, which was good for the forest, is an example of adaptation by natural selection. Let's think about the period during which fossas were evolving from being almost all black to almost all white.

5. During this transitional period, individual fossas became lighter over the course of their lifetimes. True or false?

True	False

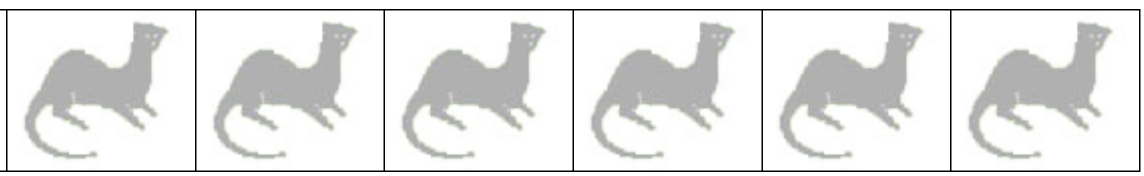
6. During this transitional period, offspring had on average lighter fur than their parents. True or false?

True	False

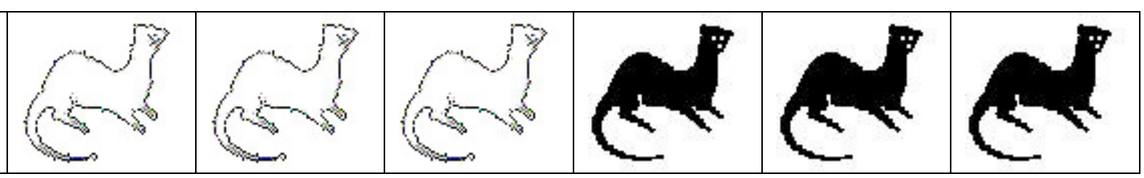
7. During this transitional period, genetic mutations which make fur lighter were more likely to occur than they had been before the forest was cut down. True or false?

True	False

8. Which of the two diagrams, A or B, best represents the way the population of fossas would have looked half way through the transitional period of evolution?

A	

or

B	

9. Which of the following two statements is the best description of the process which led to almost all fossas on the open plains being white?

A	The proportion of individuals in the population with white-coated parents gradually increased

B	The species had to change itself to avoid being made extinct by competing

	species

10. If the climate and vegetation in Madagascar suddenly change, what is most likely to happen to the fossa?

A	It will go extinct, to be replaced by another species better adapted to the new conditions

B	Fossas will continue to live there, but their behaviour and appearance may be different

11. Evolution is often said to be driven by competition. Against what is a fossa most directly competing in evolutionary terms?

A	Other fossas

B	Other species of animal

12. How, in general, would you expect a fossa to behave?

A	In such a way as to benefit the species

B	In such a way as to gain the maximum benefit for itself

13. Suppose that one fossa learns to swim during its lifetime, and as a consequence develops big muscles in its front legs. A few generations later, which fossas will have big muscles in their front legs?

A	All fossas

B	Only the direct descendants of the one that learned to swim

C	Only those fossas who swim themselves

D	No fossas

14. Many thousands of years ago, fossas diverged from an ancestral species of mammal. If you had access to pictures of each generation of the population that lived over this long period, which of the following would you see?

A	Individuals became gradually more like modern fossas over the generations, but there was no particular point at which fossas suddenly appeared

B	There was an identifiable moment when the fossa species evolved from the ancestral species

Section three

In this section, there are some questions about you.

1. How interested are you in the theory of evolution?

Not interested at all	Not very interested	Neutral	Quite interested	Very interested

2. How likely do you think it is that the theory of evolution is true?

Not likely at all	Not very likely	Neutral	Quite likely	Very Likely

3. To what extent are you convinced that there can be change within a species over time?

Not at all	Not much	Neutral	Somewhat	Very

4. To what extent are you convinced that one species can change into another species over time?

Not at all	Not much	Neutral	Somewhat	Very

5. How well would you say you understood the theory of evolution?

Not well at all	Not very well	Neutral	Quite well	Very Well

6. To what extent do you agree with the statement 'the theory of evolution explains why animals are the way they are'?

Strongly disagree	Slightly disagree	Neutral	Slightly agree	Strongly agree

7. To what extent do you agree with the statement 'the theory of evolution explains why humans are the way they are'?

Strongly disagree	Slightly disagree	Neutral	Slightly agree	Strongly agree

8. How much biology have you studied previously?

Little or none
GCSE combined sciences
GCSE biology

A or AS level biology
University level biology

9. How much do you like animals?

Not at all	Not much	Neutral	Quite	A lot

10. Do you like visiting zoos or safari parks?

Not at all	Not much	Neutral	Quite	A lot

11. How much do you like to read books or magazines about animals or about natural history?

Not at all	Not much	Neutral	Quite	At lot

12. How much do you like to watch documentaries on television about animals or natural history?

Not at all	Not much	Neutral	Quite	A lot

13. How much interaction with pets did you have whilst you were growing up?

None	Not much	Some	Considerable	A lot

14. How much direct experience of animals have you had overall, counting pets, hobbies such as horse-riding, work experience, spending time on a farm etc.?

None	Not much	Some	Considerable	A lot

Questionnaire: Human version

Thinking about evolution

Please imagine you are a Martian biologist who has come to earth to study human beings. When you arrive, the only humans on the planet are living in a remote corner of Madagascar. They live by hunting birds and small mammals. They used to live in dense forest, but hundreds of years ago the forest was cut down, and they now live on open sandy plains. They have either black or blonde hair. Back in the days when there was dense forest where they lived, almost all of them had black hair. This gave them good camouflage in the forest. Nowadays almost all of them have blonde hair. This gives them good camouflage on the open sandy plains where they now live. Now please answer the following questions as best you can given this information. If you are not sure, or can't tell from the information given, please follow your hunches and guess, but do answer one way or the other.

Section one

Imagine you come upon the first man you have ever met. You study his behaviour. You observe that he is most active very early in the morning, has a sleep in the afternoon, sharpens his knife on the trunks of small trees, and knows how to get honey out of a beehive by making a hole in the hive wall. Now, imagine that a few weeks later you encounter another man from this community, a few miles down the road. Please rate your degree of belief in the following statements:

1. The second man will also be most active in the morning.

Definitely untrue	Probably untrue	Impossible to say	Probably true	Definitely true

2. The second man will also have a sleep during the afternoon.

Definitely untrue	Probably untrue	Impossible to say	Probably true	Definitely true

3. The second man will also sharpen his knife on the trunks of small trees.

Definitely untrue	Probably untrue	Impossible to say	Probably true	Definitely true

4. The second man will also know how to get honey from a beehive by making a hole in the hive wall.

Definitely untrue	Probably untrue	Impossible to say	Probably true	Definitely true

Section two

The fact that humans nowadays almost all have blonde hair, which is the best colour to have in the open plains, whereas they used to almost all have black hair, which was good for the forest, is an example of adaptation by natural selection. Let's think about the period during which humans were evolving from being almost all black-haired to almost all blonde.

5. During this transitional period, individuals' hair became lighter over the course of their lifetimes. True or false?

True	False

6. During this transitional period, children had on average lighter hair than their parents. True or false?

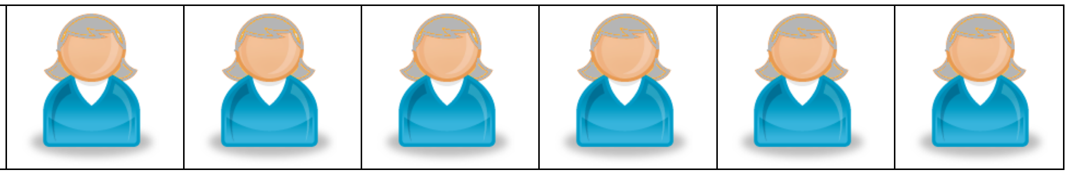
True	False

7. During this transitional period, genetic mutations which make hair lighter were more likely to occur than they had been before the forest was cut down. True or false?

True	False

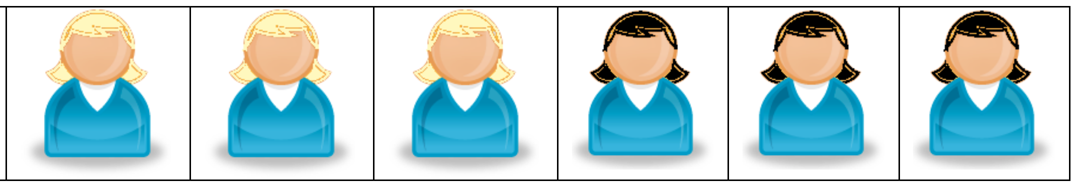
8. Which of the two diagrams, A or B, best represents the way the population would have looked half way through the transitional period of evolution?

A



or

B



9. Which of the following two statements is the best description of the process which led to almost all humans being blonde?

A	The proportion of individuals in the population with blonde-haired parents gradually increased

B	The species had to change itself to avoid being made extinct by competing species

10. If the climate and vegetation in Madagascar suddenly change, what is most likely to happen to humans?

A	They will go extinct, to be replaced by another species better adapted to the new conditions

B	Humans will continue to live there, but their behaviour and appearance may be different

11. Evolution is often said to be driven by competition. Against what is a person most directly competing in evolutionary terms?

A	Other people

B	Other species of animal

12. How, in general, would you expect a person to behave?

A	In such a way as to benefit the species
B	In such a way as to gain the maximum benefit for his or her self

13. Suppose that one man learns to swim during his lifetime, and as a consequence develops big muscles in his arms. A few generations later, which people will have big muscles in their arms?

A	All people
B	Only the direct descendants of the man that learned to swim
C	Only those people who swim themselves
D	No people

14. Millions of years ago, humans diverged from an ancestral species of ape. If you had access to pictures of each generation of the population that lived over this long period, which of the following would you see?

A	Individuals became gradually more like modern humans over the generations, but there was no particular point at which humans suddenly appeared
B	There was an identifiable moment when the human species evolved from the ancestral species

Section three

In this section, there are some questions about you.

1. How interested are you in the theory of evolution?

Not interested at all	Not very interested	Neutral	Quite interested	Very interested

2. How likely do you think it is that the theory of evolution is true?

Not likely at all	Not very likely	Neutral	Quite likely	Very Likely

3. To what extent are you convinced that there can be change within a species over time?

Not at all	Not much	Neutral	Somewhat	Very

4. To what extent are you convinced that one species can change into another species over time?

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None	Not much	Some	Considerable	A lot