## Title
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# Articulating an Explanatory Schema: A Preliminary Model and Supporting Data

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**Abstract**

The schema repertoire model claims that an explanation is constructed by selecting and articulating a schema. Novice evolutionary explanations are analyzed to identify the relevant schemas and to demonstrate competition among schemas. An intervention study shows that a newly acquired schema does not necessarily win the competition against previously acquired schemas. The difference between schemas and beliefs is emphasized.

## Explanation

Explanation is a central topic in the cognitive sciences. Systematic analysis of what it means to explain began with Hempel and Oppenheimer's (1948) now classical claim that an explanation is a deductive argument, a claim that philosophers have since replaced with an emphasis on semantic models (Thompson, 1989) and causal relations (Salmon, 1984). Artificial Intelligence researchers realized early that expert systems ought to explain their reasoning to users (Clancey & Shortliffe, 1984) and much research in computational linguistics is aimed at providing computer systems with such explanatory capabilities (e.g., Moore & Paris, 1993). To cognitive psychologists, explanation is an intellectual performance with measurable effects on learning (Chi, DeLeeuw, Chiu & LaVancher, 1994) and a close relation to the elusive concept of understanding (Schank, 1986). In educational research, the ability to construct an explanation is often used as a criterion of successful learning.

In spite of the effort allocated to the topic, central questions about explanation remain without widely accepted answers. What is an explanation? What are the knowledge structures that underpin explanatory competence? How are such structures acquired and applied?

We propose a preliminary model of the cognitive processes involved explanation. Like the prior formulation by Schank (1986), the model puts the concept of an explanation pattern at the center. The model is as yet informal, but makes qualitative predictions. Two corpora of students' explanations of biological adaptations are analyzed to identify their explanatory schemas and to demonstrate intra-individual competition among schemas. Two attempts to teach the Darwinian explanation schema show that successful schema acquisition does not have the effect on the students' explanations that our common sense concept of learning would lead us to expect.

## The Schema Repertoire Model

Consider an everyday *explanation question* like, "Why is flight X delayed?", where X is some particular flight. Answers that come to mind include equipment malfunction, bad weather, a tardy pilot, delays elsewhere in the air traffic system, airline management problems and so on.

Several observations are pertinent. First, because we can access these answers in the absence of specifics (which flight? when? where?), we must be accessing *explanation types* instead of particular explanations. Second, each explanation type captures a prototypical *genesis* for flight delays. Equipment problems, bad weather, etc. signify typical ways in which a flight comes to be delayed. Third, the explanation types are relatively *abstract*. To explain a particular flight delay, one must supply the specifics (which malfunction? what weather? delays where?). Fourth, there are *multiple* explanation types, so the process of explaining a particular delay requires selecting one schema over others.

Figure 1 depicts a model that incorporates these observations. The long horizontal line separates the observables (below the line) from the hypothesized cognitive processes (above the line). Time runs from left to right, roughly speaking. The iconography is of course arbitrary, but the claims expressed by it are not.

The central claim, adopted from Schank (1986), is that explanation types are not only in the eye of the beholder. Explanations fall into types because they are generated from explanatory *schemas* in the knowledge base of the person doing the explaining. Schemas are abstract (Ohlsson, 1993; Ohlsson & Lehtinen, 1997).

The ellipses in the middle of Figure 1 depict the explainer's repertoire of schemas. A question *activates* multiple schemas, to varying degrees. A second claim of the model is that there is a process of *selection* among those schemas that compete for control of the explanatory discourse (depicted in Figure 1 as a repetition of the outline of the winning schema to the right.)

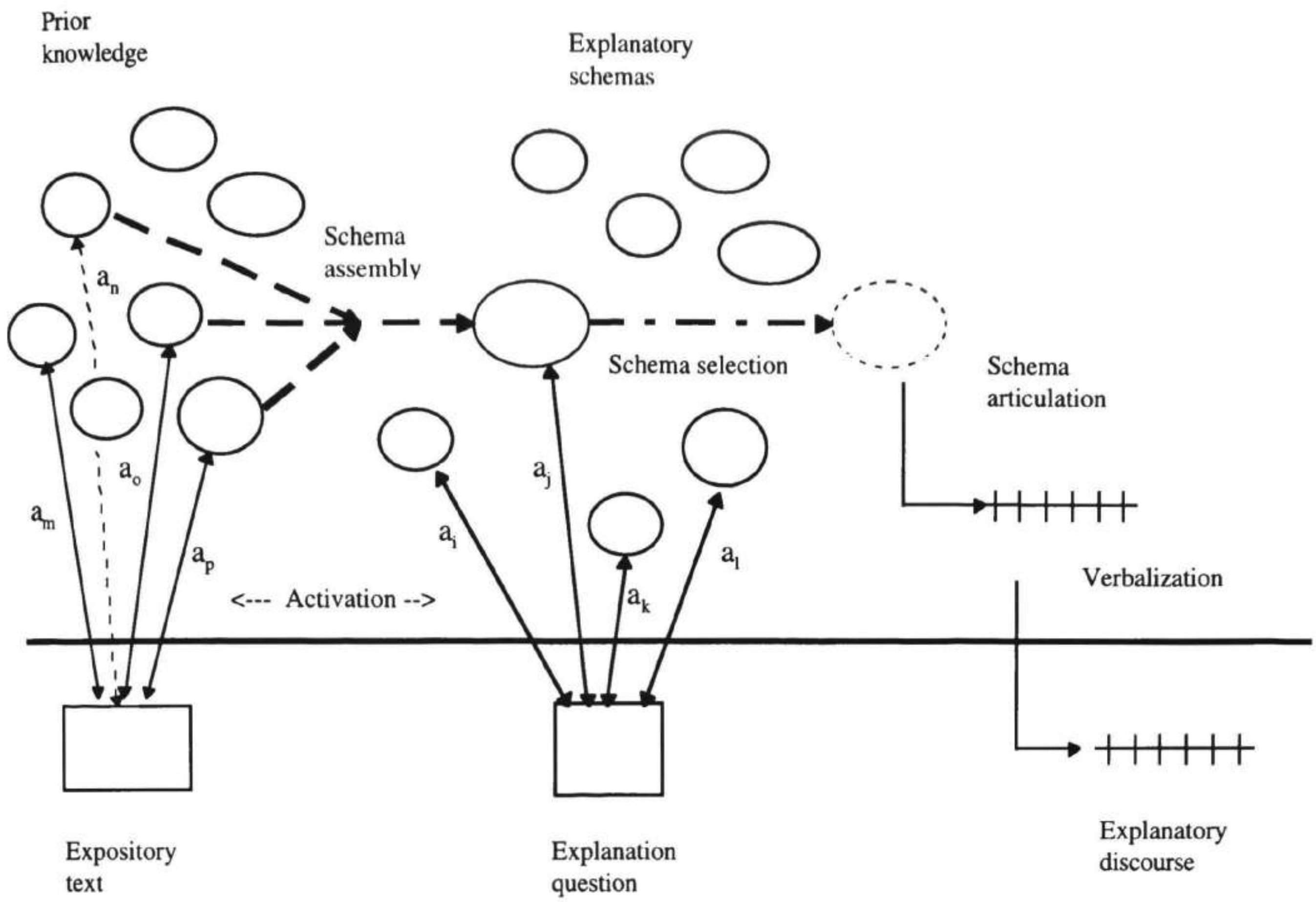


Figure 1: A model of the acquisition, selection and articulation of an explanatory schema.

Because an explanatory schema is abstract, there must also be a process *schema articulation* (Ohlsson, 1992) in which the winning schema is applied to generate a particular explanation (depicted by the upper hashed line to the right), which may or may not be *verbalized* (lower hashed line) depending on context and conditions.

The articulation process constructs a story conforming to the type specified by the schema about the event mentioned in the question. To tell a *delays-elsewhere* story about a flight out of Chicago is to spell out the current weather conditions in another locale, the connection between that locale and the flight (e.g., the aircraft is there) and the consequences of the weather conditions (e.g., the aircraft cannot take off). Different *delays-elsewhere* stories differ in locales, type of weather, impact on the relevant flight and so on. To articulate the *delays-elsewhere* schema is to flush it out with the facts about a particular target event.

The left part of Figure 1 depicts the process of acquiring a new schema in response to instructional input, most typically an expository text. During reading, the text is assimilated to prior knowledge; for the sake of brevity, let us conceptualize prior knowledge as consisting of nothing but schemas. The result of assimilation is then a new knowledge structure that both instantiates an existing schema and represents the message of the text. (Low level reading processes are deliberately ignored here.)

If the text describes an explanatory schema or theory (as is the case in, for example, science education), then two consequences follow. First, successful comprehension should produce a new explanatory schema, to be inserted into the repertoire and so be subject to competition when an explanation question is encountered. Second, the prior schema that guides the assimilation of such a text must be more abstract than the schema communicated by the text.

Finally, consider what happens when there is no prior schema to which the text can be assimilated. Either the text is not understood properly or else a new abstract schema is constructed during reading. The model claims that schema construction is not a matter of induction but of *assembling* prior schemas into a new configuration (Ohlsson & Lehtinen, 1997). This process is depicted by the converging arrows to the left in Figure 1.

The schema repertoire model is as yet too informal to generate quantitative predictions. However, it suggests new ways to analyze data and it does predict some qualitative properties of explanations. We report two empirical studies of novice explanations in biology which illustrate and support those predictions.

## A Schema Repertoire For Biology

Evolutionary biology is a rich source of examples of explanations and explanatory knowledge. The basic explanation question in this domain is, "Why did species X evolve trait Y?" or, "How did species X acquire trait Y?". I will refer to this as *the phylogenetic question*. There are other types of questions, e.g., "Why is species X distributed geographically in the way it is?", but they will not be dealt with in this paper (see Kitcher, 1993, for a discussion of question types in evolutionary theory). What types of explanations do students construct in response to the phylogenetic question? Our theory implies that their explanations should fall into a set of types, corresponding to schemas acquired in other contexts.

**Method** Two groups of psychology students, 50 from the University of Pittsburgh and 95 from the University of Illinois at Chicago, participated in return for course credit. The two sets of explanations they generated will be referred to as *the Pittsburgh corpus* and *the Chicago corpus*.

The participants were given sheets of paper with a version of the phylogenetic question written across the top and asked to write down their answers. The Pittsburgh participants were asked why dinosaurs became so large and how birds developed flight, while the Chicago participants were asked those two questions, plus how tigers got their stripes. Both groups were encouraged to ignore factual issues (e.g., the climate millions of years ago) and to invent an explanation that seemed plausible to themselves. They were given no help or instruction.

**Results** The answers fell into recognizable types, including the following (paraphrases of observed explanations in parentheses):

(a) *Environmentalism*. Traits develop when the environment provides a demand or an opportunity. (Dolphins needed to reach food in the water, so they became aquatic.) (b) *Survival*. Both the relevant trait and its opposite were once present in the species, but all members without the trait died. (There were once both large and small dinosaurs, but all the small ones were eaten.) (c) *Creationism*. Animals were created by a deity with the characteristics they have today. (Dinosaurs were created large so as to flatten the Earth in preparation for the coming of humans.) (d) *Training* (Lamarckianism). Traits are caused by the activity of the organism. (Birds flapped their proto-wings until they grew large enough to support flight.) (e) *Mutationism*. The trait suddenly appeared in a small number of organisms. (One day a bird was born with wings.) (f) *Mentalism*. Animals decide, discover, learn or are taught new behaviors (traits?). (A bird discovered that it could fly and taught its offspring.) (g) *Crossbreeding*. Traits arise via interbreeding between species. (A black panther and a tiger without stripes mated and produced a tiger with stripes.) (h) *Dissemination*. Organisms with the trait gradually increased in numbers until they replaced those without. (In every generation there were more and more tigers with stripes.)

Once the eight explanation types had been identified, the data were analyzed by two coders. The coders were given a definition and examples of each explanation type. They went through cycles of coding examples, discussing disagreements and coding additional examples until 85% of their codes were identical. They then coded the target data set independently of each other. The first author arbitered any disagreements. The coders were instructed to look for expressions of the eight explanation types, as opposed to classify each answer into a single type. Consequently, an answer could be scored as providing evidence for more than one type.

The frequency of each explanation type in each group is shown in Figure 2. To facilitate comparison between the two unequal-sized corpora, the raw frequencies have been converted to proportions. That is, a value of .40 for explanation type X in corpus Y means that 40% of the explanations in corpus Y were coded as expressing ideas that are parts of explanation type X.

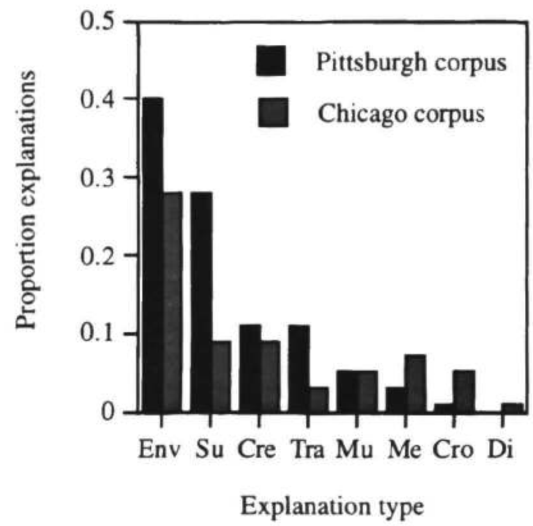


Figure 2: Frequency of eight explanation types in two novice corpora, expressed as proportions of the total number of explanations in each corpus.

Seven of the eight explanation types occurred in both groups. (There were no dissemination explanations in the Chicago corpus.) The explanation types were applied with varying frequency, but there is a rough correspondence between the two corpora. The participants regarded the environment and individual survival as key factors in evolution (as do biologists). Creationism and Lamarckianism--often claimed to be the most common ideas among biology novices (Ferrari & Chi, in press; Samarapungavan & Wiers, 1997)--are not dominant in these data. In the Pittsburgh corpus, training (Lamarckianism) is fourth from the top in frequency; in the Chicago corpus, seventh. There are other non-Darwinian explanation types (e.g., mutationism, mentalism, crossbreeding) that are as frequent or more frequent.

## Evidence For Schema Competition

The schema repertoire model claims that in the typical case, a person is in possession of a repertoire of qualitatively different explanatory schemas which are more or less relevant for a given explanation question, and that these schemas compete for control of the answer to the question. If so, we would expect single individuals to give one type of explanation in response to question X and a different type in response to question Y.

**Single cases** Compare the two following two answers to the dinosaur and tiger questions, produced by the same student in the same one-hour session:

*Dinosaurs who existed at the period of time had no competition for food source, therefore some species of dinosaur who eat as much food as they want to without any other animal stopping it. This led to the gigantic size of some dinosaurs.*
[Chicago corpus, S32, Dinosaur problem]

*The tiger was originally all black. After thousand of years, the black color of the tiger's outer body began to fade and continued to fade for generations. The black faded into the stripes we see on the tiger today. Generations from now, we may see no stripes on the tiger.* [Chicago corpus, S32, Tiger problem]

S32 explains the size of dinosaurs by referring to their eating habits. However, the explanation for the tiger's stripe is qualitatively different: It refers to a natural tendency (a type of explanation we did not yet code for) and it contains no reference to the tiger's behavior.

A similar diversity of explanations is evident in the following pair of explanations from student S55:

*I think that some species of dinosaurs became so gigantic because of the warm climate. Many other animals back then were gigantic too. I think because of the pleasant temperatures dinosaurs could develop very well. It was the temperature, very cold temperature, that cause dinosaurs to go extinct. Their bodies were mainly dependent of high, warm temperatures.*
[Chicago corpus, S55, Dinosaur problem]

*I would assume that the tiger got its black stripes from some kind of biological cross between lion and black panther. Because of the genetic combination some of the characteristics of black panther blended with some characteristics of the lion's genes.*
[Chicago corpus, S55, Tiger problem]

The first explanation is a pure environmentalist explanation; the climate was warm and this apparently constitutes an opportunity to grow in the opinion of this student, perhaps in analogy with the fast growth of plants in warm climates. The second explanation is a crossbreeding explanation that does not mention the environment.

**Broader view** Table 1 shows quantitative evidence for between-question shifts among explanation schemas. We identified all pairs of successive explanations for which both explanations could be classified in one of the eight explanation types listed above. Next, we calculated the proportion of such pairs in which the second explanation was of the same type as the first. This quantity is an estimate of the conditional probability that a student answers question N+1 with an explanation of type X, given that he or she answered question N with an explanation of type X.

As Table 1 shows, the probability of switching between explanation types was .43 in the Pittsburgh sample and .59 in the Chicago sample. Hence, the students switched explanation types as often as not. Because the explanation types are qualitatively different, these data provide no support for the idea that students operate with consistent explanatory frameworks (Ferrari & Chi, in press; Samarapungavan & Wiers, 1997; Tamir & Zohar, 1991).

**Table 1.** The probability that a student's answer to question N+1 is of the same (or different) type as that student's answer to question N.

| | Probability | |
|---|---|---|
| Corpus | Same | Different |
| Pittsburgh | .57 | .43 |
| Chicago | .41 | .59 |

Even stronger evidence for schema competition is provided by cases in which a single answer contains within itself evidence of multiple explanation types. The following example contains at least three distinct explanations:

*The stripes are just a variation of nature. They help the tiger stand out from all the rest. Its also a warning signal for other animals to stay away. It could also be used in mating. They could use their stripes to show off for the women. It also could have been that they were a genetic defect that got amplified and stayed through the years.*
[S9, Chicago corpus, Tiger problem]

This student thus proposed three qualitatively different explanations: that tiger stripes relate tigers to other species; play a role in courtship and mating; and constitute a genetic defect. There are no transitions in the student's text. It is as if each schema automatically took over as soon as the previous one had spent its potential to control verbal output.

## Acquiring A New Schema

A biologist's answer to the phylogenetic question draws upon five distinct ideas: (a) Variation. The members of a species are not all alike. (b) Selectivity. Some species members are better adapted than others. (c) Replication rate. Better adapted members reproduce more. (d) Inheritance. Reproducing members of the species pass on their traits to the next generation. (e) Accumulation. Small changes from generation to generation eventually add up to a large change. Kitcher (1993) refers to the explanation schema built out of these five ideas as the *simple individual selection* schema (p. 28).

The schema repertoire theory makes a counterintuitive prediction about what a student's behavior should look like after acquiring the Darwinian schema: Very little should change. The reason is that there is no process in the model that erases old schemas. New schemas are added to the repertoire, but they do not replace previously acquired schemas. Hence, contrary to the wishes of a hopeful teacher, there is no reason to expect a newly acquired schema to dominate a student's explanatory discourse, *even if that schema has been successfully acquired.* Instead, the new schema competes on equal terms with all the other schemas in the repertoire, winning sometimes and loosing sometimes. Hence, the acquisition of a new explanation schema should increase the diversity of a person's explanations, but not make their discourse conform exclusively to the newly acquired schema.

To investigate this prediction, we conducted an intervention study. As in the base line study, the data collected consisted of written answers to phylogenetic questions. The answers were coded for presence or absence of the five Darwinian ideas described above. (The coding method was the same as in the base line study.) Each explanation was assigned a score between 0 (no trace of any Darwinian idea in the explanation) and 5 (all five Darwinian ideas are expressed in the explanation). This *Darwin score* is a rough measure of how closely an explanation conforms to the Darwinian schema.

**Method** Two groups of students were taught the Darwinian explanation schema with two different instructional methods. (a) Text only. Twenty undergraduate psychology students from the University of Pittsburgh read a two-page exposition of Darwin's' theory that emphasized the five ideas described above. They were given no other help, instruction or preparation. After reading, they were asked to explain the size of the dinosaurs and the tiger's stripes. (b) Text plus feedback. Twenty psychology undergraduate students read the same expository text as the students in the text only group. They then answered five phylogenetic questions, pertaining to horses, tigers, ducks, polar bears and dinosaurs. After each answer, they received feedback in the form of an expert answer to that question. That is, the participants read a phylogenetic question, wrote down their own answers, turned the page and read a Darwinian answer to that same question.

**Results** Given the famously poor science knowledge of U.S. students and the religious opposition to the theory of evolution, one would not expect young adults in the U. S. to spontaneously generate Darwinian explanations. The data confirm this sad expectation. Figure 3 shows the frequency distribution of Darwin scores in the base line study. (The Chicago and Pittsburgh corpora were combined in this analysis.) For ease of comparison, the frequencies displayed in Figure 3 are expressed as proportions of the number of explanations produced by each group. That is, a value of .20 for a Darwin score of 2 in study X means that 20% of the explanations produced in study X contained 2 out of the 5 Darwinian ideas.

Without instruction, zero on the Darwin scale was the modal value. Approximately 35% of the explanations in the base line group contained no trace of the five Darwinian ideas, and an additional 30% expressed no more than one of those ideas. None of the 385 explanations from the base line groups contained traces of all five Darwinian ideas.

The distributions for the two intervention groups are very different. A Darwin score of five is the most frequent value. Over half the explanations contain either four or five Darwinian ideas, while less then 10% have zero such ideas. In short, the interventions worked in the sense that they increased the students' use of the target ideas.

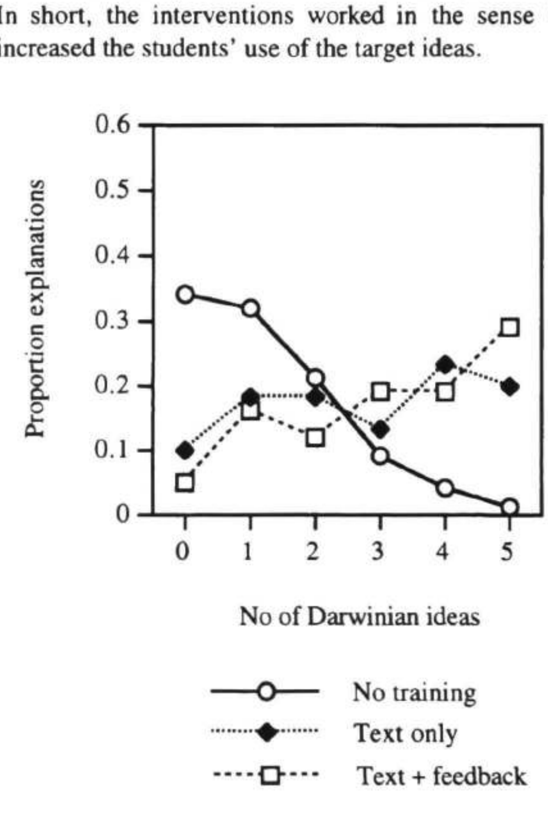


Figure 3: Frequency distributions for the number of Darwinian ideas per explanation (range 0-5) in each of four studies. The frequencies are expressed as proportions of the total number of explanations produced in each study.

It is correct but misleading to summarize Figure 3 by saying that the students learned something about Darwinism. The schema repertoire theory warns that the acquisition of the Darwinian schema does not cause prior, non-Darwinian schemas to disappear. Figure 4 shows that this warning is indeed warranted. In this analysis, we asked how many different explanation types each participant used in each of the three studies. Once again, we show the entire distributions instead of the merely the means and we have converted frequencies to proportion for ease of comparison.

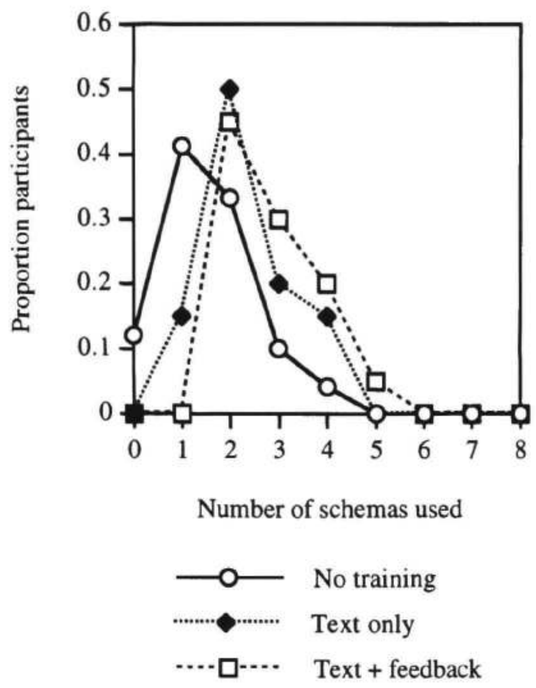


Figure 4. The frequency distribution of participants who used N of the 8 explanation types (N = 0, 1, ..., 8), expressed as the proportion of all participants in each study.

The result is clear: Successful acquisition of the Darwinian schema did *not* lower the tendency to use the eight non-Darwinian explanation types. This is what the schema repertoire theory predicts. There are no processes that erase prior schemas, and there is no guarantee that a newly schema will win over the prior ones on every relevant explanation question. Hence *successful* schema acquisition will not necessarily affect a student's explanations.

## Discussion

The theory presented here differs from alternative theories by insisting on the distinction between schemas and beliefs or explanatory frameworks (Ferrari & Chi, in press; Samarapungavan & Wiers, 1997; Tamir & Zohar, 1991). It is highly unlikely that the explanations we recorded expressed entrenched beliefs or consistent frameworks. The participants in our studies had probably never thought about how this or that animal acquired such-and-such a trait. They made up their answers in response to our questions by articulating schemas acquired in other contexts.

Where did these schemas come from? Consider crossbreeding. Many students have come across the concept of crossbreeding in the context of animal breeding. Also, crossbreeding is only a specialized version of a yet more abstract schema of blending or mixing: Combine X and Y and you get something that is intermediate between X and Y. The latter schema applies to colors, spices, decorating styles and many other everyday phenomena. Similarly, the training schema (Lamarckianism) is strongly present in everyday culture: Exercise and your limbs will grow bigger. The origins of the other schemas in everyday experience is no more mysterious.

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