Third Misconceptions Seminar Proceedings (1993)

Paper Title: Model Statements of Student Conceptions Regarding Evolutionary Change
Author: Moody, David E.

Abstract: At the core of the theory of evolution stands the fundamental principle of natural selection. The legitimacy Darwin succeeded in conferring on the theory was due to the plausibility of natural selection as a mechanism of evolutionary change. Half a century prior to the appearance of *The Origin of Species by Means of Natural Selection*, Lamarck (1809) had offered a full-scale theory of evolution, but one that was fatally flawed by the inadequacy of the proposed mechanism of change. The proper presentation of evolution in the classroom is a complex, multi-faceted affair; but the essence of successful instruction must be to convey the meaning and appropriate application of the principle of natural selection.

Keywords: Concept Formation,Testing,Research Methodology,Cognitive Formation,Cognitive Measurement,Cognitive Tests,Concept Teaching,Comprehension,Cognitive Development
General School Subject: Biological Sciences
Specific School Subject: Biology
Students: Secondary

Macintosh File Name: Moody - Evolution
Release Date: 4-21-1994 A, 11-9-1994 I

Publisher: Misconceptions Trust
Publisher Location: Ithaca, NY
Volume Name: The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics
Publication Year: 1993
Conference Date: August 1-4, 1993
Contact Information (correct as of 12-23-2010):
Web: www.mlrg.org
Email: info@mlrg.org

A Correct Reference Format: Author, Paper Title in The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Misconceptions Trust: Ithaca, NY (1993).

this paper on to a colleague, please make sure you pass it on intact. A great deal of effort has been invested in bringing you this proceedings, on the part of the many authors and conference organizers. The original publication of this proceedings was supported by a grant from the National Science Foundation, and the transformation of this collection into a modern format was supported by the Novak-Golton Fund, which is administered by the Department of Education at Cornell University. If you have found this collection to be of value in your work, consider supporting our ability to support you by purchasing a subscription to the collection or joining the Meaningful Learning Research Group.

----- -----

<u>Model Statements of Student Conceptions Regarding Evolutionary Change</u>

David E. Moody, Ojai, CA, U. S. A.

At the core of the theory of evolution stands the fundamental principle of natural selection. The legitimacy Darwin succeeded in conferring on the theory was due to the plausibility of natural selection as a mechanism of evolutionary change. Half a century prior to the appearance of *The Origin of Species by Means of Natural Selection*, Lamarck (1809) had offered a full-scale theory of evolution, but one that was fatally flawed by the inadequacy of the proposed mechanism of change. The proper presentation of evolution in the classroom is a complex, multi-faceted affair; but the essence of successful instruction must be to convey the meaning and appropriate application of the principle of natural selection.

Among the many reports of students' preconceived ideas about the world and the way it works, a few have touched upon the present topic. Deadman and Kelly (1978) described an interrelated nest of notions held by boys ages 11 to 14 regarding evolution and heredity. Most of the subjects held a somewhat Lamarckian idea of evolutionary change: the characteristics of species were the result of the adaptive action of the individual organism; such self-induced changes were inherited by the individual's offspring. Here as elsewhere (cf. Wandersee, 1986; Duschl, 1990), the cognitive development of the student recapitulates that of science.

Brumby (1979) demonstrated that the Lamarckian idea of change was also well established in the thinking of students of college age. Her original study, conducted with students in England, was replicated with students in Australia whose courses in secondary school were designed to prepare them for careers in medicine (Brumby, 1984). Bishop and Anderson (1990) reported comparable results with college students enrolled in a biology course for non-majors in the United States. The net effect of the foregoing findings was to confirm a systematic misunderstanding of the central idea of evolutionary theory. The dominant idea among students suggested a teleological idea of change (individual organisms strive to improve themselves) and implicitly subscribed to the long-discredited notion of the inheritability of acquired characteristics.

A corollary of these findings was an indictment of standard forms of classroom instruction in biology. Both Brumby and Bishop and Anderson maintained that understanding of natural selection was equally poor among those students who had, and those who had not, enrolled in courses in biology at the secondary level. Their conclusions, however, were based not upon any direct examination of students of secondary age, but rather on comparisons among students enrolled in college. In the context of a larger investigation into characteristics of instruction in evolutionary theory at the secondary level (Moody, 1991), this question warranted examination in a more straightforward fashion. If classroom instruction has no effect at all on misconceptions, researchers will be disinclined to examine such instruction in further detail. If, however, instruction in fact enjoys some success, the further study of it is in order. Among the considerations at issue is Shulman's (1987) injunction not to overlook the wisdom inherent in hard-won pedagogical content knowledge.

The studies referred to above described a widespread preconception in discursive terms. Bishop and Anderson provided in addition a graphic representation which contrasted the dominant conception with a corresponding depiction of natural selection. In so doing, they presented a *model* of student thinking rather than a description of it. (Such a distinction may seem somewhat fine and elusive in the abstract, but in practice it assumes a concrete significance, as is demonstrated below.) Conspicuous by its absence, however, was a corresponding *verbal* model of the misconception. In the present study, the discipline of producing a verbal model of cognition, rather than a visual model or a mere description, introduced a degree of rigor that proved advantageous in the subsequent analysis of instruction.

METHOD AND PROCEDURES

A short, open-ended essay prompt was administered to 209 students in four schools. All the students were enrolled in a standard, year-long course in biology at the secondary level. The prompt was administered in the fall and again in the spring, with an interval of at least one month preceding and following the unit on evolution.

The schools were selected to represent a diversity of educational contexts. One was a small (population < 1000) public school in a semi-rural setting (school A); one was a private parochial school (school B); one was a non-sectarian private school noted for the high calibre of its academic program (school C); and one was a large (population > 2000) public school in an urban setting (school D). All were located in the coastal area of southern California, north of Los Angeles. Schools A, B, and C each employed only one teacher of biology, and all the biology classes taught by that teacher participated in the study. Scheduling difficulties in school D (*e.g.*, students changing instructors at the semester break) restricted participation to a single class of students.

The assessment of student cognition was greatly facilitated and simplified by the work of previous investigators. The open-ended prompt shown below was adapted from a multiple-choice question employed by Bishop and Anderson. Brumby had demonstrated the efficacy of an open-ended format in her work with students of college-age, but a written question of this kind had not previously been attempted with students at the secondary level. One outcome of this study was to show that Brumby's approach could elicit appropriate responses for this topic from secondary students.

In contrast to the test items employed by Bishop and Anderson, Brumby had been careful to exclude any mention of scientific terms such as *evolution, natural selection*, or *survival of the fittest*. This provision was preserved in the present study in order to help elicit responses based on students' independent comprehension of the question. Other efforts to ensure that students would feel free to present their own understanding included teachers' oral instructions stating explicitly that "This is not a test." Students were not required to put their names on their papers; they were told their responses would not be graded; and the written instructions that appeared on their papers asked them to give the answer that "makes most sense to you."

The analysis of student thinking and the construction of the model statements were based upon responses to the following question:

> Water birds, such as ducks, have webbed feet. This makes them fast swimmers. Other birds do not have webbed feet. How might this difference have come about?

RESULTS

Inspection of the responses given to the foregoing prompt revealed that the large majority could be grouped into five categories. Close examination of the responses associated with a given category in turn made it possible to articulate a model form expressing the category's essential characteristics. *The model form represents the complete statement of the thought that, in most cases, received only partial or fragmentary expression in the responses of the individual students*. Accordingly, it is important to consider the model statements in conjunction with several of the actual responses to which the model corresponds.

The first category contained by far the largest number of responses. Partly for this reason, the category was subdivided in the following manner. The model for Category 1a states that changes in species occur because individual organisms acquire those physical characteristics they need for survival. Category 1b describes the role of the environment in stimulating organisms to undergo the kind of adaptive change described in 1a. The former category emphasizes the element of *need,* whereas the latter emphasizes *adaptation*. By examining the logic of these responses, it is possible to see that they represent opposite sides of one explanation. To be more precise, they describe a cause and effect relationship, *i.e.*, an animal's need, arising from environmental pressures, is the cause which induces the effect of adaptation. Model statements for categories 1a and 1b, with examples of each, are shown below.

1. a. <u>Need</u>: An animal species acquires or is given those characteristics that it needs. If a species of bird needs webbed feet in order to swim fast, to catch food, to escape predators, to survive, then it will develop webbed feet.

Other birds do not need webbed feet. Ducks need them because they practically live on the water. They need to be able to swim fast. Others birds need to fly rather than swim, webbed feet would reduce the flying speed of birds. Ducks can't fly for a long period of time, others without webbed feet can.

ducks spend most of their time in water so they need and use the web feet. As for flight birds they do not need the weeb feet, they need toes and nails to hold and grip onto whatever they might sit on.

b. <u>Adaptation:</u> The physical characteristics of species represent adaptations to the environment, acquired over time. Webbed feet are an adaptation to the environment of water.

This occured because over the hundreds of years the birds have been on this planet they learned to adapt to the environment in which they lived. Some birds have wings where as others don't. Some have long beeks where as others don't It all depends on the situation and standard of living they have aquired and adjusted to.

These birds are suited to their environment and lifestyle. The webbed-feet birds live in land where there is a great deal of water. The others live in drier land and some, like hawks, hunt, so they have feet with talons so they can grip prey well. They can also grip branches better than birds with webbed feet.

While Categories 1a and 1b expressed the interrelated elements of need and adaptation respectively, Category 1c represented responses in which the two elements were expressed together. As such, no new model statement for this subcategory was constructed, but examples of such responses are shown below.

> All creatures have to adapt to their enviorment. If a bird lives near a body of water and it needs food then through the corse of time the bird is going to go through changes through evolution that will alow it to get food out of the rich source of the water.

> Water birds have webbed feet as an adaptation to their environment. Other birds do not because their is no Biological need for them, as in water fowl it is a way to survive.

It should be noted that the perspective represented by Category 1 is Lamarckian only by implication. Need is something experienced by the individual organism, and its association with the element of adaptation *implies* the adaptative action of the individual. By introducing the element of need, students are implying that goal-directed behavior produces change; the further implication is that those changes are transferred from the individual to its offspring. Thus, responses in Category 1 offered no explicit account of how the changes in question came about. The remaining categories have in common that they do provide some such explanation. To that extent, these categories represent an improvement over the responses characteristic of Category 1.

Responses in the model statement for Category 2 invoked an outside agency, a divine being, whose action is responsible for the attributes of organisms. Although God is referred to in the model statement, as well as in many of the student responses, some responses adopted this explanation without mentioning God by name. Both varieties are shown below.

2. <u>God:</u> That is the way God made them.

That's how God made them that way. We should not try to figure out why an animal came about a certain why. God created it, and we should be happy with it.

Well when ducks where brought to this world they already had web feet. and other birds have other things that ducks don't have. That is how that might of came about.

The model statement for Category 3 expresses an appeal to genetics. The mechanism of inheritance is an element in the sequence of steps associated with evolution, but Category 3 fails to account for the relationship between the trait and the environment. A characteristic such as webbed feet has utility in one environment but not another. As shown in the following examples, the genetic explanation neglects to take this relationship into account.

3. <u>Genetic Inheritance</u>: An animal's physical characteristics are the result of the genetic contributions of its parents. Webbed feet in birds may have resulted from a bird mating with a reptile that had webbed feet, for example.

I would say it is in the genes. If a water bird happened to, at one time, mate with another bird without webbed feet then they would produce some baby ducks with feet and some without. Or even if a duck with webbed feet mated with a duck with, perhaps, a different kind of webbed foot though time and evolution those feet would eventually fade away.

Maybe long ago when all the dinosours were on earth some kind of fish had little legs to be able to walk out of water for short periods of time and some bird was near and for some odd reason and way reproduced.

The model statement for Category 4 represents an explicit version of the Lamarckian explanation of acquired characteristics. It is the most successful of the explanations reviewed thus far in that it not only posits a mechanism whereby traits may increase in a population, but one that relates the adaptiveness of the trait to its environment.

> **4. <u>Acquired Characteristic</u>: Characteristics acquired by the individual are passed on to offspring. These characteristics may be acquired by deliberate action or as a by-product of interaction with the environment. Thus, webbed feet may occur because the toes stick together due to spending much time in the water.**
>
> When the water birds first started to live in water they might have streeched apart their toes to swim and then started to grow that way and after years of reproduction it stayed in a webbed kind of way. And the other birds didn't need to swim so they didn't streech their feet out so their's stayed normal.
>
> Thousands of years ago, a certain group of birds might have lived on or around water. Their feet would get used to the water causing a slight change in texture and form. As these birds began to reproduce, each generation living with the water, they feet began slowly changing to satisfy their need to swim.

The model statement for Category 5 expresses the accepted scientific account. As in other categories, most student responses exhibited only a fragmentary portion of the model form of this response.

> **5. <u>Natural Selection</u>: Physical characteristics with high survival value tend to increase in a population due to the increased reproductive success of individuals with those characteristics.**
>
> Maybe ducks long ago discovered that there was pluntyful food in the water and so started to dive for fish etc. Slowly

mutantes occured for webbed feet and this mutants got more food and lived longer because of this and breed more and soon the trait of webbed feet became a comon trait of all ducks.

> Some ducks had webbed feet and some didn't. The ones who didn't have webbed feet were caught by predators. The ones with webbed feet, being faster swimmers lived to breed more ducks with webed feet.

A final (sixth) category consisted of responses that could not reasonably be classified in the set of categories shown above.

> The ones with webbed feet swim more often than those without.

> Just different type of a bird

Some responses did not fit neatly into the designated category, or contained elements from more than one category. The intention of the model statements was to define central tendencies. Individual responses were matched to those models as closely as possible, while recognizing that a perfect fit was not possible in every case. The accuracy of grouping responses in the categories established was verified by three independent scorers. These three scorers and the investigator independently categorized the first 75 student responses obtained in the study. Of the 75 responses, in 58 cases there was complete agreement among the four scorers regarding the category in which a response belonged. In an additional 9 cases, three of the four scorers agreed with one another. In the remaining 8 cases, two scorers selected one category, while two selected another. These results are presented in Table 1.

Table 1
Extent of Agreement Among Four Scorers in
Categorizing 75 Student Responses

	# of Responses	% of Total

1. Complete four-way agreement	58	77%
2. Three of four agreement	9	12%
3. Two select one category, two another	8	11%
4. Four scorers select three categories	0	0%
5. Four scorers select four categories	0	0%
Total	75	100%

The distribution of responses by instructional treatment is shown in Table 2. It is apparent from inspection of the Table that, contrary to the inferences of Brumby and of Bishop and Anderson, the effects of ordinary classroom instruction on student misconceptions were by no means negligible. This conclusion was confirmed by statistical analysis, as shown in Table 3. The Table shows the number of responses expressing the principle of natural selection on the pre- and post-tests by school (instructional treatment). In two of the four schools, the effects of instruction were pronounced ($p < .001$).

Table 2
<u>Distribution of Pre- and Post-Test Conceptions of Students in Four Schools</u>

	School A pre	School A post	School B pre	School B post	School C pre	School C post	School D pre	School D post
N = ( )	(100)	(87)	(49)	(47)	(26)	(25)	(34)	(28)
1a. Need	24	15	14	9	4	1	4	3
1b. Adaptation	17	20	6	15	9	0	6	13
1c. Combination	20	13	8	6	8	3	7	6
2. God	10	2	8	3	0	0	7	2
3. Genetic Inheritance	6	4	2	1	1	0	0	0
4. Acquired Characteristic	9	3	1	0	0	0	3	0
5. Natural Selection	3	26	0	6	3	19	1	2
6. Unclass-ifiable	11	4	10	7	1	2	6	2

Table 3
<u>Correct Responses and Chi-square Values by Instructional Treatment</u>

School	Pre-test (a)/(b)	Post-test (a)/(b)	Chi-square	p
A	3/100	26/87	15.284	.0001
B	0/49	6/47	3.397	.0653
C	3/26	19/25	11.108	.0009
D	1/34	2/28	.336	.562
All	7/209	53/187	25.57	.0001

In each case, df = 1.
(a) = # of correct responses (b) = # of students

DISCUSSION

The model categories constructed here confirmed the findings of previous studies but added some important refinements. The teleological and Lamarckian flavor of the dominant conception of evolutionary change was quite evident. Several alternative notions appeared as well, however, including one in which the Larmarckian mechanism of change was made explicit. The sheer complexity and variety of existing conceptualizations comprised perhaps the foremost descriptive finding of the study. No simple one-to-one relationship obtained between the scientific construct and student thinking.

Contrary to the inferences of previous studies, significant effects of classroom instruction on the distribution of student conceptions were observed. A notable increase in understanding of natural selection was only the most conspicuous of these. All other categories of student response but one exhibited a decline in frequency following instruction. Category 1b, by constrast, which emphasized the concept of adaptation, showed an increase in frequency on the post-test in three of the four groups. This result merits some reflection.

The resistance of established preconceptions to extinction is well-established (Champagne, Gunstone, & Klopfer, 1985; Osborne & Wittrock, 1983). The present result suggests one mechanism by means of which the potential benefits of instruction may be thwarted. The foregoing discussion of model categories showed that the concept of adaptation is interwoven in student cognition with the notion of need. Together, these concepts determine a nexus of (mis)understanding in which the experience of the individual organism is prominent. Against this cognitive background, classroom instruction occurred in which the valid biological construct of adaptation was no doubt interwoven. The intended meaning of that construct, however, was evidently co-opted, as it were, into the existing (erroneous) network of student cognition. (See Lucas, 1971, for a discussion of ambiguities associated with 'adaptation'). In this process, a prevailing pattern of misunderstanding was reinforced rather than remediated. Such an outcome is designated here *the chameleon effect*, suggesting that a misconception may assume the outward appearance of the conditions to which it is exposed, without changing its basic nature or structure.

In spite of the apparent operation of a chameleon effect, significant increases in student understanding of natural selection were achieved in two of the four schools examined. This finding suggests that teacher expertise, or pedagogical content knowledge, is not negligible for this topic, and that its characteristics merit further examination.

On the evidence of the present study, the construction of model statements of student misconceptions has several salutary effects. It encourages a close textual analysis of student responses. It promotes the presentation of actual artifacts of student thinking in published reports of the investigator's inferences from those artifacts. It requires that equally careful attention be given to misconceptions of greater and lesser frequency in the student population. It facilitates consideration of nuances in student cognition that may carry implications for instruction. One such nuance in the present study consisted of the pronounced difference between an implicit and an explicit Lamarckian conceptualization.

A final benefit of the construction of model categories of cognition pertains to future studies. By risking such definitive statements of the forms of student thinking, the study invites further refinement in our understanding of this issue. A general and discursive description of student cognition is *ipso facto* difficult to challenge. A precise and rigorous model, by contrast, represents a fixed target for others to confirm or overcome.

CONCLUSION

Model statements of student conceptions of the process of evolutionary change were constructed based upon responses to an open-ended prompt. This approach facilitated resolution of the question whether ordinary classroom instruction has any effect on those conceptions. Additional benefits of the approach were noted.

It may be argued that so meticulous an examination of misconceptions is appropriate only for topics as fundamental to their disciplines as evolution is for biology. This is a practical and empirical issue that ought not to be judged in advance. Misconceptions are notoriously difficult to overcome, and any advances in methods of seeing what they are may prove instrumental in the effort to transform them.

References

Bishop, B. A., & Anderson, C. W. (1990). Student conceptions of natural selection and its role in evolution. *Journal of Research in Science Teaching*, 27, 415-427.

Brumby, M. (1979). Problems in learning the concept of natural selection. *Journal of Biological Education, 13,* 119-122.

Brumby, M. N. (1984). Misconceptions about the problem of natural selection by medical biology students. *Science Education, 68*, 493-503.

Champagne, A. B., Gunstone, R. F., and Klopfer, L. E. (1985). Effecting changes in cognitive structures among physics students. In L. H. T. West & A. L. Pines (Eds.). *Cognitive structure and conceptual change*. Orlando: Academic Press.

Deadman, J. A., & Kelly, P. J. (1978). What do secondary school boys understand about evolution and heredity before they are taught the topics? *Journal of Biological Education, 12,* 7-15.

Duschl, R. (1990). *Restructuring science education: The role of theories and their importance*. New York: Teachers College Press.

Lamarck, J. B. (1809). *The zoological philosophy*. Reprinted 1963 (H. Elliot, Trans.). New York: Hafner.

Lucas, A. M. (1971). The teaching of "adaptation." *Journal of Biological Education, 5*, 86-90.

Moody, D. E. (1991). *Student cognition and the structure of instruction in the theory of evolution*. Unpublished doctoral dissertation, UCLA, Los Angeles, California.

Osborne, R. J., & Wittrock, M. C. (1983). Learning science: A generative process. *Science Education, 67,* 489-508.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57,* 1-23.

Wandersee, J. H. (1986). Can history of science help science educators anticipate students' misconceptions? *Journal of Research in Science Teaching, 23,* 589-600.