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Teaching Biological Evolution Effectively

Biological evolution by natural selection, a concept that unifies biology and greatly influences our worldview, is taught in our school and college biology courses. However, students do not seem to understand the 'how' of the process of natural selection as put forward by Charles Darwin. Even special lectures integrating evolution with modern biology have largely failed to improve their understanding.

Introduction

Science educators are keen to find out why students tend to retain simple and often non-scientific explanations for natural phenomena, even after formal science teaching. The possible reasons for this include indifferently written textbooks, careless teaching, or incompatibility of the scientific view of a topic with the overall worldview of the student. The intrinsically difficult nature of a concept can also contribute substantially to the students' retaining naive ideas about the concept concerned.

Understanding Biological Evolution

A fundamental unifying concept in biology is that of evolution by natural selection as put forward by Charles Darwin. Indeed, this concept "... is central to our understanding of modern biological thought", as stated by Dobzhansky in 1973. Another fact, not realised by many in the teaching community, is that this theory can have a bearing on one's social and religious views. A proper understanding of the theory of evolution can help to answer fundamentally complex questions regarding origins, history and structure of living organisms, issues that are also addressed by most religious creeds and myths. Unfortunately, teachers in India give a perfunctory treatment of this important topic and, in the process, fail to excite and educate students regarding some of the most fundamental questions about our origins.

"Evolution is central to our understanding of modern biological thought"

Several studies in biology education have revealed that both students and teachers have a poor, often erroneous, understanding of evolutionary theory. The idea of evolution is today universally accepted by biologists and had been around long before Darwin. The problem arises with understanding the mechanism of evolution. There are two processes involved in evolution: the occurrence of variation among individuals and the selection of individuals with attributes that enable them to live longer and produce more offspring. Charles Darwin proposed the mechanism of random variation and natural selection to explain the evolutionary changes in different life forms. The development of genetics has clarified the origins of variation due to mutations and sexual recombination in a population.

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Though these concepts are not as abstract as several others in science (such as quantum mechanics or general relativity in physics), students often seem to be confused about them. This is probably because these Darwinian concepts make less intuitive sense than the Lamarckian ideas of the origin of useful variations, or creationist ideas of designing organisms for their efficient functioning. This confusion among students has been observed in several countries worldwide. A preliminary study conducted at the Homi Bhabha Centre for Science Education in Mumbai among junior college (+ 2) and BSc students both, non-biology and biology, in 1992 revealed that students largely think of evolution in Lamarckian terms, i.e. they believe that organisms when confronted with changes in the environment have an innate ability to acquire such characteristics (or exclusively experience changes) that would enhance their chances of survival in that new environment. Moreover, the characteristics acquired during the lifetime of an organism are then transmitted to future generations. Though formally aware of the random nature and low frequency of genetic variations, students instinctively tend to think that organisms have the ability to exclusively or preferentially experience only desirable (helpful) changes.

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The work reported here is an extension of the 1992 study in which an attempt was made to find out if teaching well focussed

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lectures that linked principles of genetics and population dynamics to evolution of life forms improved the understanding of this concept. Differential understanding, if any, among students who were exposed to such lectures and others, who were not taught genetics and evolution in this well focussed manner, was assessed. Moreover, an effort was also made to find out which aspects of Darwinism confuse students the most. Though of a preliminary nature, this work gives us a fairly good idea of students' understanding of this important topic. Our results largely coincide with those of other workers and could provide useful hints to teachers.

Development of the Test

A set of 16 questions on biological evolution prepared and used in our 1992 study was used for this study too. The questions were largely based on the contents of school biology textbooks. In fact, the biology texts prepared by NCERT discuss evolutionary ideas right from the 8th standard. The questions in the test were of multiple choice nature, with each statement followed by four choices based on Darwinian, Lamarckian, teleological and orthogenetic modes of evolutionary reasoning. The latter three arguments, among several others (often considered as myths or misconceptions), were used in framing the clues as students and teachers are known to think along these lines. For instance, students believe that: (i) organisms direct their own evolution in a given environment, and there is an inheritance of acquired characters (Lamarckian argument); or (ii) organisms evolve unidirectionally towards more complex forms (orthogenesis); or (iii) there is some purpose/goal in the movement – evolution – of organisms (teleological argument).

The Darwinian clues relied on the reasoning that no two members of a species are identical in all respects, and those with certain attributes/traits are fitter due to improvement in some functions necessary for survival and they leave behind more offspring which can also survive and reproduce in large numbers.

For the purpose of analysis, the questions were divided into two broad categories: recall type, and those needing conceptual understanding of the mechanism of evolution. While analysing the results, the individual Darwinian clues were also checked for the presence of the following ideas: (i) variants as the raw material for the selection to act upon; (ii) origin of the variants by random processes; (iii) the genetic basis of these variants and (iv) natural selection as reproductive success.

Student population

Two groups of students (Group A and Group B), each numbering 35 and studying in third year BSc in a college in Mumbai, were given the test.

Group A: The questionnaire was given directly to Group A. These students had been exposed to evolution lessons during their junior college (+2 level). In the degree college, they continued to study biology with microbiology as a special subject. Special lectures on biological evolution were not given to them.

Group B: These students were studying life science as their special subject. In addition to studying evolution at the junior college level, they were exposed to a course of about 50 lectures (each of 50 minutes) highlighting genetic basis of inheritance, the origin of variation, concepts of gene frequency in a population, the effects of selection and mutation on gene frequency and their relevance to the process of evolution.

The responses to the questionnaire were statistically analysed in terms of the percentage of students in the two groups (A and B) opting for Darwinian versus other responses.

Responses of Students

The responses of students to the questions in the first category, which assessed the general background information regarding evolution, suggest near-parity among the two groups of students for four of the six questions in this category (*Figure* 1). In the second category, answering questions correctly required proper

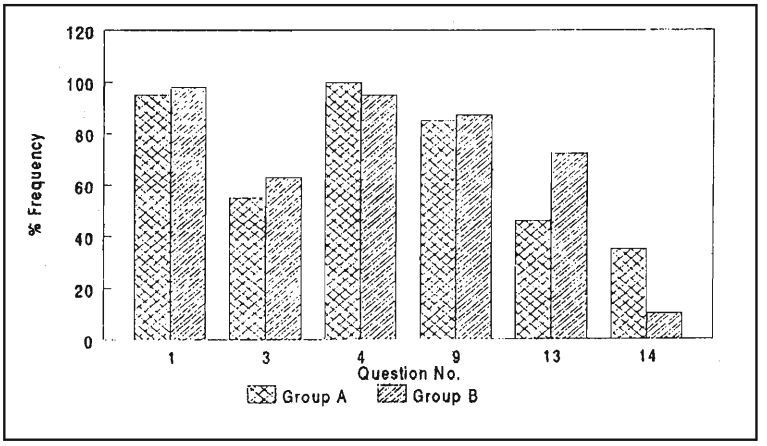

Figure 1. Responses of students to general questions on evolution (category 1): about origin of life on earth, temporal dimension, etc. Extra lectures (group B) have not improved students' understanding.

understanding of the evolutionary process. On the whole, group B students exposed to extra lectures performed better than group A (*Figure 2*). A careful look at individual questions and their responses, however, revealed that certain questions (5,7, 10 and 12) evoked less percentage of correct responses from students in both groups. The Darwinian responses in these questions referred to the occurrence of variation as a random process and selection as reproductive success. The poor response to questions 5 and 7 indicate that students in both groups have difficulties in understanding these aspects of natural selection. On the other hand, the students' understanding is good regarding the other two aspects of Darwinism, highlighting variants as raw material for natural selection (2 and 6) and the genetic basis of variation

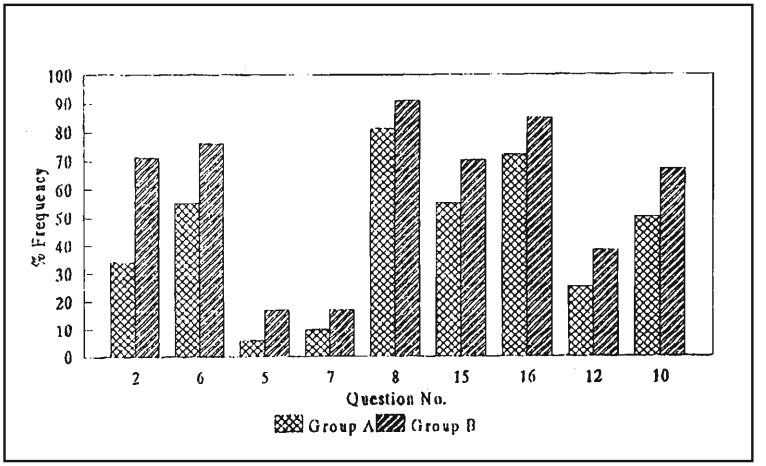

Figure 2. Frequencies (%) of the two groups of students (group A and B) indicating the understanding (Darwinian reasoning) of the process of natural selection. Group B exposed to extra lectures performed slightly better than group A. Certain questions (5, 7, 10, 12) drew less percentage of correct responses than others. These questions dwell on variation as a random process and selection as reproductive success.

(8, 15 and 16). This is observed in both groups of students, though group B students performed slightly better than A. As in earlier work, students largely prefer Lamarckian clues (rather than the orthogenetic or the teleological ones) whenever they seemed to have difficulties with Darwinian explanations. Hence extra focussed lectures seem to have only marginal effect in improving the understanding of evolution by natural selection.

Conceptual change via instructional lectures is only partly effective in promoting scientific understanding of neo-Darwinism.

Discussion

The main purpose of this work was to find out whether integrating relevant topics from genetics, molecular biology and population dynamics in a course of evolution helped in better understanding of the mechanism of natural selection. The performance of students exposed to these focussed lectures was marginally better than those who were not exposed to these lectures (Z-tests for the two groups of students were done and statistically significant differences were obtained for only two questions, 2 and 6, referring to variation as the raw material for evolution). Other researchers have also observed that conceptual change via instructional lectures is only partly effective in promoting scientific understanding of neo-Darwinism.

Our work also suggests that students have difficulties in understanding the random nature of different variations and their role in evolution, along with selection as reproductive success. That variations are random and not directed to suit the needs or wishes of an organism seems to have been missed by the majority of students, in spite of direct, emphatic explanations.

The question, then arises: how does one teach this important biological concept? Some researchers have made use of an inquiry approach and historical arguments in their teaching, with moderate success. Thus teachers could try separating the different ideas in neo-Darwinism and explain them through specific examples from natural history. Others have suggested that evolution by natural selection is too complex a topic to be comprehended at an early stage in schools and, therefore,

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"For a biologist the alternative to thinking in evolutionary terms is not thinking at all."
Sir Peter Medawer
Nobel Laureate

misconceptions based on Lamarckism, wherein the ideas are relatively simple, dominate in students' minds. These workers argue that students should first be exposed to topics such as geological time, natural changes in the environment of the earth, the variability and alteration of organism's genetic make-up and certain aspects of population biology, which could facilitate the learning of evolution at a later, more advanced stage.

With the above points in mind, it may be worthwhile for teachers to adopt an active, inquiry-laden approach while teaching evolution. They could also confront students with instances from natural history and from our immediate environment and pose the possible consequences if Lamarckism were to operate. A laboratory component could be incorporated to improve its understanding. In schools and colleges in India biological evolution is taught largely through lectures, with almost negligible experimental component. In the process, students fail to appreciate its relevance to the rest of biology and merely pick up the jargon of the subject. The challenge is to develop classroom demonstrations of the process of evolution! We invite ideas from readers so that an experimental unit in evolution can be developed.

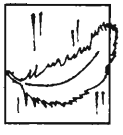
Suggested Reading

[1] **Richard Dawkins.** ***The Blind Watchmaker.*** **Penguin Books, London, 1988.**

[2] **Adrian Desmond and James Moore.** ***Darwin.*** **Penguin Books, London, 1992**

[3] **B S Mahajan. Understanding of Evolution.** ***Biology Education.*** **July/ September; 200– 208, 1992.**

[4] **Stephen J Gould.** ***The Panda's Thumb.*** **Pelican Books, 1980**



If it can't be expressed in figures, it is not science; it is opinion.

Lazarus Long