An Analysis of the Treatment of Evolution by Natural Selection in NCERT Textbooks

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Abstract

Our analysis of the treatment of evolution by natural selection in NCERT textbooks indicates that although the treatment in the current books is generally good, there are a few problems. The main problems are in the higher level books: the treatment of evolution is too confusing and abstract, there is some tendency towards teleology, there are a few mistakes and misconceptions, the visuals are inadequate, the teaching method is too didactic, the syllabus is too vast, and there is some tendency towards genetic determinism. However, we find that the textbooks at the primary and middle school levels have many merits: they are in many ways pedagogically sound; they suggest very worthwhile activities that prepare students to learn about evolution; and their design and visuals are attractive and functional.

Keywords: Evolution, Natural selection, Textbook analysis, NCERT

Framework of Analysis

Here we analyse the presently used NCERT (National Council of Educational Research and Training) 2006 textbooks, which we find to be generally of a high quality compared to many textbooks published by private companies in India. It is apparent that a lot of thought has gone into their writing and design. A sincere and informed effort has been made to apply sound pedagogical principles, as outlined in NCF (2005), in the development of these books. Many textbooks produced by state textbook boards also follow the NCERT textbook model, although we will not review them here.

We will first summarise what we mean by evolution by natural selection, what we think is essential to teach about it, and why it is essential. Our answers to these questions are based on our previous experience in teaching and learning about evolution, and are discussed in more detail elsewhere (Haydock and Arunan, 2012; Haydock, 2014, in preparation).

Since the study of biology requires an understanding of evolution and the mechanisms of evolution, it is clear that students who study biology need to study something about evolution at some point before their graduation. Although evolution by natural selection is very difficult to define, we suggest the following as a good working definition, which will the serve as our basis for this exercise in textbook analysis:

Evolution by Natural Selection

(1) There is variation between the individual organisms that make up any population. (A population is a group of organisms of the same species living in the same place at the same time.)

(2) This variation occurs partly because there are random mutations in the genome (differences in the DNA) of individual organisms. These mutations can be passed to offspring.

(3) Throughout the individuals' lives, their genomes interact with their environments to cause variations in traits. (The environment of a genome includes the molecular biology

in the cell, other cells, other individuals, populations, species, as well as the abiotic environment.)

(4) Individuals with certain variants of the traits may survive and reproduce more than individuals with other variants.

(5) Therefore the population evolves.

In order to learn about evolution by natural selection, it makes conceptual sense to start with abstract concepts, leading finally to investigate examples and particular observations related to evolution. However, in our extensive experience in teaching students and teachers about evolution, we find that this is not usually the best pedagogical approach. Students find it is easier to start with what they already know through direct observation and proceed to more abstract concepts.

After trying many different approaches in teaching/learning about evolution, we have concluded that it is best to take a similar approach to the method scientists have been using to build up an understanding of evolution. In other words, students use the scientific method to learn about evolution. Accordingly, they rely on particular observations of physical reality at many stages throughout their study: in order to look for characteristics and relationships between different forms of life; to sort things into categories; to make generalisations; to test hypotheses, to communicate, and to suggest new questions - though not necessarily in this order, of course. We are basing our textbook analysis upon this understanding of the scientific method, and upon the view that the teaching/learning of biology must be concerned primarily with learning this method of science rather than with 'learning' science as a 'body of facts'.

We take the view that students need to explore biology and evolution in order to improve their scientific temper - and they need to improve their scientific temper in order to explore biology - and textbooks should be designed with this in mind. We define scientific temper as the practice of using the scientific method throughout one's daily life in order to ask and search for answers to all sorts of questions, bearing in mind the interconnections between science and social, political, economic, moral, and aesthetic factors.

Our pedagogical stance is in agreement with the stance outlined in the National Curricular Framework (NCF, 2005) upon which the NCERT textbooks have been framed. Thus, the aim is to use an educational constructionist approach as much as is practical - which is not the constructivism of the sociology of science (Matthews, 1998). This approach also aims to encourage all students to become engaged in inquiries, observations, activities and arguments with themselves and with each other. Through this process they confront contradictions and misconceptions and work to resolve them. The contradictions may be between different people's beliefs, between the beliefs of one person, between statements in one or more textbooks, between statements in textbooks and beliefs, or between beliefs and observations of physical reality.

According to this approach, even the authority of a teacher or a textbook can be questioned. To quote Eleanor Duckworth, "In science, the 'stuff' is the authority" (Duckworth, 2012). The 'stuff' is the physical reality which we observe. In an area as complex as biology, one main objective is to critique and ask relevant questions rather than just to become confident in supplying correct answers on exams. Becoming confused can also be seen as a goal, since it may be required in order to learn. Thus, the question arises as to whether it makes pedagogical sense to have textbooks which contain contradictory statements in order to try to confuse students so that they will try to resolve the contradictions.

A related question is whether it is even possible to avoid all contradictions in textbooks, particularly in relation to a topic as complex as evolution. Avoiding contradictions becomes all the more difficult when attempts are made to simplify the topic for young students. Simplifying means presenting simple models, which necessarily disregard some features in order to concentrate on others. However, in biology it is very important to investigate the interconnections and interdependencies between different characteristics, behaviours, and components of the environment.

The Syllabus and Learning Objectives

The current NCERT (2006) textbooks refer explicitly to evolution mainly in the Class X Science and the Class XII Biology textbooks. However, the textbooks for earlier classes also contain some very useful and necessary material that builds towards this later more detailed treatment. This includes discussions and activities related to the development of scientific temper, categorising organisms, similarity and variation, changeability, the complexity and interdependence.

Evolution is taken up in depth in Chapter 9: "Heredity and Evolution" (Class X). The topics covered in this chapter are indicated by the chapter headings, as shown in Table 1. Evolution is not discussed in the Class XI textbooks, but is treated in detail in Chapter 7 "Evolution" (Class XII). This chapter attempts to give an account of the evolution of the universe, the origin of life, and the evolution of life forms, as shown in Table 2. In addition, Chapter 5 (Class XII) discusses "Principles of Inheritance and Variation".

Class X (2006) Ch 9: HEREDITY AND EVOLUTION pp 142-159
9.1 ACCUMULATION OF VARIATION DURING REPRODUCTION
9.2 HEREDITY
- 9.2.1 Inherited Traits
- Activity 9.1 Observe the ears of all the students in the class.
- 9.2.2 Rules for the Inheritance of Traits – Mendel's Contributions
- Activity 9.2 In Fig. 9.3, what experiment would we do to confirm that the F2 generation did in fact have a 1:2:1 ratio of TT, Tt and tt trait combinations?
- 9.2.3 How do these Traits get Expressed?
- 9.2.4 Sex Determination

9.3 EVOLUTION
- 9.3.1 An Illustration
- 9.3.2 Acquired and Inherited Traits

9.4 SPECIATION
9.5 EVOLUTION AND CLASSIFICATION
- 9.5.1 Tracing Evolutionary Relationships
- 9.5.2 Fossils
- 9.5.3 Evolution by Stages

9.6 EVOLUTION SHOULD NOT BE EQUATED WITH 'PROGRESS'
9.6.1 Human Evolution

Box: Charles Robert Darwin (1809–1882)
Box: Origin of life on earth
BOX: Gregor Johann Mendel (1822–1884)
Do you know? JBS Haldane
Box: How do fossils form layer by layer?
More to Know! **Molecular phylogeny**

Table 1: Chapter headings (Ch. 9, Class X, Science, NCERT, 2006))

Class XII (2006) Ch. 7: EVOLUTION pp 126-142
7.1 ORIGIN OF LIFE
7.2 EVOLUTION OF LIFE FORMS - A THEORY
- 9.2.1 Inherited Traits
- Activity 9.1 Observe the ears of all the students in the class.
- 9.2.2 Rules for the Inheritance of Traits – Mendel's Contributions
- Activity 9.2 In Fig. 9.3, what experiment would we do to confirm that the F2 generation did in fact have a 1:2:1 ratio of TT, Tt and tt trait combinations?
- 9.2.3 How do these Traits get Expressed?
- 9.2.4 Sex Determination

7.3 WHAT ARE THE EVIDENCES FOR EVOLUTION?
- 9.3.1 An Illustration
- 9.3.2 Acquired and Inherited Traits

7.4 WHAT IS ADAPTIVE RADIATION?
7.5 BIOLOGICAL EVOLUTION
- 9.5.1 Tracing Evolutionary Relationships
- 9.5.2 Fossils
- 9.5.3 Evolution by Stages

7.6 MECHANISM OF EVOLUTION
7.7 HARDY-WEINBERG PRINCIPLE
7.8 A BRIEF ACCOUNT OF EVOLUTION
7.9 ORIGIN AND EVOLUTION OF MAN

BOX: Gregor Johann Mendel (1822–1884)

Table 2: Chapter headings (Ch. 7, Class XII, Biology, NCERT, 2006))

Keeping in mind that there are 16 chapters each of the Class X and XII books, we think that the syllabus is much too vast. It would be better to concentrate on investigating a few aspects of evolution in more detail than to try to 'cover' everything from Mendelian genetics to micro and macro evolution to classification, geologic evidence, and human evolution. In our experience we find that with such a vast syllabus, students turn their efforts to memorising the text, and they end up forgetting almost all of it within a few months after their examination. If students instead practice using a scientific method to ask questions, observe, experiment, analyse and practice critical thinking, they will be able and motivated to investigate particular topics as and when they need them.

If the syllabus is to be reduced, the question arises as to which topics could be removed and whether evolution by natural selection should be removed. We believe that this is one topic that is essential, for three main reasons: (1) natural selection is central to evolution and evolution is central to all of biology; (2) biology is the science of life, we are living, and, to quote Socrates, "An unexamined life is not a worthy human life" ("ὁ δὲ ἀνεξέταστος βίος οὐ βιωτὸς ἀνθρώπῳ" (Plato, c.340 BCE); and (3) social progress is possible through applications of biology in agriculture, healthcare, engineering, and environmental sciences. In particular, plant and animal breeding is evolution by artificial selection. Solutions to environmental problems require investigations of evolution. In addition we think that an understanding of evolution by natural selection can be both the result and the cause of a progressive way of looking at the world which may have many ramifications throughout people's lives.

Pedagogy

We find that in order to understand evolution by natural selection, students need to be prepared with a functional scientific temper so that they are able to question, observe, compare, and find answers through experimentation, communication, and critical thinking. The importance of understanding and practicing the creative process of science, rather than concentrating on the 'content' of science has been emphasized in numerous pedagogical studies in other countries, and is particularly important in relation to the topic of evolution (Matthews, 1994, Lederman, 1992, Chiapetta & Fillman, 2007)

In order to cultivate a scientific temper, students need to do science, and by doing, understand the process of science and make doing science a habit throughout their lives. Teachers and textbook writers therefore need to be discouraged from portraying science as a body of knowledge or list of 'facts' to be memorised. Otherwise students hear, read, and memorise the definitions and facts of evolution, without understanding or trying to figure out how understanding evolution is relevant to their own lives.

Therefore it is commendable that throughout the NCERT primary school textbooks students are encouraged to practice a number of science processes. For example, in a number of books students are asked to closely observe plants and animals.

In the chapter, "Super Senses" (Class V), students are asked to do activities, discuss, and compare differences in sensory abilities and behaviours of different people and of other animals. There is a discussion on the connections between structure and function, a topic which is relevant to any understanding of evolution. Students are asked to list animals whose ears can be seen and to think about whether there is a link between the size of the animals' ears and their hearing. This is similar to the exercise (Class IV, Chapter 2) in which the students are asked which animals have ears that cannot be seen. This could become an interesting activity if students were asked to find the answer by devising and carrying out tests to observe whether particular animals can hear, and on that basis guess whether they have ears.

In other textbooks the students are asked to make drawings of chana which they sprout, go to a pond and draw "the kinds of plants that you see there," compare the appearances and behaviours of different animals, categorize things, draw pictures, make models, do experiments, and analyse data. All of these are useful in establishing an understanding of the nature of science and in enhancing scientific temper, which is needed to understand evolution.

At several places throughout the textbooks students are asked to draw plants or animals. It will be particularly useful if students draw what they observe as they observe it, because drawing encourages keen observation. It will also help students to realise the large amount of variation as well as similarity that exists even within one population. Drawing is a form of model making, since a drawing is a simplified 2-d representation of physical reality. In order to make a drawing, students need to decide which aspects to simplify. If, as often happens, the students are instead asked to copy drawings from the board, from a textbook, or from memory, the learning will be limited. The students will miss the opportunity to closely observe things first hand and construct their own models.

One theme of Unit 9, Class II (according the notes for teachers at the end) is "to give children a feeling of interdependence with their world". This is done by fostering a love for elders: there are several poems and stories about grandparents and about loving relationships between children and grandparents. Exploring interdependence is required for learning about evolution.

We find that the NCERT textbooks - particularly at the primary level - are quite innovative, and are designed for use in activity-based, constructivist, or inquiry-based teaching. However, in our experience in both private and government schools, we find that most teachers use didactic methods in which 'learning' means that students hear, read, memorise, and regurgitate the exact words on examinations, ignoring the innovative methods and activities which are suggested in the textbooks. Teachers resort to didactic teaching methods due to their working conditions. Most teachers have large class sizes, with more than 25 students in each class - and sometimes more than 100 in a class. Teachers typically are asked to teach between 6 to 8 periods in a day. If there are different batches of students each period, the teachers are barely able to even remember their names. Very few schools allow teachers adequate non-teaching time for planning and assessing. Newly implemented requirements that teachers must stay in school for several additional hours after such gruelling timetables do not solve this problem. Class discussions or activities in which students DO science, are almost impossible to plan or carry out under such conditions. When teachers are employed as contract teachers, with extremely low salaries, no benefits, and little respect from the community, adequate teaching is not viable.

Categorising organisms: Observing Similarity and Difference

Evolution, and life itself, is dependent upon the existence of both similarity and variety within any population of organisms. No two organisms in a population or species are exactly alike, even though they have certain similarities which allow us to group them together as one population and as one species. We categorise organisms based on both similarities and differences. In order to understand evolution and its mechanisms, students need to see that similarity and difference is an inherent characteristic of any population. If individuals are too different they might not interbreed, thus ruling out the possibility of evolution. If a population does not contain enough variation, there may not be enough different types for selection of more viable individuals in case of changes in environment, disease, etc.

Noticing similarities between species is also the first step in realising that different species are related to each other because they have common ancestors.

Probably one of the reasons that natural selection was not identified earlier as a mechanism of evolution was that people did not investigate the variety within a population or species - they were more intent upon identifying the differences between species. Both Darwin and Wallace, who discovered the mechanism of natural selection, were probably able to do so because they had extensive experience in the field, where they were struck by the enormous variation within each species. This detailed observation is something that many classifiers of organisms might overlook, since they are trained to focus their attention on only those particular characteristics upon which classification of species are based.

Therefore it is essential that students get experience in investigating similarities and differences, in identifying characteristics, and in sorting and categorizing things into groups. These kinds of activities are some of the easiest ways to start understanding evolution, so it is important that students begin doing these at early stages (Nadelson et al., 2009).

Starting from the primary level, the NCERT textbooks do suggest a number of activities which involve identifying and comparing characteristics of organisms (and various objects) and sorting them into categories.

In Chapter 1 of the Class III book, students are encouraged to go outside and observe nature, which is a good prelude to learning about evolution, and also helps inculcate a scientific temper. They are asked to spend some time under a tree, observe and record which animals are seen on different parts of the tree and on the ground. The students are then asked to sort the animals

they find in order of size. This is an excellent biology activity, appropriate for any age or level since it is so open-ended. Students are also asked to classify animals based on ways of moving, and whether or not they live in the house of the student. This sort of classification, which is based direct observation and analysis, is much preferred to being asked to memorise given classifications (mammals, reptiles, etc.).

Of particular relevance are activities in which students are asked to observe and find differences between leaves, trees, and plants (Ch. 2 in the Class III Environmental Studies (EVS) textbook), and flowers (Ch. 11 in the Class IV EVS textbook). Although students are not specifically asked to look for differences between individual plants of the same species, this could be an interesting extension, and one which is needed in order to understand evolution. It is commendable that at these early stages the students are not asked to unnecessarily memorise too many technical terms with regard to the plants. However, it is unfortunate that students are not asked to find both differences and similarities.

Interestingly, students are asked to sort things based on a wide variety of characteristics. For example, (Class IV, Chapter 15 "From Market to Home"), students are asked to compare bhindi: find the longest and the shortest, compare the thickness and colour, compare the cut cross-section, etc. They are also asked to sort vegetables into two sets: those that spoil quickly, and those that can stay for some days; those that are smooth and those that are rough; heaviest and lightest, etc. This sort of exercise is very useful in that it indicates that there are many different ways of sorting things into sets, which is important when students consider how species are classified.

There are instances in which the primary textbooks suffer from being too reductionist in their efforts towards simplicity. For example, the Class I Hindi textbook "Rimjhim-1" students are asked to sort various vegetables according to their colours, but apparently each vegetable is to be classified as being either red, green, purple, yellow, blue, or black. Subtleties or variations or multiple colours are not considered. If students get in the habit of thinking in such a reductionist manner, they may have problems later on in understanding evolution and biology.

Another example of this is in Class IV, Chapter 16, where students are asked to sort their pictures of animals into three groups according to whether they live on land, in water, or in trees. As with many sorting activities throughout the textbooks, the possibility of overlapping groups is not mentioned. Apparently, students are to be taught that animals either live in a pond or in a jungle or in a house; objects either float or sink, but do not float then sink or sink if they are dropped one way and float it they are dropped another way; things can either be cut with scissors or with a knife but not both; we either eat the roots or the shoots of a plant, but not both, objects either roll or slide, etc. Even in the chapter on "Sorting Materials into Groups" (Class VI, Chapter 4), students are asked to sort things into non-overlapping sets. The possibility that two objects may have some similar characteristics as well as some different characteristics - which makes them difficult to sort - is not mentioned. It seems that each group is separate and individual, and each object belongs to either one group or the other. Characteristics are considered to be either of one type or not of that type. Answers to questions are either true or false.

However, problems are bound to crop up if the students actually do the activities. Categorisation is not so simple - and the complexity is what makes categorisation interesting and relevant. These problems are very important when we attempt to categorise and classify living things and understand evolution, as discussed below.

Actually it is not difficult to introduce the concept of overlapping sets through the use of Venn diagrams. Even young children who do not yet know how to read can sort things into overlapping sets. By doing so, they find out what is interesting about physical reality - and they get practice doing science.

In Chapter 5 "The Fundamental Unit of Life" of the Class IX textbook students are asked to compare different plants' cells and also cells from different parts of the same plant through a microscope and tell what similarities and differences they find. This is a very worthwhile activity. However, we find that in many schools students do not actually do it - because of overcrowding, shortage of microscopes, shortage of time, or a lack of belief that it is important. It is important

because through direct observation students come to find evidence that shows that cells develop and differentiate to look similar but different from parent cells, and that different organisms evolved to have cells that have both differences and similarities to each other.

Similarity and diversity is taken up again in Chapter 7, "Diversity in Living Organisms" of the same textbook. This chapter starts with a discussion of human diversity, and then asks students to do an activity in which they compare desi and Jersey cows. Starting the chapter with humans and animals that are familiar to the students makes pedagogical sense. Hopefully teachers will adapt the activity to include discussions of whatever animals are present in the local environment. In our own experience in teaching units on variation, for example in the Hoshangabad Science Teaching Programme (Bal Vaigyanik, Kaksha 6 1978), students have collected and compared the similarities and differences between leaves, goats' tails, ants of the same or different species, and their own hands.

Students need to study similarity and variation in order to identify and classify species. The term 'species' is used for the first time when it is defined in Class VIII, Chapter 5:

> "Species is a group of population which are capable of interbreeding. This means that the members of a species can reproduce fertile offspring only with the members of their own species and not with members of other species. Members of a species have common characteristics."

It might be better to introduce the term 'species' without any explicit definition, just by using it when discussing and comparing different types of organisms. In later classes there could be a discussion on the difficulties of defining species.

In Class VII, Chapter 17 "Forests: Our Lifeline" there is a good discussion of the consequences of variety:

> "By harbouring greater variety of plants, the forest provides greater opportunities for food and habitat for the herbivores. Larger number of herbivores means increased availability of food for a variety of carnivores. The wide variety of animals helps the forest to regenerate and grow. Decomposers help in maintaining the supply of nutrients to the growing plants in the forest. Therefore the forest is a 'dynamic living entity' - full of life and vitality.

However, this does not mention that because of individual variation within a population, a population is more likely to survive changes to its environment, through natural selection.

The Class X textbook stresses the importance of both similarity and variation in reproduction of DNA, cells, and organisms (Chapter 8, "How do Organisms Reproduce?"). In this chapter, the concept of evolution by natural selection is described (Section 8.1.1 "The Importance of Variation"), although, strangely, it is not referred to by name:

> "Populations of organisms fill well-defined places, or niches, in the ecosystem, using their ability to reproduce. The consistency of DNA copying during reproduction is important for the maintenance of body design features that allow the organism to use that particular niche. Reproduction is therefore linked to the stability of populations of species. However, niches can change because of reasons beyond the control of the organisms... If a population of reproducing organisms were suited to a particular niche and if the niche were drastically altered, the population could be wiped out. However, if some variations were to be present in a few individuals in these populations, there would be some chance for them to survive."

This is actually a clearer definition of evolution by natural selection than the formal definition that appears later in the same book in Chapter 9 "Heredity and Evolution".

In the Class IX textbook (Chapter 5) we read that "Cells divide to produce cells of their own kind. Thus, all cells come from pre-existing cells." In that case, how did the first cell evolve? And, how does the variety of cells we find in one human body develop from one fertilised egg cell? Students must be confused. Hopefully this confusion will lead them to investigate further.

Throughout our education, teachers teach that statements are either true or false. Therefore, we come to use a sort of Aristotelian logic which confines things to separate, individual, unchanging categories, even when this is contradictory to our real life observations. This leads to difficulties in understanding evolution by natural selection, which is based upon the inherent possession of both similarities and differences between individual organisms in the same population.

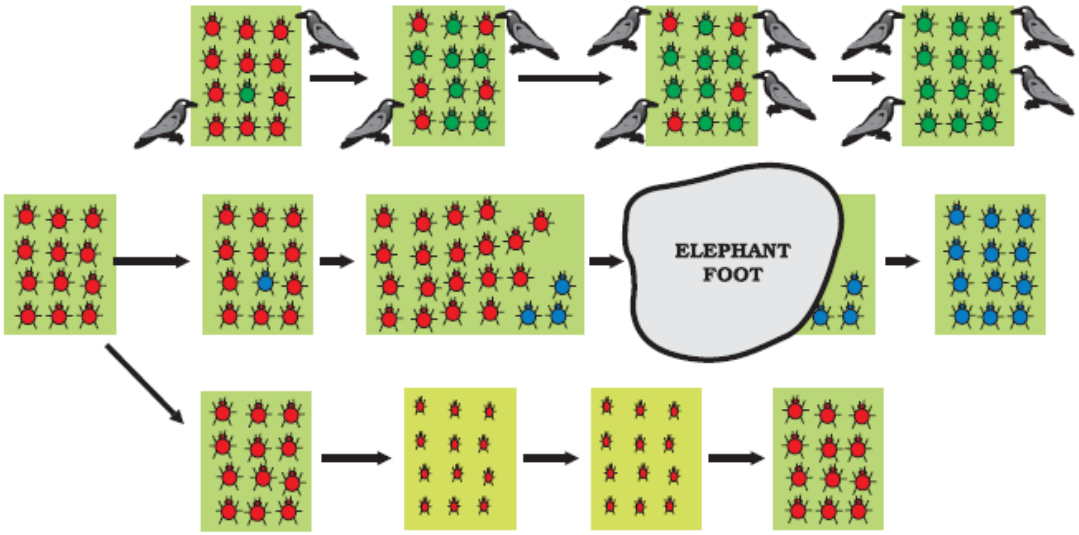

Figure 9.7 *Variations in a population – inherited and otherwise*

Figure 1 Variations in a population (Fig 9.7, Ch. 9, Class X Science, NCERT, 2009)

It is commendable that the topic of evolution by natural selection is introduced in the Class X book through an example of beetle evolution, and that this is visually illustrated (Figure 1). However, we find that this illustration is very difficult to understand, and it also may reinforce a serious misconception - which is that before and after the process of evolution by natural selection a population may consist of identical individuals. If that was the case, selection, evolution, and life itself, could not occur. Every population contains inherent similarities and differences, as indeed was implied by the first sentence of the chapter. So here it would be helpful to show obvious differences as well as similarities. Even the accompanying text is confusing in this regard, with the sentence, "Their population will grow by sexual reproduction, and therefore, can generate variations," implying that perhaps asexually reproducing populations cannot generate individual variations.

Also, the impression should not be given that variation arises only as a result of interactions with environmental factors that cause the selection. But in the top series of pictures the variations in beetle colour appear to arise only after the crows also appear, which may reinforce this misconception. Students need to realise that the appearance of variation is dependent upon random mutations. It would have been better if some obvious variation was shown in the first frame on the left as well as in the last frames on the right.

Everything Changes

It is useful to introduce young children to examples of different kinds of change, including evolutionary changes in organisms. This can be done, for example, by investigating fossils, which can be found in many parts of the country. Some schools have collections of fossils. Even a piece of coal can be observed and found to have impressions of leaves in it.

In Class VIII, Chapter 5: "Coal and Petroleum" the formation of coal is described:

> "About 300 million years ago the earth had dense forests in low lying wetland areas. Due to natural processes, like flooding, these forests got buried under the soil. As more soil deposited over them, they were compressed. The temperature also rose as they sank deeper and deeper. Under high pressure and high temperature, dead plants got slowly converted to coal. As coal contains mainly carbon, the slow process of conversion of dead vegetation into coal is called carbonisation.
>
> Since it was formed from the remains of vegetation, coal is also called a fossil fuel."

Although the word fossil is used here, students may not realise that what is being described is the fossilisation process. There is no mention of the connection between fossils, extinction, and evolution.

Dinosaurs are one of the most common examples of extinct animals, and some children hear about dinosaurs outside of school. However, it is strange that the only mention of dinosaurs in the primary books is in Chapter 2 of the Class IV book, where there is a line drawing of a dinosaur to colour. The accompanying text says: "Many many years ago there were dinosaurs on earth, but not any more. Now we see them in films, photos and books". This might lead some children to assume that dinosaurs disappeared relatively recently and that people must have been around when they were living and they took photographs and made films of them. We find that there is a surprisingly widespread misconception amongst both children and science teachers that people coexisted with dinosaurs in the past. Huge timescales are difficult to comprehend, and the NCERT textbooks do not attempt to tackle this problem.

The Class III and IV NCERT (2007) EVS textbooks include a few activities related to changes in plants and animals in recent times. Students are asked to talk to their grandparents to find out what changes they may have observed in the numbers and types of different plants and animals in their environments and whether any of them have completely disappeared or whether there are now any new types that did not exist before. This helps students realise that living things change. It may provide concrete examples of evolution from the lives and communities of the students. The topic of foods and seeds changing over the past few generations is raised again in "A Seed Tells a Farmer's Story" (Chapter 19, Class V). Although the words "evolution" or "plant breeding" are not used, questions about change and social progress are raised.

In Class V, Chapter 5 "Seeds and Seeds", there is a discussion of how seeds, fruits, and vegetables spread to different places. There is also a discussion of how from the same seeds, plants will grow differently, depending on environmental effects such as water, soil, etc. However, there is no mention that populations of seeds evolve.

Then, in Chapter 21, "Like Father, Like Daughter" (Class V), there is some investigation of human traits that are passed from generation to generation. Students are asked to tell which characteristics they have which are similar to those of someone else in their family and whether particular traits are learned or passed on from their parents. This chapter also contains a box in which the authors' attempt to describe Mendel's experiments with peas in a very simple way. However, it is not intelligible:

> "Seeds which are either green or yellow give rise to new seeds which are either green or yellow. The next generation does not have seeds with a mixed new colour made from both green and yellow. Mendel showed that in the next generation of pea plants there will be more plants having yellow seeds. He also showed that the next generation will have more plants with smooth seeds. What a discovery!"

It is doubtful whether any student can make any sense of this. Maybe a carefully illustrated example could have been more successful.

Definitions of Evolution

Evolution is defined several times in the Class IX textbook, each time in a slightly different way, without cross-referencing. In Chapter 7, "Diversity in Living Organisms" a discussion of the large diversity of life forms on earth leads to what is the first use of the word 'evolve' in this book: "This bewildering variety of life around us has evolved on earth over millions of years." After a discussion about how we classify organisms and what sorts of characteristics we use for comparison, there is a three paragraph unillustrated section on "Classification and Evolution". However, it contains some rather confusing passages:

> "All living things are identified and categorised on the basis of their body design in form and function. Some characteristics are likely to make more wide-ranging changes in body design than others. There is a role of time in this as well. So, once a certain body design comes into existence, it will shape the effects of all other subsequent design changes, simply because it already exists. In other words, characteristics that came into existence earlier are likely to be more basic than characteristics that have come into existence later."

Even a reader who understands quite a bit about evolution will have a hard time understanding what the author was trying to say here. In the next paragraph, evolution is defined as follows:

> "What is evolution? Most life forms that we see today have arisen by an accumulation of changes in body design that allow the organism possessing them to survive better. Charles Darwin first described this idea of evolution in 1859 in his book, The Origin of Species."

There are several problems with this definition. (1) It could easily be misunderstood to mean that an individual organism accumulates changes over its lifetime, which is development, not evolution. (2) It confounds the definition of evolution with a definition of the mechanism of evolution. (3) It implies that an organism changes in order to allow it to survive better, which sounds teleological. (4) It implies that Darwin was the first to describe the idea of evolution. Actually, many people before Darwin had realised that evolution occurs, but Darwin was one of the first people to understand the mechanism of evolution due to natural selection, and communicate this idea widely. This misconception is further reinforced in the Class XII book (Chapter 7, section 7.2), in which evolution is called "a theory" which "strongly challenged the biblical "theory of special creation." Many authors have pointed out that it is a mistake to refer to either of these as "theories" (Cleaves and Toplis, 2007). It is unacceptable to describe evolution as "a common permissible conclusion" that Darwin and his followers made, rather than as an observation which biologists make (and made even before Darwin).

The rest of the chapter is concerned only with nomenclature and listing and defining the categories into which organisms are classified, which students may find rather tedious, especially if they are asked to memorise the difficult Latin names such as "pteridophyta" , "coelentera", and "platyhelminthes". Learning to spell these words will distract the students from the science. Some of the activities in the chapter are more worthwhile, such as one in which students are asked to find out the names of certain plants and animals in as many languages as they can, and another activity in which students are asked to find out the scientific names and compare them to the common names. The acts of finding and comparing names are science. The acts of memorising and regurgitating names are not science. Due to confusions over definitions of the term 'theory', it should be carefully defined, and while mechanisms of evolution could be called theories, evolution itself should not be.

There is one more chapter in the Class IX textbook in which evolution is defined, although without calling it evolution, which is Chapter 15, "Improvement in Food Resources". In this chapter there is a section on "Crop Variety Improvement" in which it is stated that, "Varieties or strains of crops can be selected by breeding for various useful characteristics such as disease resistance, response to fertilisers, product quality and high yields." Thus, the evolution of varieties by artificial selection is described, although this phrase is not used. It would have been useful if this was mentioned as being another example of evolution. Even Chapter 1 "Crop Production and Management" (Class VII) mentions that "good quality seeds are selected" [by farmers], but it does not mention that in so doing farmers may be practicing evolution by artificial selection.

Chapter 9 of the Class X textbook gives a definition of evolution based on the beetle example (shown in Figure 3), as "the frequency of an inherited trait changed over generations. Since genes control traits, we can say that the frequency of certain genes in a population changed over generations. This is the essence of the idea of evolution."

The main problem with this definition is that, despite being based on the beetle example, it is too abstract. We have found that before (and often after) they enter university, students have tremendous trouble understanding what a 'gene' might be. When they are told that a gene is a carrier of 'information', they are even more confused, because this is too abstract. They cannot understand whether 'information' is a physical thing or an idea, and thus they also cannot understand whether a gene is a physical thing or an idea. When told that a changing gene frequency is the essence of evolution, it seems to follow that the way to know whether evolution is occurring is to observe a changing gene frequency - but how can gene frequencies be measured? Students can only see traits. The concept of 'genes' is inherently difficult to understand. Also lacking is a reminder of what is meant by 'population' and an explicit discussion

of the misconception that an individual can evolve. We will have more to say about this definition in the section on Teleology, below.

In the Class X chapter on "Heredity and Evolution", evolution is defined as, "the gradual unfolding of organisms from pre-existing organisms through change since the beginning of life". The metaphorical use of the word 'unfolding' is problematic, making this definition difficult for students to understand. A more literal definition would be better. It is commendable that the following statement is included.

> "The problem of origin and evolution of the organism has always perplexed the human mind. Almost all the ancient literature provides description of origin and evolution of living organisms. All these explanations are obscure and do not fit into the parameters of scientific principles."

However, no further explanation for this statement is given, leaving the reader to guess why e.g. a belief in reincarnation of different animals is not scientific.

The chapter includes a discussion of Lamarckism, said to be a theory of inheritance of acquired characteristics, and a rebuttal of this theory by the mouse tail cutting experiment performed by Weismann. We have found that some students and teachers who have used these books tend to have a misconception that Lamarckism and Darwinism are two theories that both explain evolution quite well, although the latter is more widely accepted - and indeed this chapter does support that misconception.

In the Class XII Biology textbook (Chapter 5), there is a mention that in the past 10,000 years humans practiced selective breeding to produce plants and animals such as Sahiwal cows in Punjab. However, the process is not described in enough detail to make it comprehensible. Although the authors call it artificial selection, they do not mention that it is evolution.

In Chapter 7 (Class XII), evolution and evolution by natural selection is defined a number of times, but the overall impression is quite confused. For example, in describing the evolution of peppered moths we read: "In a collection of moths made in 1850s, i.e., before industrialisation set in, it was observed that there were more white-winged moths on trees than dark-winged or melanised moths." The problem is, the authors do not mention that the different colours of moths are all varieties of the same interbreeding species. This leads students to the misconception that evolution is a change in the numbers of different species, rather than a change within one species or population. Then there is the statement; "...evolution is not a directed process in the sense of determinism. It is a stochastic process based on chance events in nature and chance mutations in the organism." But the text does not mention that selection cannot be not just a matter of chance.

Teleology and Other Misconceptions

A tendency towards teleological thinking (the belief that things occur intentionally) is one of the major obstacles to understanding evolution by natural selection. Therefore it is important that textbooks should not reinforce this tendency.

Some instances of teleological language needlessly occur even in primary level textbooks. For example, Chapter 16 "A Busy Month" in the Class IV EVS textbook focuses on observing and comparing different kinds of birds and other animals. This is a good idea, which helps in forming the basis for studying evolution. However, half of one page consists of a section entitled "Bird Feet - Different Kinds for Different Needs". Five different kinds of bird feet are pictured and labelled "To swim in water", "To hold tree branches", etc. This is useful for forming a foundation to the study of evolution, but it would have be better to use the word "function" rather than "need" in order to avoid teleological thinking. After all, the birds cannot choose to have particular types of feet according to their needs - they use whatever feet they have for whatever functions they can. Perhaps there are times when a water bird needs to clutch onto a branch to avoid getting swept away in a storm. It will have difficulty doing so even though it needs to do so! And who knows, maybe birds with web feet are in the process of becoming extinct because they are not able to clutch branches. Their feet are not 'perfect' enough.

Other examples of how teleological ways of thinking are subtly reinforced by some of the ways of writing are found in the following statements in the Class VI textbook, Chapter 9 "The Living Organisms and Their Surroundings": "Most desert plants have roots that go very deep into the soil for absorbing water." Roots do absorb water, but plants do not grow roots in order to find water. "[Animals in mountains] have thick skin or fur to protect them from cold." Thick fur does protect animals from cold, but they do not have fur in order to get protection. It would be better to say that they "have thick skin which protects them from cold". Such statements, which can be easily misinterpreted to be teleological, are interspersed with much better statements such as, "It's light brown colour helps it to hide in dry grasslands."

The chapter would be improved by simply asking students to identify and compare plants and animals living in different habitats, characteristics of the habitats, and analyse the functions - not the purposes - of various characteristics. In fact, it would be a good idea to explicitly point out at this stage that organisms do not have these characteristics because they need them or want them. For example, the chapter could state, "How could it be that a plant decides to grow longer roots? Plants do not have brains. Plants cannot think or have desires!" This could work very nicely together with the nonsense poem, "Said the Table to the Chair..." of Edward Lear which is already included in this chapter in order to discuss the difference between living and non-living.

Of course, we often use teleological language when we talk about the characteristics of animals. We commonly say "Birds have wings in order to fly". Scientists know that wingless animals cannot intentionally get wings because they need to fly. Even though such language is common, we suggest that teachers and textbook writers should try to avoid it.

A few similar problems of teleological phrasing occur in Chapter 7 "Weather, Climate, and Adaptations of Animals to Climate" in the Class VII textbook. For example, "Polar bears have white fur so that they are not easily visible in the snowy white background", and "It also has a thick skin and a lot of fat to protect it from cold." On the other hand, the accompanying figure avoids such teleological language. It states various characteristics and tells how they help to polar bear to do various things.

A related misconception in this chapter is the following implication of 'the struggle for survival':

> The climatic conditions in rainforests are highly suitable for supporting an enormous number and a variety of animals.
>
> Since the numbers are large, there is intense competition for food and shelter.

Large populations do not necessarily mean intense competition. Actually the reason that there are a large number and variety of animals is that there is also a large amount and variety of food.

The definition of evolution in the Class X book, which we critiqued above as being too abstract, is also too determinist and teleological. The phrase "genes control traits" supports a teleological stance - some readers might interpret it to mean that genes purposely direct traits. Actually genes do not completely control or determine traits. Traits are determined by complex interactions between genes and their environment - and their environment includes everything from the molecular biology of the cell to other cells, other organs, other individuals, other populations, other species, and the adiabatic environment. To ignore all these factors fosters over-simplification and genetic determinism. The text goes on to say more about how the beetle population evolved:

> "... the variation became common because it gave a survival advantage. In other words, it was naturally selected. We can see that the natural selection is exerted by the crows [who ate beetles]... Thus, natural selection is directing evolution in the beetle population. It results in adaptations in the beetle population to fit their environment better."

We find that upon reading this text, many readers get the impression that maybe the crows are purposely selecting and intentionally directing the course of evolution - even though in this case they are getting a population of beetles which is harder for them to see!

This is another example of the insidious teleology that creeps in partly because the structure and terminology of our language makes it difficult for us to express non-teleological concepts. Even

Darwin (1860) complained that 'natural selection' is a bad term - because it sounds like an intentional process of selection is occurring. He suggested that maybe 'natural preservation' is a better term, but then abandoned it because it "would not imply a preservation of particular varieties & would seem a truism". In the same letter he wrote, "I am beginning to despair of ever making the majority understand my notions."

It is unfortunate that the popular books written by Dawkins, although he says that evolution by natural selection is not teleological, also encourage teleological thinking through their unnecessarily metaphorical language:

> "If we allow ourselves the licence of talking about genes as if they had conscious aims, always reassuring ourselves that we could translate our sloppy language back into respectable terms if we wanted to, we can ask the question, what is a single selfish gene trying to do? It is trying to get more numerous in the gene pool. Basically it does this by helping to program the bodies in which it finds itself to survive and to reproduce." [Dawkins (1976)]

In the Class XII Biology book (Chapter 7), there is a discussion on the relation between structure and function of homologous forelimbs, as evidence for evolution. But unfortunately teleology enters with the statement, "Hence, in these animals, the same structure developed along different directions due to adaptations to different needs." In the same chapter, there are more examples of confusing and subtly teleological language:

> "Hence, moths that were able to camouflage themselves, i.e., hide in the background, survived. ... This showed that in a mixed population, those that can better-adapt, survive and increase in population size."
>
> "Nature selects for fitness. ... some organisms are better adapted to survive in an otherwise hostile environment. Adaptive ability is inherited. It has a genetic basis. Fitness is the end result of the ability to adapt and get selected by nature."

On the other hand, in Chapter 2 (Class XII), the importance of diversity in plants is emphasized, and it is stated: "Flowers do not exist only for us to be used for our own selfishness" - which reinforces a non-teleological stance. Artificial selection (selective breeding) is mentioned in Chapter 7, but it is not explicitly pointed out that while this is a teleological mechanism of evolution, evolution by natural selection is not.

The Class XII material on evolution is much more disorganised and confusing than what we find in the Class X book, and contains many misconceptions. For example, it raises the question of whether evolution and/or natural selection "is a process or the result of a process", rather than simply stating that natural selection is a mechanism of evolution. In the section entitled "Mechanism of Evolution" there is no mention of natural selection, but only a discussion on mutation, saltation, and speciation. There is an inexplicable statement that since bacteria (which reproduce within 30 minutes) evolve within a few days, then animals like fish or fowl (which reproduce within a year) would take millions of years to evolve.

Despite our criticisms, we should point out that the present NCERT textbooks are relatively better than most other textbooks with regard to teleology. They at least avoid using the phrases "struggle for existence" or "survival of the fittest", unlike an Oxford University Press textbook (Beckett & Gallagher, 1989), in which "Nature" appears to be rather intentionally cruel:

> "Nature selects the fittest and strongest for survival by killing off the weaklings."

Many of the teachers who have attended our workshops have previously used texts with similar statements. Perhaps that is why we still frequently hear BSc students using phrases like "struggle for survival".

There is a common misconception that species have evolved to be more and more perfect. This is indirectly countered poem in Unit 2 of the Class II book, called "I am Lucky" in which various animals are commended for their different abilities. Perhaps this implies that there is no hierarchy of better or worse between different animals or people. This is in line with the realisation that different species cannot actually be fit into a linear evolutionary progression from lowly species to those that are more and more highly evolved. For this purpose, the poem may be useful.

Freedom

Chapter 3 of the Class IV EVS book celebrates a kind of teleological individual freedom. There is a description of the activities of a young elephant in a herd in which the author imagines what the elephants are thinking and feeling. The author assumes that elephants think and feel just like people do, and decide to do things based on whether or not they like doing these things: they eat their favourite foods, they love to play in mud and water, and, in sum, "Nandu (the baby elephant) did things that he liked to do." The possibility that they have a herd mentality is not mentioned.

In this chapter, the students are asked to make two lists: why they would like to live in a group, and why they would not like to live in a group - as if that is an option. While it is true that doing things intentionally is important for people, even people don't always do things just because they like to do those things. As a study of evolution shows, there are needs as well as desires. All animals have constraints on their individual freedom, and it is important to recognise the social interactions upon which we all depend, and the social and environmental factors which contribute to the decisions we make and the way we act. Investigations of animal behaviour and comparisons between different kinds of animals are important subjects that arise in connection with evolution.

The anthropomorphism of this chapter culminates with an exercise in which the students are asked to imagine how animals feel. For example, how a snake carried in a basket by a snake charmer feels, how much pain a horse feels when horseshoes are fixed to its hooves, how monkeys are made to dance even if they don't want to, etc. This contrasts with Chapter 2 of the Class V book in which snake charmers are discussed rather sympathetically - seemingly in praise of 'tradition' and 'traditional knowledge'. However, this chapter too contains an activity in which students are asked to imagine what it feels like to be an animal in a cage. There are a series of leading sentences to complete: "I am afraid when...", "I wish I ...", "I am sad when...", "If I had a chance I would...", "I do not like it at all when...". It is not difficult to guess what the answers are supposed to be. However, these simplistic answers ignore the fact that these animals in captivity usually live much easier and longer lives than if they were in the wild. Despite its post-modern relative objectivity, the textbook does not mention the large number of people who are killed by snakes, wild cats, and elephants, or the crop damage they do. The solutions are not simple - whether or how to protect each and every wild animal and prevent all extinction at any cost are debateable. Even school students could take part in such debates.

There are a few places in the textbooks where nature is romanticized a little too excessively. For example, there is mention of a natural preserve in which "animals roam freely without fear" (Chapter 4, Class IV). Surely the animals are eating each other. Is that freedom? Are animals afraid of being eaten? Or would they rather be living in a zoo where no one will eat them? Do they even have an intention to survive?

Adaptation

The difficult term 'adaptation' is introduced in the Class VI textbook in Chapter 9 "The Living Organisms and Their Surroundings". Section 9.2 is called "Habitat and Adaptation", and it describes and compares fish found in the sea to camels found in the desert, stating that the features of a fish help it live in the sea and the features of a camel help it live in the desert and that the presence of such features that allow animals to live in their surroundings (habitats) is called adaptation. We question whether it is necessary or advisable to introduce such a difficult term at this stage, when the students probably have no idea how an animal might get such features. Students may assume that individual animals acquire adaptations over their lifetime, or that they intentionally acquire adaptations. To avoid such misconceptions, we think it would be better to explain the process of evolution in more detail before using the term 'adaptation'. In the meantime, it will be better to use a less teleological term such as "characteristic" or "trait".

However, this chapter also includes an activity which we think is very useful at this stage: the students are asked to do an experiment in which they compare how moong seeds sprout in different conditions in order to investigate the effect of abiotic factors like air, water, light, and heat. Perhaps the students could be encouraged at this stage to design such experiments

themselves, rather than just following the instructions in the textbook. They might even pay attention to which variables they should keep fixed and which variables they could manipulate in order to find the answers to their questions. The realisation that characteristics may be due to the seeds as well as to the abiotic (and biotic) environment is very important in order to understand mechanisms of evolution.

A discussion on climate and adaptation in Class VII, Chapter 7 begins with the statement, "Animals are adapted to survive in the conditions in which they live." This can be interpreted in a teleological way to mean that animals intentionally change in order to survive. In the same paragraph, the word evolution is introduced for the first time in the NCERT books by saying, "Features and habits that help animals to adapt to their surroundings are a result of the process of evolution." However, evolution is not referred to again in the book, which probably leaves students confused.

In the Class XII Biology book (Chapter 7), the term 'adaptation' is used in very confusing ways. For example: "Adaptive ability is inherited. ...Fitness is the end result of the ability to adapt and get selected by nature."

Visuals and Textbook Design

Illustrations and design are very important parts of any textbook, and most of the NCERT primary school textbooks are laudable for their design and diversity of illustrations. A number of different artists have contributed, in some cases even for the same textbook. This diversity is suitable for textbooks which are used for many months by large numbers of students throughout a very diverse country. Especially praiseworthy is the inclusion of non-western styles of artwork, ranging from Madhubani, to Worli, to even a few examples of children's' drawings (e.g. on Class IV book cover). This helps students recognise and appreciate styles which are their own. Especially for Classes I to VI, the illustrations are large and colourful, and in our experience students find them appealing.

For example, Chapter 2 in the Class III EVS book has colour and black and white drawings and photographs of leaves, leaf rubbings, and children doing activities with leaves. It also has photographs of pictures made from leaves, similar to those made by the famous artist Vishnu Chinchalkar. Chapter 11 in the Class IV EVS book, is full of colourful photographs of flowers, a Madhubani painting which contains flowers (Figure 2), and borders made from flower garlands. One page in the former book is almost completely covered by a picture of a room containing decorative curtains, bedcover, cushions, and various other items and the students are asked to find examples of patterns of leaves and flowers on them. Thus the books demonstrate interesting ways of integrating art and science, which is an important aspect of scientific temper.

Figure 2: A Madhubani style painting which includes flowers and animals (Chapter 11, Class IV EVS, NCERT, 2006)

It is also commendable that in some of the books the drawings of people do not have very pale skin colours - they look Indian. This is in contrast to other textbooks, such as the NCERT (2002) Class III textbook in which people are appear more caucasian (apparently the illustrator could not manage to make eyes that were not blue). This is alienating, demeaning, and racist.

The main exception we find to the variety of illustration styles is in the Class I and II English textbooks, which rely mainly on a typical western commercial style, both in

content and in form. They also contain less space devoted to illustrations and more space devoted to text, compared to the Hindi textbooks for Class I and II and the EVS Class III book. In the English books, most of the trees consist of green blobs on brown posts (if they have fruit, they are probably red apples). Stereotypical birds live in stereotypical nests. There may very likely be a rainbow in the sky. The houses all have peaked roofs (usually bright red). There is even a question, ""What is the colour of the tree?" with a small box for the one word answer. Presumably 'green' is the only correct answer. If children were asked to actually observe a real tree and then tell what colours they observed, their learning experience would be magnified many-fold. Not only would they be doing science, they would also realise that life is complex and trees are much more exciting than what is suggested by the solid green blobs in the illustrations.

In these two English textbooks, people have pale pink skin, and usually wear western clothes ("My father" is shown in a shirt and tie.) The fruits are predominantly those which are also found in the west. Words like, "giraffe", "igloo", "merry-go-round", "whale", "zebra", and "Xmas tree" are illustrated and labelled, and appear repeatedly. The children in the rain hold umbrellas and wear rain coats and galoshes (thankfully not labelled as such). Such illustrations alienate the students, and lead them to think of the 'learning' they do in school as something which is very foreign to their everyday lives. Evolution might then fit into this paradigm, becoming just another foreign, irrelevant concept to memorise.

It makes pedagogical sense to first emphasize the animals and plants which children see in their own environment, as most of the other textbooks do. It is a shame if students know how to spell 'giraffe' but have no idea about the different breeds of cows they encounter in their own streets - breeds which are good examples of evolution by artificial selection. We are happy to see that the diversity of cows (not giraffes) is discussed in Class IX. Rather than emphasizing the existence of a few desirable western fruits, plants, and animals, the cause of diversity may be promoted by mentioning a variety of local plants and animals. Textbooks may be playing a part in reducing crop diversity if they fail to mention the large variety of local species, varieties, and individual variation within a population. This is worrisome because future evolution by both natural and artificial selection depends upon the existence of variety in the gene bank. If students only see pictures of fruit and vegetables with a 'perfect' shape and colour, they may grow up looking for such 'ideal' forms, and be unwilling, for example, to purchase or eat fruits or vegetables that deviate from this stereotypical outward appearance.

It is encouraging to see that the Hindi book for Classes I and II are much better in many of these respects. For example, students are asked to go outside to observe and collect leaves (Chapter 4, Class I). Names and types of leaves are not given, and the point of the exercise is not identification. If students were asked to concentrate on naming, they would loose sight of more interesting aspects. Instead, students are asked to make pictures with the leaves they collect (as in Chapter 2, Class III). It is commendable that no examples or 'answers' are given for the activities. This discourages copying and memorising, and encourages students to collect leaves themselves.

Comparing Chapter 9 of the present Class X textbook to Chapter 13 of the 2003 version, we found the amount of space devoted to illustrations decreased from 10.7% to 9.5 % of the total page size. The text space also decreased from 70% to 60%. Although both of these chapters deal with evolution, the total number of pages increased in 2006, mainly because the division of topics into different chapters changed. In 2003 the topic of evolution was also included in the Class XII textbook, unlike in the 2006 version.

The Class X (2006) Chapter 9 has a word count of about 8500 words, including the question sections which are mainly at the end of the chapter. There is an average of one small illustration on each page, for a total of 14 figures and 8 additional small illustrations, all of which are in full colour. The illustrations utilise about 10% and the text utilises about 60% of the total page space. We consider this to be a very small amount of space for illustrations. Many of the concepts which are presented through text alone could be more usefully presented through illustrations integrated with text. In order to design a textbook in which this occurs, the authors and illustrators will have to work closely together, and illustrations will have to be given more importance.

Some of the illustrations in the higher level books are problematic if you believe, as we do, that an illustration should be as self-explanatory as possible. For example, the last line of pictures in the beetle evolution diagram (Figure 1) is particularly confusing. We have yet to find anyone who can understand this part of the illustration without reading the text. The text explains that it shows that as a beetle population "begins to expand, the bushes start suffering from a plant disease. The amount of leaf material is reduced. The beetles are poorly nourished as a result. The average weight of adult beetles decreases...", etc. Who would guess that a reduction in leaf material is represented only by a slight change in the green colour of the rectangle in which the beetles are framed? The illustration is quite inadequate. And since the change in colour is not shown to occur before the change in beetle size, which thing caused which effect is also not clear.

Conclusions and Suggestions for Improvement

Even with very young children, we can begin activities and discussions related to evolution. Evolution can be shown simply as an observation, and the mechanisms of evolution can be discussed later.

For example, we have found that even before they are able to read, if a book like "From Bone to Stone"(Haydock, 1999) is read (or sung) to young children, they begin to see that (1) in the past the earth was very different from what it is today; (2) we know this because we find fossils of some kinds of animals that no longer live on earth.

Another aspect of evolution that very young children can start to investigate is similarity and variation, both between different species and within the same population. This is being done in the present textbooks, but it could be improved by including activities in which students explore (1) the intrinsic ubiquity of both similarity and variation, (2) the existence overlapping sets (using Venn diagrams), and (3) complexities and difficulties in identifying characteristics and assigning categories.

We have had a long experience in teaching and developing teaching material for students at the middle school level in which we have found that students need a lot of practice to be able to identify both similarities and differences between things. For example, we have asked Class IV and V students to identify similarities and differences between the sun and the moon, or between the sunset and the sunrise. We have found that students need experience in carefully observing and trying to think of both similarities and differences. Typically, if they think two things are basically similar they will have difficulties in finding differences, and if they think things are basically different they have trouble finding similarities.

However, we have also found that with practice students do learn this basic aspect of the scientific process, and they are able to transfer the skill across domains. For example, over the course of one year in which they attempt to identify similarities and differences between things in the sky, things in air, and things in water, they are generally better able to compare and find both similarities and differences between plants. Of course it is necessary that in order to do this they must observe the actual things, not just pictures of the things, rather than relying on their memories of the things.

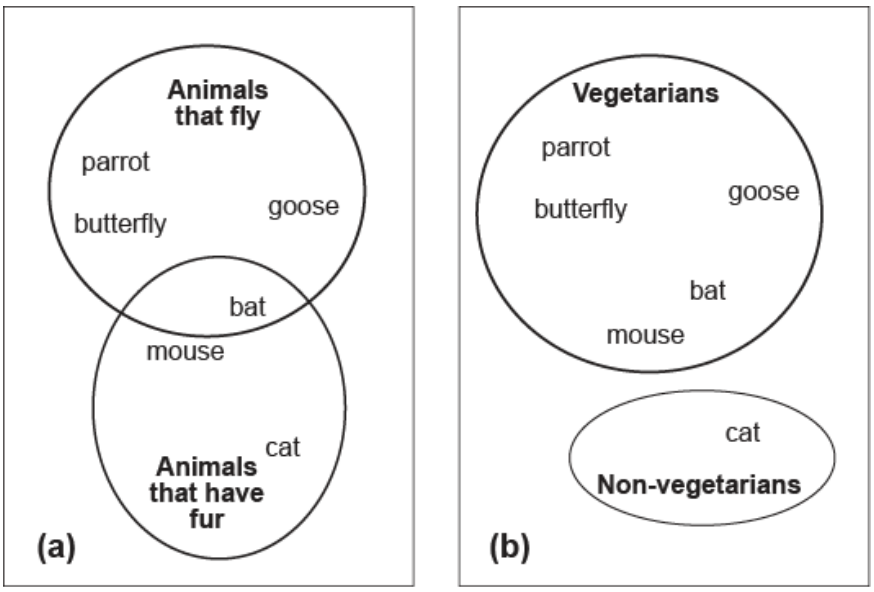

Figure 3: Venn diagrams could be used to help students do realistic sorting activities. For example, if the same organisms are sorted based on different characteristics, they may appear in different sets, as shown here. (a) Sorting on the basis of flying or having fur - which also illustrates overlapping sets. (b) Sorting based on being veg or non-veg.

For such preparation we find it useful to ask students to categorise the same things in different ways, based on different characteristics (e.g., Figure 3).

Through such exercises, students come to see that things do not inherently belong to particular categories, but that people define categories according to various characteristics, according to their needs. Thus students also come to see that categorisation is not always straightforward or easy - and this is something that makes science interesting and worth doing.

Instead of beginning by explaining the mechanism of evolution by natural selection, it will be easier for students if they start with a discussion of evolution by artificial selection, which is more concrete and less abstract. Children may already have some experience with plant and animal breeding. We find that village children usually know that there are different kinds of wheat and rice - older varieties and the newer 'hybrid' varieties. Although they do not understand how, they generally know that people developed the newer varieties. We might ask children to learn more about plant and animal breeding by talking to other people. Farmers and agricultural workers can be the teachers.

We suggest that rather than trying to include too many topics related to evolution in the school syllabus, there can be a few mandatory core topics and some optional topics. Teachers and students can pick and choose amongst the optional topics, preferably only investigating topics that arise in conjunction with particular problems that are relevant and important in their own community or environment. For example, macro evolution, speciation, and the Hardy-Weinberg Principle can be optional topics which may arise during investigations of the local biodiversity around the school, or during investigations of bacterial resistance. Students need not be asked to memorise the names of organisms and their classification. They will remember names if and when they need to use them.

Thus, textbooks can be more like reference books, in that they can contain optional material that is just there in case it is needed. Large numbers of separate reference books and optional modules of all kinds should also be made freely and readily available to students and teachers in all schools, rather than trying to include too much in each textbook.

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