Understanding causality in natural selection: Towards the problematic of learning Darwin's theory of evolution

A Thesis

Submitted to the
Tata Institute of Fundamental Research, Mumbai
for the degree of
Doctor of Philosophy in Science Education

by
Abhijeet Bardapurkar

Homi Bhabha Centre for Science Education
Tata Institute of Fundamental Research
Mumbai
July, 2008

"*[L]et the theory guide your observations*, but till your reputation is well established be sparing in publishing theory. It makes persons doubt your observations." (Charles Darwin in a letter to an Edinburgh botanist, John Scott, quoted in Gruber 1981, p.123).

"[T]he construction of a new theory is far from being reducible to the accumulation of data, but necessitates an extremely complex structure of interpretive ideas which are linked to the facts and which enrich them by framing them in a context." (Jean Piaget in the Foreword to the first edition of Gruber 1981; p. viii)

"Knowledge is a laudable aspiration, and speculation is laudable too as long as we are aware of what we are doing. And between these termini, inclusive, there stretches our whole fluctuating spectrum of beliefs" (Quine, W. V. and Ullian, J. S. 1978. The Web of belief (2nd ed). New York: McGraw-Hill p. 14).

DECLARATION

This thesis is a presentation of my original research work. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions.

The work was done under the guidance of Dr. G. Nagarjuna, at the Homi Bhabha Centre for Science Education, Tata Institute of Fundamental Research, Mumbai.

[Abhijeet S. Bardapurkar]

In my capacity as supervisor of the candidate's thesis, I certify that the above statements are true to the best of my knowledge.

[Dr. G. Nagarjuna]

Date: July 11, 2008

Contents

Acknowledgements

During my doctoral work I received generous and kind support from all quarters of Homi Bhabha Centre for Science Education. I am grateful to all the academic and administrative members of the institute for their help at various stages of this work. I received financial support and fellowships to attend various conferences abroad and to work with Peter Lipton. I am grateful to the Homi Bhabha Centre for Science Education, Tata Institute of Fundamental Research Alumni Association, and Sarojini Damodaran Charitable Trust for this help. This work has benefited from the discussions with a number of colleagues and friends. I owe deep gratitude to all of them, and especially to: Prajit Basu, Beena Choksi, Amitabh Gupta, Jon Hodge, S. G. Kulkarni, Arvind Kumar, Tim Lewens, Peter Lipton, Michael Matthews, Joel Mintzes, G. Nagarjuna, H. C. Pradhan, Stathis Psillos and B. M. Udgaonkar, for their comments and critique on various parts of this work. The support from the schools, the students, the school principals and the biology wing of the HBCSE's National Initiative on Undergraduate Science programme, and the data transcription support from Rashmi Jadhav and Meenakshi Sapkal, was gracious, and I would like to record my deep gratitude for their generosity and patience. I am grateful to all my friends, both at this institute and beyond, for seeing me through difficult times of the doctoral work. I owe much to my wife, Rakhi Banerjee for being with me, always. Finally, the constant and constructive critique, and continuous kind help of G. Nagarjuna, has nurtured this work throughout these years. Many thanks to him for all this.

Introduction

This work is primarily aimed at the explication and articulation of the cognitive difficulties in understanding Darwin's idea of natural selection. The empirical application of the significant insight gained from this exercise demands another occasion[1], though I indicate its potentials.

This work centres on understanding how students understand Darwin's theory of natural selection, by understanding how they construe the cause of organic evolutionary change. The focus is not only on demonstrating and explicating the difficulties students have in making sense of Darwin's idea of natural selection, but also on understanding the nature of these difficulties by contrasting the student's construal of causes of evolutionary change with that of Darwin's. The ultimate aim is to develop a framework that would help the educators and teachers interested in Darwin's idea of natural selection to understand the student's construction and representation of the causal-explanatory structure of the organic evolutionary change. Since here the aim in studying student's ideas is guided by the larger goal to help them learn Darwin's idea of natural selection, the structure of student's ideas is to be understood in the context of the structure of Darwin's ideas. Hence the whole activity of understanding the problematic of evolution education is constrained on the one hand by the causal-explanatory structure of the student's naïve theories and on the other by the causal-explanatory structure of the theory to be learned and understood by the students. Thus, the present work demands equal engagement in explication of Darwin's as well as the student's construction of the ideas concerning organic evolutionary change.

A science educator has two ways to enact to achieve students' understanding. Either she studies the subject matter to be taught, understands it thoroughly

[1] The articulation/application contrast is learnt from an instance of its usage in Sober (1984/1993).

and then communicates it to the students. Or the other way – which flourished in the contemporary constructivist paradigm – is to study the conceptions students bring to the classroom, understand these thoroughly, and help build the students their understanding concerning the subject matter. Each of these is important, but in focusing on one of them, we often forget to take into account the other one. For effective learning, the learner's ideas are to be studied, but they are to be studied in the context of the subject matter to be communicated to the students.

In sum, my theorising about the cognitive difficulties of the students in understanding evolutionary change by natural selection is constrained by how students tend to understand evolutionary change *and* also by how Darwin understood it in his theorising. I call the former an empirical element of the science education research and the latter a normative element.

In what follows, I first undertake an analysis of Darwin's theory, primarily based on his *Origin of Species* (Darwin, 1859). This is followed by an analysis of the student's understanding. First I analyse the understanding of the student studied in the science education research literature, and then I move on to a detailed discussion of the student in the present study. All this then leads us to our goal of defining and explicating the problematic of understanding causality in natural selection.

1 Darwin's Understanding of Organic Evolution: Causal-explanatory Structure of the theory of Natural Selection[2]

Our overall goal is to define the problematics of learning Darwin's theory of evolution. Learning involves the learner and (in this case) the theory being learned. As a biology teacher or education researcher, to analyse and understand the cognitive difficulties in the learning of Darwin's theory, we have to study both the theory and the learner. We have to understand Darwin's understanding vis-à-vis the student's understanding: that is, the causal structure of the student's explanation vis-à-vis the Darwin's. Here, by *understanding*, I mean causal-explanatory-understanding. In this view, one's understanding could be accessed and assessed through the study of her causal-explanations of the relevant phenomena. The other chapters dwell into the empirical studies – including mine – on how the student understands evolutionary phenomena. This chapter (and the following one) constraints and complements the work in those chapters by explicating the causal structure of Darwin's theory and the development of his theorising.

The present work draws primarily and extensively from the *Origin of Species* (Darwin, 1859/1964; hereafter the *Origin*). I find that the structure of the *Origin* and its representation of the theory of natural selection are, by far, immensely fruitful[3] both pedagogically and in illuminating the problematics of understanding Darwin. It engages us in clear and clean delineations of the causal-explanatory structure of the theory and helps us deal: What is the object

[2] Parts of this work have been presented at the 2007 meeting of the International Society for the History, Philosophy and Social Studies of Biology (ISHPSSB), held at the University of Exeter from July 25 to July 29, 2007. I owe deep gratitude to the audience there and to Beena Choksi, Jon Hodge, Arvind Kumar, Peter Lipton, G. Nagarjuna, H. C. Pradhan and Stathis Psillos for their comments on the ISHPSSB paper.

[3] Of course, I am not alone in thinking this. Similar views could be found, for example, in Kitcher 2003, p. 45 and Hodge 1987, p. 234.

of the theory of natural selection? How the theory describes and explains this object? How is the artificial related with the natural? Wherein lays the locus of causality in natural selection and how to characterize this causality? What is the effect of natural selection and how is it effected? In short, what is the causal structure of the theory of natural selection as proposed by Darwin?

1.1 The object of the theory of natural selection

To understand Darwin's theory, we have to understand what the theory aims to explain, what the object of the theory is. The object of Darwin's theory is the "passage from one stage of difference to another and higher stage" (Darwin 1859/1964, p.52). It focuses on individuals and the differences or variation among them. But it never attempts to explain the *origin or cause* of the *individual* differences; it explains the *accumulation* of individual differences. The *origin* of the individual change is beyond the domain of Darwin's theory. For instance, while writing on "the subject of instinct", Darwin says, "I must premise, that I have nothing to do with the *origin* of the primary mental powers, any more than I have with that of life itself. We are concerned only with the diversities of instinct and of the other mental qualities of animals within the same class" (ibid., p. 207; my emphasis). Thus the theory of natural selection presupposes that the individuals in a population vary from each other and also across generations, never concerning itself with the questions of how the individual change comes into being. Darwin takes this to be as an easily observed (commonsensical) fact of the world.

The object of the theory comes into much sharper focus if we contrast the cause and the consequence, or the origin and the evolution, of an individual variation. Individuals of *a* population vary from each other in various properties. If the individual variation is so common and prevalent, then some individuals may happen to vary in such a way that, whatever may be the cause of that variation, its consequence is of benefit to those varying individuals; in

such cases we say that the individual variation is adaptive. The object of the theory is the consequence – *whether adaptive or not* – of the individual variation, not the cause. In the theory of natural selection, his aim is to explain how adaptations are perfected, *not* how they originate and from what cause do they originate. Darwin asks two complementary questions: one, "how have all… [the] exquisite adaptations of one part of the organization to another part, and to the conditions of life, and of one distinct organic being to another being, *been perfected*?" (ibid., p. 60; my emphasis); and two, "how does the lesser difference between varieties become augmented into the greater difference between species?[4]" (ibid., p.111). The theory is a causal-explanatory narrative of the journey from a least distinct but slightly adaptive stage of (individual) differences to another more distinct and greatly adaptive stage of (evolutionary) differences. In Darwin's own words: "I look at individual differences, though of small interest to the systematist, as of high importance for us, as being the first step towards such slight varieties as are barely thought worth recording in works on natural history. And I look at varieties which are in any degree more distinct and permanent, as steps leading to more strongly marked and more permanent varieties; and at these latter, as leading to sub-species, and to species" (ibid., p. 51-52).

The theory of natural selection explains the accumulation and augmentation of slight individual adaptive variation into the greater (evolutionary) adaptation[5]. It is not concerned with the cause or with the origin of the adaptive (as well as non-adaptive) individual variation. The focus is always on the consequence of a variation for the individuals, and on how profile of the variation in a population changes across generations.

[4] Darwin's theory does explain the origin of species, but only from preexisting species (or species like populations of individuals), and as I detail in the text, it also explains (evolutionary) adaptation, but only from the preexisting, slightly adaptive, individual variation.

[5] The following sections discuss this in detail.

1.2 Man's selection[6]

Organisms change in the hands of breeders. Breeders start breeding one variety and may end with another. To understand how the Darwin's theory explains the evolutionary change[7] from one variety to another, let us focus on the character of this change and its causes in man's selection.

1.2.1 Change by transformative action vs. change by accumulative selection

A population of individuals could be changed in two fundamentally distinct ways[8]: either by a cause that acts on the individuals thus transforming them, or by a cause that selects some of the slightly-transformed individuals thus accumulating them. I call the former change by *transformative action*, and the latter change by *accumulative selection*[9]. Selection does not change the existing individual entities, there is no transformative-action on the individuals; one is just preserving and *accumulating what is available*. In contrast, in transformative-action, one is *changing what is available*. Selection preserves the existing individual change whereas transformation effects the change. Let us take an example to clarify the differences in the operation of

---

[6] Instead of using "artificial selection", here I prefer using this phrase commonly used by Darwin in the *Origin of Species* (1859/1964/), because using "man's selection" sharpens the causal agent -- human being -- in the selection.

[7] Recall that we have been contrasting the individual change or the individual variation with the evolutionary change or the evolutionary variation. While individual change is at the level of individuals, evolutionary change is at the level of populations. While the former is limited to the individual life cycles, the latter is trans-generational, that is for a change to be evolutionary it has to be stable and inherited across a number of generations. In other words, we say that individual change is ontogenic (following Greek: *ont* refers to being and *genic* to genesis), whereas evolutionary change is phylogenic (following Greek: *phylo* refers to race or tribe). But, historically, evolution meant different things in different times, see Richards, 1992. Also see the Section 1.5.1.1

[8] There is a third, and perhaps even more fundamental, way – "Creation from the scratch", but I will set that one aside for the present purpose.

[9] This distinction has it roots in Lewontin's (e.g. 1984) distinction between "transformational" and "variational" evolution.

these two kinds of causal processes. One way to change a pile of stones into a pile of sand is to transform it, say by hitting with hammers. Another way can be that you begin by selecting stones of smaller and smaller size, as and when they become available. Eventually, if you are lucky to have the stones of the desired size, you could end up having a pile of sand particles. Instead of producing a pile of sand particles through transformative action, you kept on selecting and accumulating the stones of size closest to the desired size of sand particles, from the available stones.

Transformative action could be divine or earthly. If earthly, it could be either artificial or natural. But, be the agent that transforms individuals be God, human, environment or genes, change by transformation is fundamentally different from change by selection. When the entities are transformed through the action of non-supernatural, non-artificial causes – environmental conditions, for example; it would be a change by "natural *transformation / production*", not "natural *selection*". For example, Jordanova (1989) calls Lamarck's theory of transformism as "a theory of natural production" (Jordanova 1989, p. 74): "Lamarck had to find a way of infusing nature with activity without suggesting that the activity denoted a separate agent." (Jordanova 1989, p. 92). In the present context, "natural *production*" forms a nice comparison with Darwin's theory of "natural *selection*"[10]. Though Lamarck opposed personification of nature or the belief in the direct creation of natural objects by God – the reasons that make him naturalistic, his theory was the theory of natural production; the theory that can be classified under the broad category of theories that explain change by transformative-action[11].

[10] For Lamarck, Jordanova says, nature was a "constantly active power… lacking intention or goal" (Jordanova 1989, p. 74-75)

[11] "For Lamarck, activity in nature derived from motion on one hand, and laws governing motion on the other … Nature can neither create nor destroy matter, only modify it continually" (Jordanova 1989, p. 76-77).

1.2.2 Seeing "selection" in the breeding

Darwin was not the first one to look at domestic breeding practices as an evidence of organic evolutionary change. But he saw *selection* there that others could not. Darwin's "Historical sketch" (Darwin 1872, pp. xiii-xxi)[12] at the beginning of the O*rigin* can be taken to provide a contrast between Darwin's and his predecessor's view of domestic breeding practices in the context of organic evolution. It is his bird's eye view of how close or far were the thoughts of those who thought about the organic evolution, to his idea of natural selection. For example, Darwin writes that both Lamarck and Spencer alluded to the "analogy of domestic productions" (Darwin 1872, pp. xiv and xix) but perhaps just as an evidence of modification of domesticated species; they did not see any "selection" as a cause of the modification. Lamarck "attributed something to the direct action of the physical conditions of life, something to the crossing of already existing forms, and much to use and disuse", whereas Spencer found the cause of the natural modification of species in the "change of circumstances" (ibid., p. xix).

Why the *selection* in the domestic breeding practices remained so opaque to those who looked at it as an evidence of mutability of species, and even to the breeders who were directly involved in it. First reason that Darwin has is that, they were so impressed by the distinct differences in the varieties that they rarely thought about the slight individual differences. They did not reflect on their breeding practices, "though they well know that each race varies slightly, for they win their prizes by selecting such slight differences" (Darwin 1859/1964, p. 29). The second (and perhaps pedagogically more important) reason is that, they did not "sum up in their minds slight differences accumulated during many successive generations" (ibid.). To understand *selection* as a cause of evolutionary change, first one has to recognise the

[12] Except the "historical sketch", all other references to the *Origin* are from the first (1859/1964) edition.

slight individual variation and then "see" it being selected and accumulated in successive generations by the breeders.

1.2.3 The cause in man's[13] selection

How one variety evolves into another in man's selection? By the breeder's selection – the breeder is selecting, not transforming. For example, the breeder-selector does not manipulate the external conditions in which the individuals are living or manipulate the habits of the individuals to transform them. But, the breeder selects from the individual variation that is already present in the population.

Variation is common; the selector selects a variant of her interest from the existing pool. Individuals of the same species living in the same locality, offspring from the same parents, have individual differences. In fact a whole "catalogue of facts" could be offered to show the commonness of individual variation. But only the variation that is inherited to the following generations is of importance in Darwin's theory because it is the material for "selection to accumulate" (Darwin 1859/1964, p.45), and "the number and diversity of inheritable deviations of structure, both those of slight and those of considerable physiological importance, is endless" (ibid., p.12).

1.2.3.1 What is artificial in man's selection?

The world of living entities is full of variety, adaptation and their (*almost*) faithful reproduction. The history of humanity has seen a number of attempts to make sense of this living world. These attempts can be categorized into three broad categories based on the types of causes each one invokes in its explanations: a category using the causes that go beyond *this* material world, a category using the causes that belong to the existing material world, a category

[13] See the note 6.

that uses the causes that belong to the human world. If the existing, material or physical world is dubbed as the natural world, then the three categories we have just seen can be labeled respectively as the categories of supernatural explanation, natural explanation and artificial explanation.

Slight individual differences and their re-occurrence in the next generation is a *naturally* occurring phenomenon. Here, "natural" is to be contrasted with "supernatural" and "artificial". The cause is a natural cause if it has its origin neither in the act of supernatural power nor in the act of human beings[14]. Of course, this definition is anthropocentric, because *we* -- the human beings, are attempting to understand the causality around us, and from this perspective, what is artificial is caused by us, mostly for us. Existence and inheritance of variation is not an artifact of man's deeds -- whatever may be its cause, it is not caused by the selector with the view of modifying the breed in a certain manner. Both variation and inheritance are not in the selector's hands, they are naturally available to her, not artificially produced for the purpose. What makes "man's" selection *man's* selection is not the variation and its inheritance, but the act of selection and preservation of particular variation in each of the generations. Unlike variation and its inheritance, which happens without man's mediation, selection and preservation of particular variations need mediation: the selector selects and ensures the journey of selected variations through many generations. Variations useful to human beings will not be preserved without the selector. Variation and its inheritance are caused by the natural mechanisms but the selection is caused by the selector, and this is the reason artificial selection is artificial. The selected individual-changes or variations, because they are hereditary, "accumulate" (Darwin 1859, for example see p. 32) in a certain direction decided by the selector. Over the generations the number of particular variants as well as the magnitude of

[14] Historically, the meaning of "natural" emerged in contrast to that of "supernatural". See, for example, Greene 1959, p. 57, 78 and pp. 54-55.

variation increases. For example, the tail length as well as the number of long-tailed pigeons would increase as a result of selection of long-tailed pigeons. One domestic variety changes into another because of the continual preservation of slight individual differences and their consequent accumulation during successive generations.

1.2.3.2 Refining the cause in man's selection

The accumulative selection in domestic populations is caused by the selector's preserving the variation in the successive generations. This explains how a domestic variety evolves from its ancestral population. But it does not explain the adaptation found in domestic varieties (dray-horse and race-horse, the various breeds of sheep fitted either for cultivated land or mountain pasture, with the wool of one breed good for one purpose, and that of another breed for another purpose; many breeds of dogs, each good for man in very different way). When we compare a variety that has changed due to the selection, with the one with which the selector had begun, we notice that the variety after the selection, compared to its ancestral form, is more in tune with "wants or fancies" (Darwin 1859/1964, 38) of human beings -- they are adapted to *our* conditions of life and beauty. Indeed, it would appear as if the selector has transformed slightly valuable variety into one that is more valuable or that appears beautiful to us. But, as we have seen, the selector is not attempting to transform the individuals. Instead of producing or making this great adaptive change, the educated eye of the selector does the work of selecting only those individual variations that are already, though slightly, of use and beauty to *us*. The slightly useful individual variations -- preserved in each generation by the selector, and from one generation to the next, by the natural mechanisms of inheritance -- augment into a greater adaptation. This is a paradigmatic example of change by accumulative selection: "nature gives successive variations; man adds them up in certain directions useful to him" (Darwin 1859/1964, p. 30).

By now, you must have noted that the "accumulation" we are talking about becomes apparent at the level of populations, after the gap of multitudes of generations. There is no accumulation as such at the level of individuals, in the sense that individuals are undergoing some sort of development. The augmentation of adaptedness takes place because, in each generation, the selector selects best adaptive variation that gets inherited to the next generation. The organic change, according to Darwin's theory is neither transformational nor developmental; it is an accumulative change, and the accumulation is contingent on the availability, selection and inheritance of individual variation.

To sum up then, evolutionary change in domestic varieties is effected through the selector's continual preservation of slight individual variation during numerous generations. This change is adapted to suit us, because each of the selected variants was suitable to us: in each generation, a change is selected because it suits the needs and fancies of the selector. Profitability of a variation for the selector can thus be said to be the cause of its preservation by the selector, the preservation that will eventually cause the formation of a distinct domestic variety adapted to human conditions and demands.

1.3 Questioning the essence and immutability of species: From the artificial to the natural

Darwin held that there are no *essential* differences between different natural species, between natural species and natural varieties, and between natural varieties and domestic varieties. The species of larger genera, have a large number of varieties, and, just like varieties are, the species of these genera are unequally related and clustered around each other. This analogy between the species and varieties clearly suggested Darwin that these "species have once existed as varieties and have thus originated" from the accumulation of differences. "[W]hereas, these analogies are utterly inexplicable if each species has been independently created" (Darwin 1859/1964, p.59). Moreover,

there is no “marked distinction” (Darwin 1859/1964, p. 16) between domestic races and species in nature; such categorization is purely empirical. Hereditary domestic varieties vary from each other “in the same manner as do closely-allied species of the same genus in a state of nature” (ibid.). Secondly, it is difficult, Darwin says, to ascertain if different domestic races/varieties (which are known to truly inherit their own kind) have descended from different or the same parent species. If various domestic varieties are indeed the descendents of one and the same natural species, then it would seriously question the claim of the immutability of species. Thus, in Darwin’s view, the doctrine that each species has a distinct essential character demarcating it from others and the thesis of immutability of natural species are in serious doubt.

Further, if there is no essential difference between domestic and natural varieties, and if we know how the domestic varieties are produced, we would be able to generalize this knowledge to think of how the new species are formed in nature. This generalisation is possible because Darwin, by the way of his theory, abolished the otherwise unsurpassable distinction between domestic and natural varieties and also between natural species and natural varieties. Darwin quotes the case of polymorphic genera for the difficulty and dispute among the experts in setting clear boundaries between species and varieties of these genera. This indicates that there is nothing unique in species that could help naturalists to objectively distinguish them from other species and varieties. “[I]n determining whether a form should be ranked as a species or a variety, the opinion of naturalists having sound judgment and wide experience seems the only guide to follow.” (Darwin 1859/1964, p. 47). And this judgement has no essential-objective basis as such. Darwin claims that in a number of closely related forms, often the naturalist gives a status of species to a form that is discovered first or is found most commonly. He recalls that: “when comparing, and seeing others compare, the birds from the separate islands of the Galapagos Archipelago, both one with another, and with those from the American mainland, I [Darwin] was much struck how entirely vague

and arbitrary is the distinction between species and varieties." (Darwin 1859/1964, p. 48).

In sum, Darwin saw no essential difference between species, sub-species, incipient species, varieties, and individual difference. He says: "I look at the term species, as one arbitrarily given for the sake of convenience to a set of individuals closely resembling each other, and that it does not essentially differ from the term variety, which is given to less distinct and more fluctuating forms. The term variety, again, in comparison with mere individual differences, is also applied arbitrarily, and for mere convenience sake." (Darwin 1859/1964, p. 52).

Collapse of these distinctions were immensely important for Darwin, as it is for us, because these observations took Darwin towards understanding *how* the accumulation of individual differences result into the formation of varieties, and the further accumulation to formation of incipient species and then the formation of species: "*These differences blend into each other in an insensible series; and a series impresses the mind with the idea of an actual passage*" (Darwin 1859/1964, p. 51; my emphasis). From the continuous spatial diversity of forms, Darwin interprets the evolution in time. Once it is accepted that the only difference between species and varieties is of the difference of degrees the central question, in my view, that the theory asks is: "how the lesser differences between varieties will tend to increase into the greater differences between species." (Darwin 1859/1964, p. 58; See Section 1.1).

1.4 From selector's selection to natural selection

Establishing that organisms can be extensively modified over generations in domestic breeding and hence putting a big question mark on immutability and essential nature of species, is not enough to reach to and develop the idea of natural selection. As we saw in Section 1.2.2, we have to *see* how *selection* causes the evolutionary change in domestic breeding. But, to have understood

the selection by the breeders (or selectors) is not sufficient for understanding *natural* selection – to understand natural selection one must understand *how* it happens under natural conditions. Here, the case of M. Naudin is illuminating. Unlike, Lamarck or Spencer, he just did not take the formation of new varieties in domestic breeding as an evidence for mutability of species, but saw "man's power of selection" as a cause of change effected in domestic breeding. But, as Darwin did, "he does not show *how* selection acts under nature." (Darwin 1872, p. xix; my emphasis). Darwin discovered how selection causes evolutionary change both artificially as well as naturally. Darwin's historical sketch brings out a very important point: It was crucial but not enough to have discovered the causal process of selection in domestic breeding practices, what was even more crucial for his theory was the discovery of the possibility of an analogous process under natural conditions.

The crucial conceptual transformation to the idea of natural selection comes through when one sees how the selection "so potent in the hands of man, apply in nature?" (Darwin 1859/1964, p. 80). But, the transition from man's selection to natural selection (note: *not* nature's selection!), alas, is historically, and cognitively, the most difficult transition to attain. Difficult because in man's selection, man is selecting, who is the selector in nature? Doesn't selection need selector, what is the selecting agency in nature? Who or, to be naturalistic, what replaces the "man" in "man's selection"? No one, Darwin would say. And this is the core of the idea of natural selection – selection is natural not because it takes place in the natural world out there, but because no mediation is necessary to run the selection. This transition from selector's selection to natural selection had to wait for Darwin[15]. One may recognize that breeders are able to produce astonishingly different varieties; one may recognize that like the domesticated ones, animals and plants do very

[15] For example, Darwin's predecessors, Spencer and Naudin (Darwin 1872, p. xix) gave due importance to domestic productions but, apparently, could not traverse the transition from the artificial to the natural. It was Darwin who achieved this.

in wild; one could even think of how it is the breeder's or farmer's selection in each generation that leads to the production of newer varieties of animals and plants; and this understanding might even compel one to question the boundaries between varieties and species and the immutability of natural species. But then how do species change in nature? Is it because they are plastic? Or they are naturally subject to progressive development? Or because of the external conditions they live in? Or because of their use and disuse of organs? Or do species change in nature like they do in the hands of the breeder – by selection? It was Darwin who developed the last possibility into the theory of natural selection.

1.5 Natural selection

Darwin saw the evolutionary change in varieties as accumulative change, effected by selective preservation of slight individual variation, and applied the same ingenious idea across the domesticated and wild varieties. But the question is how is the slight individual variation selected and preserved through generations? If the variant individuals are preserved by the selector, it is no more "natural" selection, but would be "man's" selection[16]. How then is the slight individual variation selected and preserved *naturally* -- without the agency of man? The variation or individual-change is *naturally* preserved because of its usefulness to the individual in its survival or reproduction – it is a *natural* consequence *of* the variation's advantageousness *for* the variant.

Be it man's selection or be it natural selection, the preservation of an individual variation is the consequence of its usefulness. If the change is useful to the human beings the selector ensures its preservation, if the change is useful to the individual itself, this *particular* advantageousness or

[16] Whenever the cause is conscious or intentional, it ceases to be natural; it either is supernatural or artificial. See Section 1.2.3.1.

usefulness-to-the-self *causes* its preservation. And in both cases the inheritance of the change ensures its accumulation across generations.

1.5.1 Refining the cause in natural selection: Darwin's is *natural,* not *nature's,* selection

When we reflect on the function of a structure, we generally do it in relation to the organism in question. For example, when thinking of a store of nutrients present in a plant seed, we think of the usefulness of this nutriment-store for the growth of the seedling, rarely relating it to the other growing plants around the one we are thinking about. But when we look at the function's usefulness for an individual in the context of other competing individuals, we realise that the structure-function we are focusing on has a certain *advantage* for the individual that the others lacking it do not have (Darwin 1859/1964, p. 77).

The key to understand natural selection is to understand the advantage a variation confers on the variant. The advantage allows the organism to out survive others and reproduce. Darwin advises us that: "It is good thus to try in our imagination to give any form some advantage over another." (ibid., p. 77-8). He writes: "Look at a plant in the midst of its range, why does it not double or quadruple its numbers? … In this case we can clearly see that if we wished in imagination to give the plant the power of increasing in number, we should have to give it some advantage over its competitors, or over the animals which preyed on it" (ibid.).

For illustration: Imagine a bacterial population growing in the environment where two types of sugars -- SA and SB, are available. Initially the environment had no fungal species in the vicinity of the population. Consider that a fungal species producing antibiotic FA is recently introduced. Now, given that a few FA antibiotic resistant bacteria exist in the population[17],

[17] That is they have been in existence, even before the introduction of the fungal species.

would you say that they would be selected by the changed environment or because of the advantage they have in the changed environment? I defend the latter. The environment in which the organism is present, no doubt, contributes in conferring the advantageousness of a given variation – *but not as a selector*[18]. It is due to the advantage, not due to the change in the environment, that the antibiotic resistant bacteria are naturally selected.

Take another identical population in the identical situation, but without any antibiotic producing source. Let us suppose, a few bacterial cells undergo a change that enables them to effectively catabolise sugar SB. Such a change would be an advantage to them, while all the others in that population are to depend entirely on sugar SA for their survival. The variants will be naturally selected -- compared to the others in the population, they will naturally outgrow in numbers. In this second instance, unlike the first one, there is no change in the environment, and still there is natural selection, because there is the variation that proves to be advantageous to the changed individuals. Of course, here too, had sugar SB been absent or had there been no competition for sugar SA, the variation that enables the effective utilization of Sugar SB would not be advantageous. It is (trivially) true that advantageousness cannot be conceptualized in a vacuum -- advantage is always with respect to the organic and physical conditions in which the variant organism is living. *But*, natural selection is consequent on the advantage, not on the static or changing environmental conditions. Without advantageous change (of course in the given conditions of life) no organism would be naturally selected: "Only those variations which are in some way profitable will be preserved or naturally selected" (Darwin 1859/1964, p. 117).

Darwin writes, "[A]ny variation, however slight and from whatever cause proceeding, if it be in any degree profitable to an individual of any species, in

[18] What does it amount to say that the "environment selects" beyond its metaphorical connotations? See Section 1.6.

its infinitely complex relations to other organic beings and to external nature, will tend to the preservation of that individual, and will generally be inherited by its offspring." (Darwin 1859/1964, p. 61). Darwin "owes" (ibid.) this process of selection to the "struggle for life", but for Darwin it means the dependence of organic beings on each other and on the inorganic conditions of life. He uses "the term Struggle for Existence in a large and metaphorical sense" (ibid., p. 62). In a complex and nicely balanced web of relations, where organisms are "bound together", even the slightest advantageous variation preserves (not brings in) the change by natural selection. What is important for the natural selection is that there be place "in the economy of nature" that a chance variation might fill up by better adapting the variants to that "unoccupied space" (Darwin 1859/1964, p. 81). Note that in Darwin's theory competition or changing conditions do not contribute to the natural selection as a "selector", in the sense that "man" is the selector in the "man's" selection. But these might create "opportunities" for a variation. And this variation, "which in the course of ages [has] chanced to arise… favoure[s] the individuals… by better adapting them to their altered conditions" (ibid., 81). We will not understand the causal structure of the Darwin's theory by replacing a "conscious" selector in artificial selection by a "natural" agency. Darwin's is a *natural* selection, not *nature's* selection

No doubt, variation is to be viewed in the context of its complex relationship with the other variants and their physical environment. The worth of a variant, the advantage it confers on its possessor, is dependent on this context, and the "struggle" adds to the causal value of the variation. But, the struggle, in itself, does not play a causal role of the "selector". Variation is selected naturally; not because organisms possessing them are struggling to survive, but because it proves to be advantageous in the variant's struggle to survive and reproduce. This is analogous with the man's selection: here too, the selection does depend on how "educated" are the selector's eyes; nevertheless, the selector selects not because he is well trained in identifying variants, but because the variation

is of use to him. The cause of selection lies in the *advantage* of variations: in their being "useful to man" or "useful in some way to each being" (Darwin 1859/1964, pp. 80-81). For example, though "the advantage of plumed seeds no doubt stands in the closest relation to the land being already thickly clothed by other plants" (ibid., p. 77), the advantage -- not the density of the population -- contributes causally to the survival of the plum seeds to reproduce successfully. "[U]nless profitable variations do occur, natural selection can do nothing … … natural selection can act only through and for the good of each being … preserving and adding up all that is good" (ibid., p. 82, p.84). It is the advantageous variation that preserves the variant through harsh struggles in unwelcome environments.

1.5.1.1 Explaining evolutionary adaptation

Naturally selected individual variation is already useful to the individuals – in this sense then, it is already an *adaptive individual* variation. As we discussed in Section 1.1, what Darwin's theory does is explain how the existing slightly-adaptive individual variation is accumulated over numerous generations, in the prevalent conditions of life into an (evolutionary) adaptation. It is important here to distinguish between as individual adaptive variation and a (full blown) evolutionary-adaptation. Adaptation – or to be precise evolutionary adaptation – is commonly assumed to be a consequence of natural selection, and is also employed to denote the process of selection[19]. You may recall that Darwin's theory explains the adaptation, it does not explain the slight-individual-adaptive-trait – rather, it presumes its existence (see Section 1.1). Moreover, every beneficial and stable trait need not necessarily be the result of selection,

[19] There are excellent expositions of the concept of adaptation in the (history and philosophy) literature. For example: see Brandon 1996, especially pp. 36-40; and Sober 1984/1993, especially pp. 203-205, where he distinguishes between *evolutionary* and *ontogenetic* adaptations. We will get an opportunity to discuss Sober's distinction in another chapter.

and hence being beneficial is not sufficient to qualify as an adaptation[20]. The trait is *not* an adaptation, unless it inherits the causal history of selection; just being beneficial to the variant is not *sufficient* for a variation to be an adaptation[21]. But, recall and record that every adaptation is *necessarily* beneficial -- in man's selection to us, in natural selection to the individual (the variant) itself. What is common between an adaptation and its ancestral individual variation is that both of them have been beneficial. The ontogenetic causal history of an individual variation -- the question of its (immediate) origin -- is irrelevant for its selection as long as it is stable and transmitted to the next generation. What matters is its effect, the advantage it imparts on its self[22]. Moreover, the process of selection does not overwrite ontogenetic causes accounting for the origin of an individual variation. When an individual variation *is* advantageous, in virtue of this advantage, it causally contributes in its selection or preservation. And then, over the generations, in addition to having the ontogenetic causes accounting for its origin, the variation has phylogenetic causal history accounting for its preservation, consequent accumulation and augmentation through generations. Being advantageous is the causally central common thread between an evolutionary adaptation and its ancestral advantageous individual variation. Advantageousness is the *causal core* of the concept of adaptation: it unites adaptation with the evolutionary process[23]. All the instances of *natural* selection have to have an advantageous trait at the centre of its causal scheme[24].

---

[20] For those who want to pursue this point further, Brandon (1996) might be of help again. Also see Chapter two.

[21] Adaptation in the sense of evolutionary adaptation. In the Darwinian discourse adaptation means evolutionary adaptation.

[22] Again the question of the individuation of the self, the level (gene, organism, population) at which it is to be identified, is not relevant for our current concerns

[23] I have no intention to undertake an abstract characterization of "advantageousness" though the concrete meaning of "advantage" differs in each case of selection. Selection is not contingent on *how* the advantage is being conferred, as long as it *is* conferred. In any case, I am interested in the representation of the causality in

1.5.2 Teleology and natural selection

One look at any of the adaptations, adaptations of body structures for example, may entice us to think teleology: to think that these adaptive structures have been built for the functions they do, these *means* have been necessitated by the *ends* they serve. In this connection, Darwin's comment on Aristotle (Darwin 1872, p. xiii), is pretty telling. Is it by necessity, or by mere accident, that the front teeth grow sharp "adapted for dividing, and the grinders flat, and serviceable for masticating the food" (ibid.); are the teeth made for the sake of dividing and grinding, or is it just the result of an accident? And what is the case with the other parts "in which there appears to exist an adaptation to an end" (ibid.)? Clearly for Darwin the variation in the front teeth towards sharpness is a mere accident (though not without cause), and the variation was certainly not necessitated by the end (i.e. the function) it serves. Natural causes make it necessary that there be variation among individuals of the same species, but not any specific variation with its end in view. Unlike Aristotle, for Darwin the end any particular variation might serve after coming into existence is not causally relevant in its origin. At the same time, however, the end the existing variation actually serves is of immense causal importance in Darwin's theory. We have to remember that it is because of the end the variation serves that the variation is naturally selected – the variation's use or advantage to its possessor, is not only causally relevant, but is central to Darwin's theory. Darwin's theory is silent on the cause (or origin) of the variation, not on its effect (or consequence).

Darwin's *theory*, not in how it should be measured in the actual instances of selection. Construing evolution as changes in gene frequencies may enjoy the advantages of an abstract concept, but takes out the causal core of the theory of natural selection that construes evolution as augmentation of adaptive individual changes.

[24] A *potentially* disadvantageous trait -- like vulnerability to a disease when it is rare, can certainly evolve, but only if it is linked with an *actually* advantageous trait -- like running fast when there are numerous predators around (cf. Sober 2000, pp. 78-79, p.83)

1.6 A tale of misplaced metaphors

Now let me briefly point out how the metaphor "blind watchmaker" (Dawkins 1986/1988), if it claims to capture the process of selection, misrepresents it. Merely by making a watchmaker blind you are not suggesting the process of change by selection. Instead, the act of "making" in the "blind watch*maker*" is a strong pointer to a process of change by transformative-action. At best the metaphor could stand for a process of production in which the creator is not aware of what she would end up creating. Though, by making the watchmaker blind, the metaphor can be a successful rendition of a fact that the *origin* of variation is blind to the end it would eventually serve (and this is not a small feat), it fails to capture the essence of the process of selection. Natural selection is unconscious, but is not blind to its ends. A particular variation is selected, both in natural as well as man's selection, for the end it serves, for the effect it has (see Sections 1.2 and 1.5). The origin, the cause of variation -- not the selection -- is blind to its ends. The selection is an effect of inherited advantage

It would be incorrect, even according to Darwin, if we say that the man *makes* domestic races. Man is not making, but selecting and selection is impossible unless the slight variants are available for him to select from. In Darwin's words: "No man would ever try to make a fantail, till he saw a pigeon with a tail developed in some slight degree in an unusual manner… But to use such an expression as trying to make a fantail, is, I have no doubt, in most cases, utterly incorrect. The man who first selected a pigeon with a slightly larger tail, never dreamed what the descendants of that pigeon would become through long-continued, partly unconscious and partly methodical selection." (Darwin 1859/1964, pp. 38-39).

Fodor (2007, October18) is right: Darwinians are sometimes seduced by the metaphors of Watchmakers and Mother Nature (the latter one is from Daniel

Dennett). These metaphors may indeed trap our understanding into thinking that Darwin's achievement was to simply replace the conscious agent in 'man's' selection with a 'natural' (and even blind!) agency. But, this is not what Darwin's theory did. This is the (unexpected and unacknowledged!) fallout of literary efforts of Darwinians to make the theory more accessible to the general audience – in the process robbing it of its causal core. It is indeed commendable that Fodor has saved himself from the seduction of these *selector-centric metaphors*. But alas! He mistook these metaphors for what Darwin achieved in his theory, he mistook a Darwinian's seduction for Darwin's[25]: Darwin not only killed Mother Nature, but the necessity of Selector. He naturalized the process of organic evolutionary change. He told us how selection is possible 'naturally' – that is without the selector, and there is no equivocation or 'metaphorical anthropomorphism' here (cf. Fodor, 2007).

1.7 Summary

The evolutionary change effected in selection is an accumulative change. To understand *how* of selection, we understand how of *accumulation*: we ask, how the existing hereditary individual change is accumulated. In the case of *man's* selection the accumulation is caused by the selector (but see the Section 1.2.3.2). To understand *natural* selection we ask: how the existing individual changes are *naturally* accumulated. A natural accumulation of a variation is a consequence of the causal contribution of the variation in the variant's survival. A variation is naturally accumulated be*cause* it proves to be profitable in the survival of the variant. In artificial as well as natural scheme of things, *any* variation is not the subject of accumulation across generations. Only the useful and hereditary variation is "selected" in the process. This

[25] Along with Fodor's 2007 article *LRB* article, the interested reader is also referred to the February 2008 issue of *Mind and Language* (Volume 23, No.1).

accumulative selection explains the grand consequence of the evolutionary process that goes by the name of *evolutionary adaptation*.

So, what is necessary for the natural selection to occur? In order that there be selection, it is necessary that there be individual variation, it is necessary that some of the variation be beneficial to the individuals, and it is necessary that some of the beneficial variation be transmissible to the future generations. All the three conditions stated here make the selection possible. In the case of artificial selection, because the variation is often not beneficial to the varying-individuals, there is an additional necessity -- the necessity of a selector.

Finally: the theory of natural selection does not provide us with the cause of change, but tells us how the existing changes are naturally preserved. Organisms are not modified by the action of selection, they are "modified through variation, and the [existing] modifications are accumulated by natural selection for the good of the being" (ibid., pp. 85-6). Origin of change is beyond the domain of Darwin's theory. The theory could distance itself from the question of the origin -- origin of change and hence origin of slight adaptation -- because, one, it explains the evolution of *existing* individual changes; and two, it explains the evolution by *selection*. Darwin could naturalize organic evolutionary change because the explanatory structure of his theory is such that, one, the origin of change -- its cause -- is irrelevant for his theory, and two, the selector is not necessary for the selection. Recall that it's natural selection, not nature's selection. The evolutionary-change by natural preservation and consequent accumulation/augmentation of slight but adaptive hereditary individual-change is the distinctive mark of Darwin's theory, as it would be of any theory that would attempt to explain change by selection and accumulation in contrast to change by transformative action.

1.8 Concluding Remark

Understanding theories in science, like Darwin's theory of natural selection, is constrained by what the learner brings to the classroom. For example, a learner's cognitive assets, like her naïve theory of biology, do constrain understanding in a biology classroom. Hence, empirical investigations to study students' conceptions are indispensable to the discipline of science education, and we take up these in the following chapters. This chapter, however, explicates the equally essential part of the work – the causal-explanatory structure of the Darwin's theory of natural selection, with the view to understand the cognitive difficulties of the student in understanding the theory. For learning and teaching of a theory are also constrained by the causal structure of the theory being understood. If this is so, understanding how students cognize and theorize different aspects of the organic evolutionary phenomena, is not sufficient. Science educators and teachers are also expected to have the understanding of what the theory being taught aims to explain and how the theory achieves the causal-explanation.

Moreover, the explication and representation of the causal structure of the theory that this chapter lays out could of potential use in challenging the students' naïve, causally erroneous explanations and helping them learn the theory. For example, the distinction between *transformative action* and *accumulative selection*, and the distinction between *man's selection* and *natural selection*, developed here have an immense pedagogical significance: the former distinction would help students develop a clear understanding of change by selection and the latter one would help them in comprehending *natural* selection.

Finally, of course, the work in this chapter provides the underlying framework that will fruitfully constrain the efforts in the following chapters to arrive at the problematics of understanding natural selection.

2 Darwin's theorising: Insights from some historical and philosophical studies

2.1 Causal structure of natural selection

We discussed the causal-explanatory structure of Darwin's theory of natural selection in the preceding chapter. That discussion primarily draws from the *Origin* (Darwin, 1859). We continue the same thread in this chapter by focusing on some historical and philosophical analysis of the theory. In doing this, I do not aim for an exhaustive and complete picture. Rather, I discuss a few studies keeping in mind their relevance to the general thought of this thesis[26].

The concept of evolution is historical in character and presupposes a commitment to continuous change (Lewontin, 1968). Lewontin (ibid.) notes that the commitment to continuous change is central to the idea of evolution. Theories postulating sudden large-scale changes, say by floods or volcanoes, are entirely different from the uniformitarian account of continuous change by similar kind of forces operating in past and present. Former kind of theories that propose sudden changes are a version of creationistic theories, because both of them, (unlike the uniformitarian theories) postulate "special intervention of unique forces in an otherwise normally static system" (ibid., p. 203).

"Geology, cosmology, and organic evolution are historical sciences in that they are descriptions of, and attempts to explain, past events in the light of present occurrences" (ibid., p. 206). It is not typical of them to have universal laws. Rather these historical sciences make existential or historical claims, like the life history of past species that are now extinct is represented in the fossil record. But the claims like the fossil record represents *all* of the past life

[26] The number of potentially relevant historical and philosophical studies could, of course, be more than what I discuss here.

history, are never a part of historical sciences and hence they are, Lewontin explains, not amenable to Popper's falsification criteria. Further, even the mechanism of evolutionary change postulated by the Darwin's theory is not falsifiable. This is, Lewontin says, due to the immense explanatory power of natural selection. "To say that the dinosaurs became extinct because *some* change in environment caused their rate of reproduction to be lowered below the replacement point… is, by Popper's criteria, to say nothing" (ibid., p. 207). Hence Lewontin concludes that both "historical explanation and evolutionary sciences can be concerned only with offering *sufficient* explanations for past events and with prescribing *possible* future events on the basis of observation of present processes" (ibid., p. 207).

But, all evolutionary theories do not offer the same *kind* of explanation. Brandon (1996, pp. 30-45) offers a useful way of classifying theories. Theories could be fruitfully classified, he argues, based on the questions they answer, and all evolutionary theories are not answers to the same kind of question. All theories do not answer teleological questions, for example. The theory of evolution by natural selection is teleological because the theory answers teleological *what-for*-questions: e.g., in dinosaur *Stegosaurus*, "what was that line of bony plates for?" (ibid., p. 33) In contrast to the theory of natural selection, theories of physical evolution do not answer *what-for*-questions: they do not answer, for example, "what is the spherical shape of stars for?" (ibid., p. 34). Thus, we have evolutionary theories that answer teleological questions and those that do not. The objects of the teleological *what-for*-questions are adaptations[27]. Adaptation is a complex concept. According to Brandon: "to assert that something is an adaptation is to make a causal-historical statement". That is, "we know why one's better adapted than another when we understand the causal-ecological relationship relevant to differential reproduction" (ibid., 39-40). I will paraphrase Brandon's example

[27] For a discussion of the concept of adaptation see the Section 1.5.1.1

that explains this: An organism has a gene coding for the enzyme that detoxify a poisonous substance common in its environment. The product of this detoxification is a pigments that colours the detoxified individual. If the colour has no advantage, or in the Brandon's term – no 'adaptive significance', in the (poisonous) environment, it is causally irrelevant in the natural selection of the coloured individual. It is not an adaptation in the current circumstances. It is not the object of the teleological evolutionary explanation.

In what sense is the evolutionary explanation of adaptation teleological? It is teleological because the existing adaptive trait is explained by the usefulness of the past instances of that trait (or its precursors) for their possessors. The survival of the adaptive trait to the present generation is causally explained by the beneficial effect of past instances of that trait, they "increased the adaptedness" of the individuals who happened to possess them. In the just cited example, the dark colour cannot be explained by citing its effect on the dark coloured individuals, but the detoxification-trait can be (ibid., p. 40-41).

We discussed how, in Brandon's analysis, the theory of natural selection *is* teleological. The science teacher/educator interested in teaching natural selection has to live with this teleology. And hence the preceding discussion is necessary in the present context. The science educator/teacher has to have some idea of how teleology operates in natural selection. I must note that I have not undertaken a full discussion of this issue here. I have briefly discussed Brandon's (1996) analysis of teleology in natural selection. For a full picture of the issue the reader is referred to Part One of Allen, Bekoff and Lauder (1998)[28]. I must however emphasise that ends that a variation serves are important – to be specific, causally important – in evolution by natural selection. But at the same time it is to be noted that evolution has no

[28] Also see the Section 1.5.2

particular, preconceived, perfect end or goal. There is nothing like absolute adaptation (Lewontin 1968, p. 206).

Before we continue the discussion of the nature of causality in natural selection, I will make a brief attempt to recapitulate the concept of adaptation (recall that the concept is also discussed in the first chapter). Adaptation is generally understood as a trait, which is a causal consequence of the process of natural selection. That is, a trait T is an adaptation for X[29], if the selection *of* T is caused *for* it performs X. For example, the giraffe's long neck is an adaptation for obtaining food, if historically the longer necks have been contributing in the giraffe's survival by enabling the giraffe to obtain the food: in other words, long necked giraffes were naturally selected for they had the advantage in securing food; or we could say that the long neck is an adaptation because there was a selection *of* a long neck *for* it helped in fulfilling the giraffe's food necessities. Now, note that there could be the selection *of* a trait but *not for* it performs some function contributing to the survival/reproduction of the individuals (possessing it), but just because it is (genetically) linked with another trait that is being selected (for something else). Or, a trait could *presently* be performing a function that helps the individual (thus contributing in the individual's overall adaptedness), but it could just be a fortuitous event; historically the trait was not selected for the function it now happens to be involved in; that is, the present day function is not a cause of the trait's prevalence in the population. In the first case, a (linked) trait could be said to be "selected" and hence could by definition be labelled as an "adaptation" without being an adaptation for anything. Unlike the situation in the first case, in the second case a trait is presently (but not historically) useful for a particular thing, yet does not qualify to be an adaptation because it was not naturally selected for that thing (that is the trait did not serve the function it is presently serving in the individual's phylogenetic history).

[29] Where 'X' is a (physical or behavioural) function useful to the variant.

A trait could be thought to have a number of functions and each of them may not always be necessary for the organism's survival. For example, Lewontin (1978) says, having a fur in the arctic is an adaptation of polar bears and its absence may mean death. But having a *white* fur, though again an adaptation may not mean that not having a white (but say brown) fur means death: "Adaptations are not necessary conditions for the existence of the species" (p. 164). Moreover, just establishing a function of a structure in a set of circumstances is not sufficient to claim that the structure is an adaptation for the function it serves. For attributing a function to a structure is different from attributing the status of an adaptation to that structure. "[T]he assertion of adaptation implies a historical argument about natural selection as the cause of its establishment" (p. 164). For examples, if giraffes with slightly longer necks have had advantage of obtaining food more easily and thus have evolved into long neck animals, then long necks are adaptations for obtaining food. If the longer necks now are incidentally (or fortuitously) useful in attracting mates, we do *not* say that it is an adaptation for reproduction (it may be a "preadaptation"), for this particular adaptive advantage did not cause the trait's natural selection and establishment. Lewontin's example is of a large herbivorous dinosaur *Stegosaurus*. If having a slightly larger dorsal bone plates was an advantage for these animals, for they effectively disseminate heat while gathering food on hot days; and if this has caused the evolution of the plates into a full blown adaptive structure; then these plates are adaptations only for effective heat regulation, even if they now frighten off predators.

Now let us continue our discussion of the nature of causality in natural selection. Natural selection is *not* merely differential reproduction, because the latter misses out the central causal component in the natural selection. Natural selection is necessarily non-random, but differential reproduction need not be. In Brandon's (1996) words: "Natural selection should be defined as differential reproduction which is due to the adaptive superiority of those organisms leaving more offspring" (p. 37). In natural selection, survival of

chance variations in a population does not depend on their frequency alone. Except in the case of neutral variations, chance variations will always carry a casual bias depending upon their advantageousness or disadvantageousness to the variants. It is a "matter of chance as to what variations are arising in the conditions the species is now living in, but it is not a matter of chance as to which are most successful in surviving to reproduce" (Hodge 1987, p. 244). Indeed, Lewontin (1968) dubs Dobzhansky's definition of organic evolution – "a change in the genetic composition of population"– as "completely positivistic evolutionism" (p. 204; cf. Kitcher 2003). I comply with this characterisation not because I am committed in any way to the "creative evolutionism of Bergson and Teilhard", but because such positivistic descriptions fail to communicate the causal core of the process.

Hodge (1987) clearly points out that when it comes to the definition of natural selection there is a diversity of views among biologists and philosophers. For example: "Biologists call natural selection various things: an agency, a process, a factor, a cause, a force and so on" (ibid., 250). While defining natural selection, everyone agrees about the necessity of hereditary variation and differential reproduction. And as Hodge puts it: "we quickly reach differential reproduction of hereditary variants as indispensable to the definition" (ibid., 250). But an acknowledged problem with this definition is that it fails to distinguish between selection and genetic drift. Differential reproduction is possible even without selection as in "the accumulation of any successive indiscriminate or random sampling errors in the same direction. And such drift must not be allowed to count as natural selection" (ibid., p. 250). Now, Hodge notes that there are two broad ways to distinguish selection from drift. One is to say, define differential reproduction in selection to be "consistent" or "systematic" or "normal", this is more or less a statistical definition with little "peculiarly biological content" (250). In contrast, the other way is characteristically biological; it claims that differential reproduction in selection "must be due to differences in 'fitness' or

‘adaptation’” (ibid., p. 251). In defining natural selection Hodge wants us to be careful to neither be “formalistically mathematical” nor be “fatalistically biological” (cf. Kitcher, 2003): “we may be tempted to have a purely formal or mathematical restriction on differential reproduction in selection as distinct from drift: choosing a term such as “nonrandom” and then seeking for that term a purely formal or mathematical explication”. Or else, we may define natural selection as differential reproduction to be due to differences in fitness or adaptation, “with these terms explicated by reference to standards of design” (Hodge 1987, p. 251). Hodge writes, and I agree with this, that the physical causation (causal relevance of differences in physical hereditary properties to the differences in reproduction), not the finalistic or formalistic explications, distinguish selection from drift. When differences in the hereditary properties are causally relevant to the differences in reproduction, Hodge proposes to call such differential reproduction as “nonfortuitous” to distinguish it from the fortuitous differential reproduction of drift. So he defines intra-populational selection as “what is occurring when and only when there is the nonfortuitous differential reproduction of hereditary variants” (ibid., 251). Thus, to take an imaginary example given by Hodge, let us suppose that there are two identical, small, populations of butterflies, living in identical green environments. Individuals of both the populations vary in only one characteristic, colour – in both, half of them are red and half green, and these colour differences are hereditary. One population is preyed on by colour-blind birds while the other one is by colour-sighted birds. Thus, the heritable colour differences among the individuals are causally relevant only for the survival (and hence reproductive success) of individuals in the population preyed on by the colour-sighted birds. It is only in this case we should say that the differential reproduction is effected through natural selection. If the number of red-coloured butterflies dips due to other physical but fortuitous causes, like accidental landings of birds near a bulk of red butterflies, it would be “indiscriminate predatory sampling”, as opposed to the “causally discriminate sampling” in natural selection (ibid., pp. 252-3).

Thus “selection is a consequence of physical property differences among the individual”. But it should be remembered that: “An explanation that invokes drift invokes causation no less than a selection explanation does, but it invokes indiscriminate causation and so no causes of discrimination” (ibid., p. 253). The drift involves indiscriminate physical causation while selection consists in discriminate physical causation. Thus to take our butterflies example, if size is correlated with colour, then selection *for* colour will result into selection *of* size differences, even if the size difference is not causally relevant in the selection, but is only statistically relevant because of its correlation with colour. It is quite interesting to note that “the instantiation of fortuitousness is description relative, so that in our drift scenario, the deaths of red butterflies were not fortuitous events qua deaths of butterflies, but were qua deaths of butterflies in a population also including green ones preyed on by colour-blind predators in green surroundings” (ibid., p. 253).

Apart from the distinction between fortuitous and non-fortuitous differential reproduction, in the context of clarifying the concept of cause in Darwin’s theorizing, Hodge (1987) makes a distinction between a cause and a consequence of an adaptation. In (what he names as) “necessary adaptation”, conditions causing an adaptive change are same as those in which the change will be an adaptation. While in accidental adaptation, conditions causing an adaptive change and conditions to which the change is adapted are different from each other. Hodge puts this too beautifully to resist quoting him in full: “[I]n an accidental adaptation, its productive causes are independent of its adaptive consequences, in that the conditions producing it are not those causing it to have consequences such as to make it count as adaptive. The fetal conditions producing extra length in some puppy’s legs may be arising independently of the presence of the hares that make such legs post-natally advantageous. By contrast, a variant is a necessary adaptation if it is produced by the very conditions that make it advantageous, as in the thicker fur grown by puppies moved to a cold climate” (ibid., p. 244).

As it will be evident at several places when we discuss various students' causal-explanations in the following chapters, the distinction between the cause and the consequence of adaptive variation is central to the problematic of understanding natural selection. While reflecting on man's selection, Darwin recognized that the superiority of adaptations found in wild species is not "due to variation arising there differently from the case of domestication; rather, this superiority was due to the greater persistence and precision of the selection that would arise in [for example] a species making its living in the wild by hunting" (ibid., p. 245). Thus it is only in November 1838, when Darwin apparently had developed further the analogy between man's and artificial selection, that the *selection* of variation assumed the central significance in his theory. Before that the *cause* of variation, not its selection, was of central significance in his theorization – indeed, there was no difference between the cause of variation and the cause of evolutionary change. In the theory of evolution with which Darwin had begun, conditions of life directly cause adaptive evolutionary change. But now, he "was content to drop the thesis that conditions always [or necessarily] had the power to determine adaptive change directly by working heritable effects upon growth and maturation, because the analogy with the breeder's art convinced him that adequate determination would come from the way different conditions determined chances of survival and reproduction among chance variants" (ibid., p. 245). Hodge continues, "Darwin gave up having variation arise as "necessary" adaptations, as necessary effects of conditions, in favour of having it arise "accidentally" or "by chance," when and only when he came to see that its fate was under the quasi-designing control of a natural selection analogous to the skilled practice of the breeder's quasi-designing art" (ibid., p. 246). But, as science educators we have to take Hodge's analysis with a pinch of salt – we should not overstretch it to see a selector in nature playing an *identical* role played by "man" in man's selection. We have to carefully consider and communicate where the selection analogy breaks and where it continues seamlessly. But one has to remember that "Darwin's insistence on

the analogy… was no accident of expository tactics, but an essential component in the original construction of the theory" (ibid., p. 246).

Hodge (1987) also explains why the theory of natural selection does not have a law, like Newton's inverse square law of gravitation. First, one has to appreciate that Darwin's theory was not the theory of particular groups of organisms evolving into the others (fishes to mammals, for example). "The ramifying, diversifying, complexifying tendencies for which Darwin sought adequate causation were general and so could be introduced with referential anonymity" (ibid., pp. 248-9). In this generality, the theory is in conformity with Newton's, Hodge says, but it differs too, because it has no laws equivalent to the law of gravitation. This is because, in Hodge's analysis, the very existence of natural selection "requires, causally processes of reproduction, heredity, and variation; and while these processes may be and were presumed to be conforming to laws of their own, they cannot exist and conform to those laws in an empty universe void of complex interactions between what is changed and the conditions determining how it is changed" (ibid., 249). Darwin's theory should have no problem in predicting the same outcome, Hodge argues, if the same hereditary variation finds itself in the same conditions again and again, but alas, this is simply impossible. "What Darwin needs, for his explanatory purposes, is the presumption that the departures from the impossible sequence specified by that assumption are not capricious, but are occurring because of causation similar in kind, although different in degree, from those producing the controllable, approximately predictable results of the animal and plant breeders" (ibid., 249).

Darwin named natural selection because of its analogy with the process of artificial selection. But this analogy is not the only thing that makes the naming of natural selection appropriate, Hodge says. Both artificial and natural selection shares the same "character of the process – arising from heredity, variation, and the struggle for existence" (ibid.). Indeed, we could

say that Darwin's theorising is structured by the idea of artificial selection[30]. Sober (1984/1993) thinks that Darwin had to work on the idea of artificial selection before assimilating it into his developing theoretical framework, and before the idea could scaffold Darwin's theory building. A major (and perhaps undisputed) contribution of the idea of artificial selection, Sober thinks (like most others), was in drawing Darwin's attention to individual variation. But, there were three conceptual impediments, Sober thinks, that Darwin had to clear to extend the idea of selection in domestic breeding, to natural populations. First one was the then common belief that, at the most, breeders can only fine-tune the existing species into various varieties, and could never be successful in transforming a species into a new one. Darwin, according to Sober, cleared this doubt by appealing to the long (geological) time available for the natural selection to produce new species. The second block that Darwin had to overcome in extrapolating the artificial to the natural was of the *conscious* selector in artificial selection. In Darwin's era, Sober argues, the need of intelligent selector in producing domestic varieties could easily be taken to support the existence of divine designer, because if making a domestic variety needs an intelligent selector then how could we explain the existence of numerous natural varieties and species without invoking the wisdom of the divine designer – an obvious evidence of design in nature necessitates the existence of a designer. Sober points out that one of the ways in which a Darwinian could respond to such an argument is to deny any significant relationship between artificial and natural selection, to say that the relationship is merely metaphorical. But, Sober does not agree with this response. Rather, he says, for Darwin artificial selection was an *experiment*,

[30] In addition to the idea of artificial selection, Sober (1984/1993) think that two more ideas structured Darwin's theorising of evolution: Malthus' idea of *intra*specific struggle (as opposed to Lyellian *inter*specific struggle); and ideas of Scottish economists like Adam Smith. Specifically their idea of free market in which unconstrained competition between self-centred businesses eventually leads to the growing wealth, as if some "invisible hand" is guiding this change towards the betterment. But, unlike in Darwin's theory, the change here is always postulated to be progressive.

and just as conscious manipulation is a necessary and acceptable part of any experiment in physical sciences, so is it of an experiment of artificial selection. Moreover, Sober continues, "[a]rtificial selection is not selection that takes place *outside* of nature, but selection that occurs within a particular niche found *in* nature" (ibid., 19). The third difference that Darwin had to take care of was that breeders usually have a set of predetermined goal; they pre-decide the kind of variety they have to produce – cows with a very high milk yield, for example. So, for breeders, Sober says, population gets divided on the basis of broad and distinct differences – cows producing a very high milk quantities and cows that do not yield such high quantities. The selector will select only the former. But, in natural selection, what matters is *slight* variation. "Nature is subtle where the plant or animal breeder might prefer to be more heavy handed" (ibid., 20).

In Section 1.4, I have already discussed my position on the development of Darwin's theorising from the artificial to the natural selection. I have some difficulties in accepting Sober's arguments in the preceding paragraphs, except for his assertion that the domestic breeding practices drew Darwin's attention to the individual variation. First Darwin had to interpret the artificial breeding practices as the practices that use "selection". In all probability, the idea of artificial *selection* as a cause of *evolutionary* change was not in the air, ready for Darwinian naturalisation. Second, Darwin overcame the belief that what breeders end up producing are mere varieties of the existing species, by destroying the essential ontological boundaries between varieties and species. Darwin did appeal to the overarching time available for natural selection as compared to short time periods in which artificial selection results into novel domestic varieties, but it is his assumption that species are nothing but distinct and stable varieties, that nullifies objection against the efficacy of artificial selection and hence by extension of natural selection. Sober's second worry, concerning the *conscious* causal agency in artificial selection, is immensely significant. This was the central block that Darwin had to deal with. Indeed, in

my view of Darwinian theorising, this is the crux of the matter – it would be obvious to anyone that unless Darwin *naturalises the conscious causal agency*, he would not have arrived at the concept of natural selection. How did Darwin do this? Sober's endeavour here is not to engage in the details of this question and what he says here cannot be labelled as an out of way argument but his answer seems unsatisfactory to me. Darwin might indeed have boasted about the efficacy of artificial selection in producing distinct varieties as an evidence of efficacy of natural selection (as Hodge argues), and he might also have thought this evidence as akin to experimental evidence. Nevertheless, if our concerns are not with the evidence of the idea of natural selection but with its development, then the argument that focuses on the evidential role of artificial selection is of little use. Moreover, we seem to implicitly assume that to arrive at the idea of natural selection, Darwin transformed the *conscious* causal agency into a *natural* causal agency. But, does Darwin's theory really transform the conscious into the natural? No doubt, natural selection will not be natural if it is caused by a conscious causal agent like human being. But, my study of the causal-explanatory structure of Darwin's theory, indicates that Darwin achieved the great feat *not* by naturalising the conscious causal agency (that is not by replacing a conscious causal agent with a unconscious non-human agency) but by discovering how selection is possible without any selective agency.

Sober (ibid.) divides Darwin's reasoning about selection into two components, first one defines "general conditions" necessary for natural selection: individual differences in a population, some of the individuals vary in a way that is beneficial to the variant individual and this beneficial variation is hereditary. The second component is Darwin's "historical hypothesis" stating that the life on earth has in fact evolved by natural selection. Sober argues that Darwin's hypothesis is empirical because all the conditions conjectured by his are "highly non-trivial". Sober calls Darwin's central idea of evolution as "Darwinian conditional": *If* a variant trait is of benefit to its possessor survival

and reproduction and *if* it is hereditary, *then* (if *ceteris paribus*) the number of these variants will increase over generations, thus changing the composition of the population. Darwinian conditional is contrasted with his "historical hypothesis". The former is independent of the latter[31]; the conditional is one of the *empirical* possibilities that do not make any concrete statement on the actual evolutionary history of life on earth.

Recall the earlier discussion of Brandon's (1996) and Hodge's (1987) arguments of how natural selection is not merely a differential survival. Sober (1984) too argues in the same vein. He thinks that Darwinian conditional is only one of the ways in which the historical hypothesis could be *causally* explained. For, for example, evolutionary history could also be claimed to be just a "random walk" of selectively neutral chance mutations or by proposing that latter evolutionary history is constrained by the earlier historical differences[32]. We must remember that "Natural selection is not just any sort of "biasing effect" in the composition of a population, and evolution is not any sort of change in composition" (ibid., 29). Hence, the stories that dub Darwinian evolution as merely a change in the composition of a population, without illuminating causes of this change, are not necessarily Darwinian stories[33].

The treatment of whether or to what extent if at all, the idea has indeed been actualised on our earth – that is the historical hypothesis – is beyond the scope of my work here. My aim is to clarify the causal explanatory structure of the

[31] Darwin's conditional differs from his historical hypothesis in a fundamental way. Although the latter implies the existence of particular populations undergoing a distinctive causal process, the former statement is entirely silent on this" (Sober 1984, p. 28)

[32] Here he quotes Lewontin's famous example of the one-horned and two-horned rhinoceros; both the traits are assumed to be equally beneficial, the difference is explained by referring to the difference in the composition of each one's ancestral population.

[33] See my comments on Geraedts and Boersma (2006) in the Section 7.1.

concept of natural selection and to understand the difficulties we face in learning the concept. To serve this goal better, I have to keep aside the evidential support that the idea receives from the history of life on earth. The evidential discussion is equally significant. In fact considering the current trend in the west (especially in some of the states of USA) that questions the scientific credibility of Darwin's theory on various grounds, the talk of how Darwinian hypothesis is empirically valid and valuable has become almost essential. But, if the discussions about the scientificity of Darwinism get clouded by inappropriate, insufficient, misconstrued understanding of the Darwin's idea, then such evidential discussions would of little help. The evidential discussions could be of benefit, if the discussants have a solid and deep understanding of exactly how natural selection causes evolutionary change. The evidence could be easily appreciated, in my view, ones one has understood causal explanatory structure of the idea.

We very often see the idea of natural selection being cast in terms of "survival of the fit". Fitness is a technical concept and its direct discussion is not necessary in this work. But, it would perhaps be useful to understand that overall fitness is causally inert (Sober, 1984). Two organisms may have the same overall fitness – but one may be more susceptible to a disease while being much more stronger in avoiding predators, whereas the other being resistant to the disease but vulnerable to the predator attack. Here there will be selection *for* disease resistance and *for* the predator avoidance – that is these properties would *actually* contribute in *causing* the survival and reproduction of the disease resistant and predator avoiding organisms by conferring an advantage on them. Overall fitness does not have any causal contribution in the selection. In fact, it will be senseless to say so. Overall fitness tells us about all the *possible* causes that *might* affect organisms' viability and reproductive success. Even if we come across a situation where differences in overall fitness have in fact resulted into differential survival and reproduction, in knowing this, we do not have knowledge of the causal story of these

selection events – we know the consequences in terms of changing population profile but not its causes.

Sober (ibid.) draws a (now well known) distinction between *selection for* and *selection of* – between "selection of objects" and "selection for properties". If two traits are (genetically) linked to each other (*pleiotropy*, same gene or gene complex governs the expression of two distinct traits; or *gene-linkage*, the genes of two traits are closely linked that is they are located near each other on the same chromosome), and if one of the traits is advantageous but not the other (the other one is neither advantageous nor disadvantageous), then the selection *for* the advantageous trait will result into the selection *of* the linked trait. There is no selection *for* the non-advantageous trait, but its representation in the population will increase because it is linked with the advantageous trait. For example if the human chin is lined with the jaw structure, selection *for* particular structural properties of jaw structure will also result into the stabilisation of the related chin structure in the population. Because of the particular jaw and the chin structure's increasing representation in the population, we get the impression of selection *for* the jaw and the chin. But in fact the selection is caused by advantage conferred only by the jaw structure; the chin has no advantage for the individual and hence it cannot cause its selection. There is selection *of* the jaw-chin structure, but the selection is only *for* the advantageous jaw structures.

Increasing frequency of a trait in a population is no guarantee of its being naturally selected; it's no guarantee that there is selection *for* the trait in question, that the increase in the frequency is caused by the trait's conferring an advantage on its possessors. The increase may well be a result of selection, but selection for some other advantageous trait that happens to be liked with the trait in question – selection *of* a trait does not necessarily mean selection *for* that trait. Thus, the value of Sober's distinction is: "selection for" flesh

outs the cause of natural selection where as “selection of” talks of the consequence of the selection process (ibid., pp. 97-102).

Sober (ibid.) makes a distinction between *developmental theories* and *selectional theories* of evolution. Lewontin has a similar distinction between *transformational* and *variational* evolution that we will discuss below. Developmental theories explain the evolution of a population by explaining the development through time of each of the individuals in the population. Lamarck’s theory, for example, is a developmental theory of evolution. Spontaneously generated simple living forms have inherent tendency to develop into more and more complex forms. Each species’ lineage thus passes through a series of developmental stages of various complexities and at any given time we find different species’ lineages at different stages of development, accounting for the diversity of living forms we observe. Developmental theories of evolution thus ‘temporalize’ the Great Chain of Beings. Lamarck also postulated “forces of circumstance” that further diversifies and adapts the individuals to the local conditions.

Selectional or variational explanatory accounts of evolution, in contrast to developmental explanations, do not explain by referring to the individual developmental histories, by referring to how *all* the *individuals* of a kind are transformed through time. Rather, they rely on *stable and heritable* individual differences, or in other words, on individual *variations*, and explain how a composition of a *population* changes through selection of a particular variation. The explanation in Darwin’s theory is fundamentally different from the “Lamarckian” theories of evolution because it is *the* typical example of variational and selectional explanation. In Darwin’s theory, transformations of the individuals in a population do not explain its evolution. “The change in the population is not due to the fact that the individuals in it *develop*; rather, what is crucial is that they *vary*. This is the essence of variational explanation” (ibid., p. 149).

Apart from offering a different kind of explanation – a variational explanation, Darwin's explanation differs from others in what it explains, in the object of explanation. My drinking of banana milk shake can either be explained either by my being thirsty and hungry when I had it or by my being allergic to lime juice. It depends on the contrastive alternative with which I place "my drinking of the banana milk shake". Why I had the milk shake at that hour rather then not having anything at all is explained by my thirst and hunger of the hour, but why I drank the milk shake instead of lime juice is explained by my being allergic to lime. Thus an explanation explains the event in only a particular contrastive context. Darwin's selectional explanation does not explain why a population has individuals with a particular trait by explaining why the ancestors of each of the individuals in that population were transformed to have that trait, but by explaining why the individuals in that population have *that* particular trait rather than having something else. Thus natural selection does not explain why today's giraffes have a long neck by explaining the transformation of each individual's short neck into a longer one, but by explaining why today's giraffe populations have only long necked giraffes and not other ones who did not have long necks. In other words Darwin's theory explains the change at the level of population by explaining why only the individuals with a particular character are selected, *not* by explaining why each and every individual in a particular population is transformed. The object of Darwin's theory is thus very different from the transformational theories of evolution: "The theory of natural selection created a new object of explanation by placing the population fact in a new contrastive context" (ibid., 150).

Lewontin (1978) succinctly captures the central role of slight individual variation in Darwin's solution to the problem of adaptation and diversity: "Darwin's solution to the problem was that small heritable variations among individuals within a species become the basis of large differences between species…" (p. 157).

Lewontin's (2000) most significant contribution in clarifying the evolutionary thought, in my view, is his distinction between *transformational* and *variational* evolution. Evolutionary dynamic, according to Lewontin, comes in two fundamentally distinct forms: *transformational* and *variational*. In the former case, a population of entities changes because each individual member of that population undergoes a similar set of developmental transformations. In stellar evolution, for example, "every star undergoes the same general set of transformations of mass and temperature during its life cycle" (p. 54). In contrast, in *variational* evolution, entities in a population have variation in their characteristics, and most importantly, the cause of this individual variation works independently of the effect it has on the individual that possesses it[34]. In variational evolution the population of entities evolves "by a sorting process in which some variant types persist and reproduce, while others die out. Variational evolution occurs by the change of frequency of different variants" (p. 50). Lewontin's distinction is focused on the evolving system, on the evolving ensemble of entities. You may recall that, in the Chapter one, I recast this Lewontinian distinction into the one with the focus on the *causes* that cause the evolution. Lewontin's distinction rightly captures the individual variation, but not so much the *cause* that changes the frequency of various variants in a population – namely selection. Hence, for my purpose, I have distinguished between evolution by *transformative action* and evolution by *accumulative selection*. This way the causality in evolutionary change gets better focused: *transformative action* points to the cause that transforms the individual while *accumulative selection* points to the cause that effects into accumulation of (only) the self-advantageous variation (See chapter one).

The differential survival and reproduction of different individual variants causes the evolution. Lewontin (ibid.) reminds us that this differential survival and reproduction could also be caused by factors other than the natural

[34] In other words, the cause is *not* working *for* the effect it would have for the variant individual. That is the cause is not teleological.

selection of adaptive variants. Of course, the differential survival of non-adaptive variants would result in a non-adaptive evolution, but it still *is* evolution. Lewontin wants us not to confuse the claim "that all adaptation is a consequence of variational evolution with the claim that all variation evolution leads to adaptation" (p. 56). For example, a non-adaptive character in a population that has recently migrated to a new locality may go to the fixation by mere chance.

Lewontin's (ibid.) another example is of evolution of non-adaptive characters that are (genetically) linked with the adaptive characters: non-adaptive characters (redness of our blood) could just be an epiphenomenon of an adaptive structure (molecular structure of haemoglobin). The former may go to the fixation in a population, but it is not a consequence of natural selection *for* it. Agreed, but it should be remembered that the fixation of the former is a causal consequence of the natural selection of the latter. Hence, the fixation of non-adaptive character linked to adaptive characters is in fact could well be a consequence of natural selection, though the selection is *for* the adaptive trait alone.

Lewontin (ibid.) argues that though variational evolution via natural selection was indeed a "real epistemological break" that Darwin's theory achieved, for "it changed the locus of historical action from the individual to the ensemble", the Darwinian revolution is *not* located in this change of locus (p. 66). Darwinian revolution, Lewontin thinks, was that his theorising was focused on the intra-populational individual variation. Darwin's focus on *variation* demanded "epistemological reorientation". For, in Darwin's time, the focus was on abstracting the specific similarities, by ignoring (what was then thought to be) the noise of actual individual variation. "Variation among organisms was thought to be ontologically distinct from the causes of their similarity" (ibid., p. 67). The Darwinian revolution put the actual individual variation back at the centre of evolutionary theorising. For Darwin, as for

Mendel, “similarity and variation are inextricably intertwined aspects of the same reality” (ibid., p. 68).

Lewontin takes his analysis of Darwinian revolution further by proposing what is, in my view, a contribution fundamental not only to the general thought about Darwin’s theorising, but also to educationally central issues of understanding the Darwin’s theory. It is the rupture between the external and the internal – between the causes operative from within and from without the individual. With*out* this rupture, the external causes enmesh together with the internal causes, thus adaptively *transforming* the individuals in accordance with the external conditions, for example. If the evolutionary change is determined by the external causes, then it will *necessary* be a transformationist evolution – never a selectionist evolution. In Lewontin’s words: the “seamless connection between the inner and outer permeated views of nature”, in early nineteenth century. Lamarck’s theory, for example, “was a transformational one”. In Lamarck’s theory, “somehow the external forces molded the organism itself through its internal striving to adapt” (p. 73). In contrast, Darwin’s theory cleaves the external from the internal. In Lewontin’s words: in Darwin’s theory “variation among organisms arose from causes that were internal to the organisms and whose nature was independent of the demands of external world. That is what is meant when we say that the mutations are “random”. It is not that they are free from the ordinary processes of chemistry, but that their qualitative nature is at random with respect to how they will affect the organism in a particular environment… So the internal forces that give rise to variation are causally independent of the external force that selects (sic) them”.

I follow Lewontin and others in thinking that Darwin’s theory achieved an epistemological break from the earlier evolutionary thought by separating the cause of individual variation from the cause of evolutionary adaptation. Below, while explicating the development of Darwin’s theorizing, I discuss

this in more detail. I, however, do *not* agree with Lewontin in his claim that in Darwin's theory external forces *select* the individual variation. As I explain in the Chapter one, in addition to the separation of the cause of variation from the cause of evolution, Darwin's theory naturalised the selection, *not* by naturalising the cause that selects, but by demonstrating that when the individual variation is advantageous for the variant, it is *naturally* selected, that is *no* selector is necessary for the selection. Indeed, in my view, it is exactly such, apparently innocuous, characterisations of natural selection as selection by natural forces, that give rise to the confusions, that compelled Fodor to write "Against Darwinism" (In *Mind & Language*, Vol. 23, No. 1). Fodor's case demonstrates how confusing it could be to cast *natur*al as *natur*e's.

In the student's conception of evolution (see the following chapters), very often the cause internal to the individual operates in tandem with the external cause, effecting the transformation that fits the individual well into the external conditions. In explaining the adaptive evolutionary change, the student seldom distinguishes between the external and the internal cause – between the cause of variation and the cause of evolution. And hence, for the student too, the adaptive evolution is *necessarily* the adaptive individual *transformation*. In contrast, Darwin's theory achieves the separation of the cause of individual adaptive variation and the cause of evolutionary adaptation.

Representation of *selection*, and particularly how we represent the causality in the selection, is significant in the learning of natural selection. I distinguish between two types of representations – an agency-centred (agentive) and *non*-agency centred (*non*-agentive) representation. In the agency-centred representation the selection is effected by an agency, by the selector, that could either be human or non-human. In the non-agency centred selection, the

selection is effected naturally, that is without any agency, no selector is necessary here – neither artificial nor natural.

The idea of natural selection is best caste in non-agentive terms. If the idea is represented in agentive terms, it may fail to communicate the "causal-action" in *natural* selection to the students. If the agency – even if natural – causes selection, it can in principle cause the selection of *any* variant trait, not necessarily the advantageous one. Another potential non-Darwinian alternative that the agentive representation could nurture is that the agent that "selects" a trait could easily be the one that "transforms" it. That is, the agentive *selectionist* explanation can easily co-exist with the agentive *transformationist* explanation, conflating the crucial distinction between evolutionary change by *accumulative*-selection and evolutionary change by *transformative*-action.

We often come across the agentive representation where nature or environment is dubbed as a "selector", even in the books where we have little doubt that the author understands the causal-nature of natural selection. For example, while contrasting Darwin's theory with the Lamarck's and explaining how Darwin's theory predicts a tree (or a "bush") while Lamarck's (a gradually unfolding) ladder, Sober (1984) writes: "Darwin thought of organisms as being *modified* by their local environments" (p.172; change in emphasis is mine). This sentence – if seen or understood in isolation (which a very well informed reader may not do, but one cannot rule out the possibility in *all* the cases) – instantiates what I call as the agency-centred representation, where a natural agent (here the environment) seems to be at the helm, causing the modification (i.e. transformation), not even selection. Indeed, (from the sentence just quoted) if we go down a couple of sentences in Sober's narration (p. 172), we get a better representation of the contribution of changing environmental conditions in the process of natural selection, the one where environments fortuitously create newer possibilities on which evolutionary

change might proceed: “populations evolve in various directions that environments fortuitously make available”.

2.2 Development of Darwin’s theorising: From necessary individual transformation to natural accumulative selection

We discussed insights from some philosophical studies on the Darwin’s theory of organic evolution. Now I will turn to a couple of historical works on the development of Darwin’s theorising.

Darwin wrote *Notebooks* B, C, D and E from July 1837 to July 1839. A number of historians (and a psychologist Howard E. Gruber) have studied the development and structure of Darwin’s theorising during the years 1837-39. These studies are illuminating and insightful in inferring and looking into how Darwin’s idea of natural selection had developed and structured. Insights into the development and structuring of the idea of natural selection could be of considerable significance in learning and teaching the theory of natural selection. This is because, these historical studies tell us how Darwin’s ideas changed from one coherent explanatory idea to another and finally to what he called “natural selection”. They tell us how Darwin’s theory described and explained its phenomenal world, and what kind of causes did it postulate, at various points in its history documented in Darwin’s *Notebooks*.

Gruber (1981) analyzed Darwin’s notebooks of 1837-39 to study the “inner development of Darwin’s thinking about evolution during a two-year period, and the interplay between his evolutionary ideas and his ideas about man, mind and materialism”. Gruber’s “task is to see how the idea [of natural selection] changes its character as it appears and reappears at different moments in the growth of Darwin’s thought” (pp. xii, 7).

In an ornithological notebook kept on the beagle voyage, Darwin "suggests that the small variation in [the bird and tortoise] species from island to island in an archipelago [of the Galapagos] shake his belief in the immutability of species." (ibid., p.101) But, Gruber suggests that, a belief in *mutability* is quite short of a belief in *evolution*. (ibid., p. 101) Recognizing variability among the individuals of the same species and between the parents and their offspring is not enough, evolution is more than mere variability. Evolution presupposes continual change. Even the student easily recognises the variability in nature, what seems difficult for her is to consider the variability they see as a step in the long and continuous process of change called evolution.

On January 18, 1836, when in Australia during his beagle voyage Darwin noticed that the fauna of Australia is unusually different, but still strikingly similar to the one at other distant places, and beautifully adapted to its conditions. He took these observations to be an evidence for one creator but multiple and separate creations. Fossils speak of earlier creations of now extinct organisms which were presumably adapted to their physical world. Gruber thinks that this must be under the influence of Lyell's views who subscribed to the multiple creations hypothesis to avoid taking up evolutionary viewpoint. But, as Gruber (1982) points out frequently, Darwin "must have felt the tension between two contradictory ideas, a slowly evolving physical world and an unchanging, [yet] well adapted creation of species inhabiting it." (p.133), though Lyell's idea of multiple creations was meant to account for this tension. As Gruber (ibid.) points out, migration of species from a single point of origin better accounts for some of the similarities and limited mutability for some of the differences between species (p.104). But still such explanations didn't convince Lyell. Gruber (ibid.) argues that since Darwin was exposed to evolutionary views many times, even to Lamarck's theory in Lyell's book, he must have thought about evolution during the voyage.

At the beginning states of his transmutation theorising (July 1837, Notebook B), Darwin is thinking (ibid.): When a pair of organisms from a continent, get placed on an island where the physical conditions are different from the continent, this accidental encounter of the living entities with the changed physical conditions causes the adaptive change ultimately producing a new evolutionary line. This line of thought must have given Darwin the image of irregularly branching tree of life – organisms on an archipelago are similar to those on the continent, but still differ from them and from island to island. Darwin proposed such isolating mechanisms to counter the stabilizing mechanism of sexual reproduction. For Darwin the stability of species is explained by blending inheritance: "offspring derive their characters from both parents, and through widespread interbreeding, *variations are averaged and diffused, and species are preserved*" (ibid., p.137). It's interesting to compare this with Darwin's theory of natural selection in which *variations are selected and preserved, and species are changed*

Darwin's first transmutation notebook, *Notebook* B (July 1837 – February 1838) opens with a theory of evolution, a theory that differs significantly from his later views. In his first thoughts on evolution, species change to adapt to the changing world and the change in species is "the result of direct environmental influences" (ibid., p. 103). In this theory, he accounts for the *origin* of species by postulating the spontaneous generation of simple life forms, *monads*, from non-living matter. Monads, like individuals, would eventually "die" and so will all the species into which they had evolved. Thus Darwin's first theory is an account of both the origin and the evolution of species, where the spontaneously produced simple life forms change due to changing environmental conditions.

Gruber (ibid.) points out that Darwin's use of adaptive principle in his monad theory of evolution was not symmetric, "it gives the initiative entirely to the environment". In the monad theory adaptive change in the organism is a

passive response to the environmental change. “If adaptation to environmental change could just as easily erase a variant as it could produce one, there would be no cumulative change” (p.141). Note that, in the monad theory changes are not *conserved* but are made or *produced*.

At this juncture in Darwin’s thought, when he was writing his first transmutation notebook (Notebook B), we see Darwin’s first use of irregularly branched tree image, incorporating the monad theory of evolution. Generation of a monad represents the point of origin and adaptive change represents branching of a tree. Here it’s interesting to note what Darwin writes in *Notebook B*, page 23: “Would there not be a triple branching in the tree of life owing to three elements – air, land and water, and the endeavour of each typical class to extend his domain into the other domains”. But here the word “endeavour” might not be used to mean conscious effort as just a couple of pages earlier Darwin wrote, “Changes [are] not the result of will of animals, but [of] law of adaptation” (Quoted in Gruber 1981, p. 142).

In Darwin’s second theory of evolution the idea of change seems to dominate as he no longer attempts to account for the ultimate *origin* of species. Gruber writes, “Darwin soon gave up the monad theory and eventually gave up attempts to speculate about the origin of life” (ibid., p. 103). Now, unlike in his earlier theory, monads and associated species do not come into existence and “die”. Instead, Darwin’s second theory proposes that species survive by changing into another species; they die only if they do not change. From this time on, Darwin focused on causes of change or heritable variation. According to Gruber (ibid.), it is this search for the causes of change (causes of heritable variation) that led Darwin to an in-depth study of plant and animal breeding. Was this engagement with the literature of plant and animal breeding gave Darwin his understanding of “man’s selection” and then finally the big idea of natural selection?

Wherever may lie the origin of the idea of natural selection in Darwin's thought, the causal-explanatory structure of the theory represented and explained in the *Origin of Species* clearly tells us the extent to which Darwin moulds his idea of natural selection on his understating of what he calls as "man's selection".

In Darwin's early (*Notebook* B) theorising, changes in the "tree of life" – where species are equivalent to the propagating buds at the tip of various tree branches – take place by adaptive improvement and divergence, wherein animals adapt to various conditions of life. As Hodge and Kohn (1985) point out (p. 187), for Darwin, no developmental law necessitates progressive change in species (as what normally happens in an individual development). Moreover, for Darwin, similarities among the 'offspring' of ancestral species are not explained by referring to the same conditions of life to which they all are adapted but to the characters these sibling species have inherited from the 'parent' species. Thus, since the beginning of his theorising, Darwin explains the differences among the species by adaptive divergence and similarities by using the notion of inheritance (of course, over the development of his thought, his ideas of how the adaptive divergence happens, does change).

In *Notebook* B, for Darwin, evolutionary change is *necessarily* adaptive and almost always progressive. Here he is thinking about the *origin* of variation, which has to be necessarily adaptive to the external conditions because it is directly caused by those conditions. As Hodge and Kohn (1985) put it, Darwin had begun with the thought of "hereditary *adaptive* variation accompanying sexual generation in changing conditions, thanks to the impressionability of maturing organization" (ibid., p. 188). If such adaptive variation to local conditions gets reproductively isolated, preventing the blending with other variations, a new variety could be formed. Darwin argued that with adaptive divergence, a locally adapted variety might show increasing inability to breed with other varieties, thus strengthening the reproductive isolation leading to

more and more adaptive divergence. Thus in Darwin's earliest *Notebook* B views, reproductive isolation of local adaptive variations produce local varieties. Further, Darwin relied on what he calls Yarell's law, proposing that longer the character remains in the breed, deeper it embeds in the hereditary constitution, remaining opaque to crossing and changing external conditions (ibid., 189). In *Notebook* C (February – July 1838), Darwin thinks that, earlier (during its development) an individual adapts to the changing conditions of life, more are the chances of this adaptive character's transmission to the next generation. Thus if many jaguars in an area (when they are maturing) take up swimming to catch fish and this new habit of theirs adapts them to the condition (of abundance of fish in the lake) by developing webbed feet, it will be transmitted to the next generations (ibid., 190).

For a *Notebook* C Darwin, adaptive change is young individuals' maturational response necessitated by the external conditions. Puppies growing a long fur would be an example of a *necessary* adaptive response in a colder region but the same trait would be a chancy monstrosity in a warm region (ibid., 191). Long fur of a puppy in a colder region is an adaptation, according to Darwin, because it is caused by the conditions of life in maturing individuals and it is fully fitted to those cold climatic conditions. Interestingly, at this juncture, when Darwin is thinking about adaptive divergence and species production as necessitated by change in the conditions of life, he had asked himself a question which considers a possibility of 'making' a species by entirely different route: "Whether species may not be made by a little more vigour being given to the chance offspring who have any slight peculiarities of structure [?]" (ibid., 190). But, Hodge and Kohn mention that, in this context, at this point in time, Darwin considered only those traits that give an edge to males in competing for females. Thus until *Notebook* D (July 15th 1838—October 2nd 1838), for Darwin adaptive species formation is a consequence of "necessary adaptation".

In *Notebook* C, Darwin drew a contrast between "local" naturally produced varieties and "artificial varieties". Local varieties adapted to local conditions are produced when maturing organisms in that area are exposed to the same external conditions, whereas domestic varieties are produced by "picking" and mating desired variants (often monstrosities) for many generations. In the latter case, breeders begin with a monstrous variation – 'picking' and breeding it. In contrast, in 'natural' production of local varieties external conditions produce adaptive variations. In Hodge and Kohn's words: "'Local varieties' were "natural" in being produced without the arts of man" (ibid., 189). Thus Darwin talked about the artificial selection before he did about natural selection. Also, note the contrast between artificial and natural – the former is an *art of man* while the latter happen *without human agency*.

According to Gruber (1981), Darwin's theoretical construction and representation has two interdependent but distinct sides: "The branching model and the principle of divergence are mainly concerned with large-scale evolutionary dynamics. The "tree of nature" scheme is exploited to clarify the genealogical relations among many species, both extinct and extant. The principle of selection, on the other hand, is mainly concerned with local forces… Although the two ideas, divergence and selection, are closely linked, they involve two quite different styles of explanations" (p.117-118). The goal of my work is limited to explicate the difficulties students have in understanding the idea of selection.

Gruber (ibid.) talks about two groups of ideas that remain invariant in Darwin's thought throughout their development. He calls it "conservation schema" and "equilibration schema". Conservation scheme consists of the idea of irregularly branching tree with the "conservation principle". Branching model connotes an exponential increase, and since Darwin presumed that the approximate number of individuals of one species is always conserved, one must have some way of reducing the number. Equilibration schema, in my

view, is even more central to Darwin's thought. Probably under Lyell's influence, Darwin was committal to a conception of gradually and smoothly changing world. In this changing world, organisms undergo adaptive change to remain adapted to their changing environments. Since the forces responsible for the adaptive change "are thought of [by Darwin]", writes Gruber, "as changing smoothly rather than in sudden steps, the production of a continuous series of adaptive forms is implicit in this interplay [of mutually compensating forces]". Thus the equilibration schema is described as: "adaptation, adaptive change, and continuous series of forms" (ibid., p.124). Darwin knew the idea of adaptation from his Cambridge days (1827-30). The idea was popularly employed by Paley in his argument from design. Darwin's encounter with the idea of continuity in nature is both interesting and significant as it provides him with a very clear idea of distinguishing the natural from the supernatural. Sometime in his student days at Cambridge, Darwin read a book by John Bird Sumner (then the bishop of Salisbury). Sumner argues for the "divine origin of Christianity" (ibid., p.125). The argument follows from the conviction that "nature makes no jumps, but God does. Therefore, if we want to know whether something that interests us is of natural origin or supernatural, we must ask: did it arise gradually out of that which came before, or suddenly without any evident natural cause?" Sumner thought that the origin of Christianity is sudden and is sharply discontinuous with Jewish and all the preceding traditions. Darwin would use this "argument from discontinuity" to demonstrate that in living entities "adaptation could be demonstrated without discontinuity" (ibid., p.126).

According to Gruber (1981), the idea of natural selection, "as a conservative force in nature, working *against* change" (pp.104-105), was already known before Darwin. From July 1837, the idea begins entering into Darwin's writings.

According to Hodge and Kohn (1985), after reading Malthus, Darwin did not need his Spring 1837 senescence thesis to explain species extinction because, now he was convinced of Malthus' and Lyell's argument that *inter*specific competition, resulting from alien species invasion in an area or from slight changes in physical conditions, could easily explain species extinction. He had also learnt that, given tremendous interspecific competition for food and space in the economy of nature, even a slight structural difference in a species could result in great changes in its populational representation by making it either more successful or less successful in maintaining its position.

Now Darwin could draw an analogy between interspecific and intraspecific competition: just as a slight structural difference could have a great consequence for species, similarly a slight structural difference could make one individual more successful than other in its "struggle for existence". Here Hodge and Kohn (ibid.) make a very important point: in drawing an analogy between interspecific and intraspecific competition, Darwin is making "no analogy between the contribution of superfecundity to adaptation and 'picking', the practice of selective breeding" (196). Thus, here, Darwin is developing no connection between superfecundity and selection. Though the Malthusian idea of superfecundity and ensuing struggle for existence helped Darwin to redraw his views on species extinction, it had no immediate effect on his beginning (*Notebook* B, C and D and opening of E) ideas of how adaptation and evolutionary change are necessitated by the (external) conditions of life. Still, for Darwin, "the extensive changes in structure occurring, when one species is slowly formed from another require only a great extrapolation, to the eons of gradual physical change, of the transmission, sorting and embedding of the variation acquired in maturations from one generation to the next (*Notebook* E 4-9e)". Here Darwin is not talking about evolutionary change by *selection*, (again, as Hodge and Kohn write) his "talk of sorting is only to indicate the expansion and retention of the adapted and its corollary the contraction and elimination of the others. There is

implicit analogy with all sorting processes whatsoever… including mechanical siftings" (ibid., 196). As Hodge and Kohn write, there is a significant gap between Darwin's "first Malthusian reflections at the end of [*Notebook*] D and opening of [*Notebook*] E" and his talk about the "accumulation of many successive variations" (which occurs at *Notebook* E 50). It is only between November 27th and December 2nd 1838 (*Notebook* E 55e – E 59) that he thinks that, even the adaptive structures that are deeply embedded in the constitution could be subject to "innumerable variations" that can "accumulate" if they are adapted to the prevailing circumstances (ibid., 196).

This analysis could be taken as a clear evidence that Darwin's reading of Malthus did *not* yield the idea of natural selection – in fact, the ideas of superfecundity and competition were immediately fed to strengthen the evolutionary view where adaptation is directly cased by external conditions and where there is little distinction between individual adaptation and evolutionary adaptation (or evolutionary change).

One more important point, superfecundity and ensuing struggle for survival contributes to adaptation in making it more or less valuable for the individual, it does *not* directly contribute in causing the selection – it forms a larger background of various conditions in which a variation happens to be of advantage to the variant in the survival.

I will close this discussion with a developmental account of an all important distinction in Darwin's theorising, the distinction between the cause (origin) and consequence (evolution) of the variation – the distinction that that one has to learn to understand the theory of natural selection. Indeed, the causal-structure renders the *cause* of individual variation Gruber (1981) is quite impressive in identifying the value of "disciplined recognition" (p.146) of ignorance in the development of scientific thought. In his view, "the most valuable and the most heroic thing he [Darwin] ever did was to go ahead with

his work founded on [an unexplained premise of ubiquitous variability]" (p. 146)

Gruber argues that when Darwin formulated his monad theory of change, he was yet to recognize that "a theory of evolution could be constructed without reference to the origin of life". I agree; by the time Darwin wrote the *Origin* he had clearly separated the issues of *causal-origin* from the issues of *causal-consequences*. Darwin's denials concerning his engagements with the issues of origin, in the *Origin*, shows this clearly. Gruber's (1981) claim that the utility of "species-life-span idea" in the monad theory was to account for the extinction of old species, also appears to be well placed. However, Gruber thinks that after the monad theory, it took Darwin one year to transform the idea of natural selection as conservative principle to the creative one. Here, Gruber misses to see that, even in its eventual form, the idea of natural selection could have be seen as a conservative principle – as Gruber puts it, natural selection is not a "creative power" (ibid., p.149), instead it is a process that naturally causes the conservation of advantageous individual change.

Gruber (1981) identifies Darwin's "expunging" the problem of origin of life as a step towards "recognizing the evolutionary significance of natural selection" (p.151). Spontaneous generation of life was part of Darwin's first theory of evolution that he discarded in the summer of 1837. By July 1838, he clearly stated the limits of his theorizing: "In my speculations, must not go back to first stock of all animals, but merely to classes where types exist, for if so, it will be necessary to show how the first eye formed, – how one nerve become sensitive to light… which is impossible" (Notebook *D* page 12; Quoted in Gruber 1981, p. 155). What contributed in Darwin's distancing from the origin question? According to Gruber (ibid.), Darwin came across the discovery of unicellular fossil organisms that were identical to an extant form. This meant that, unlike the presumption of Lamarck, *all* simple forms of life do not complexity. If that was the case, it would have been necessary to have the

hypothesis of spontaneous generation to explain the existing simple forms of life. Gruber writes about one more reason that might have dissuaded Darwin form the question of the origin of life. In the *Origin* Darwin appears to assume single origin of life to explain the similarities in distantly related organisms. The hypothesis of multiple origins would weaken this argument (ibid., p.152). Gruber has an account of the development of Darwin's thought away form the question of origin of life, but how this non-inclusion of the origin question contributed to the theory of natural selection? It is only because Darwin decided to limit the scope of his theory, he could settle on selection as a cause of evolutionary change. Selection presupposes the existence of the material to be selected. The question of how did the entities being selected originate, is just immaterial for the process of selection, as long as they are stable. Selection is not about production, creation or making of the entities, but it is about selecting from the existing entities. That's why Darwin could write in May 1839, much before the publication of the *Origin*: "My theory leaves quite untouched the question of spontaneous generation' (Notebook E p.160; Quoted in Gruber p. 156).

In this chapter I undertook a critical review of some of the historical and philosophical work on the Darwin's theory of natural selection. This review, I hope, enriches and elaborates the analysis of Darwin's theory in the preceding chapter. The causal structure of the theory of natural selection and the brief of its development in Charles Darwin's *Notebooks*, presented in these chapters, together with the review and my analysis of the student's understanding of the evolutionary change, will help us in defining and detailing out the problematic of leaning Darwin's theory of evolution.

3 Understanding Organic Evolutionary Phenomena: A Critical Review of the Causal Structure of the Student's Explanation[35]

You may recall the distinction I made in the Introduction between *normative* and *empirical* elements in teaching-learning of a scientific theory. The first two chapters focus the former, while this and the following three chapters will deal with the latter. The causal-explanatory structure of a theory (like Darwin's theory of natural selection) that is being taught/learnt is "given" to us educators – it is not open to empirical explorations *by us*[36]. Here our role as the education researcher and teacher is different from that of the scientist; we could well be as critical towards a theory as scientists are usually supposed to be, but if our aim is to learn and teach Darwin's theory, then first we work towards understanding of the theory, even before we judiciously worry about its empirical strength and weaknesses. For the education researcher and teacher, what Darwin proposed and the way his theory explains evolutionary change is a historical "fact", we have to study it, we have to study the theory's causal explanatory structure and then help our students *understand* it[37]. In this sense I say that the theory being learnt and taught is "given" to us and it forms a "normative" element in our scheme of things; it is a norm against which the

[35] This chapter is now published in *Evolution: Education and Outreach*, see Bardapurkar, 2008.

[36] I am *not* claiming that Darwin's ideas are 'scientifically' irrefutable, neither am I claiming that the empirical limitations and strengths of the theory is not to be brought into limelight. The distinction I make is applicable when we are theorising about the problematic of evolution *education*, it should not be generalised to interpret issues in the discipline of evolutionary biology. As we all know, in *science*, no theory is "(God!) given" and all theories are open to critical and empirical revisions; but in science *education* when the aim is to help students understand a theory we need to focus on its causal-explanatory structure. Moreover, note that, here I am concerned with the issues of *understanding*: there is a difference between facilitating the student's *understanding* of a theory and facilitating her in *accepting* a theory.

[37] The issues are different if the aim is to make our students *accept* it; the interesting relationship between understanding and accepting is not my concern in this work. See Coborn 1994 and Smith 1994, for example, for some discussion of this important issue.

researchers and teachers have to assess the student's conception and develop the student's understanding towards it. But, in science education everything is not normative. From *what* is being learnt and taught – from the object, when we come to *who* is teaching and learning – to the subject, we come to the empirical element in science education. In educational theorising, it is here that the researchers and teachers have to open themselves to the empirical realities. They have to explore and explicate, among other things, the cognitive difficulties students have prior to and during their learning experiences, what their understanding of the relevant phenomena is, how they explain these phenomena, etc. This chapter critically reviews the empirical work of science educators on the student's conceptions about organic evolutionary phenomena. It presents a description of the causal structure of the student's explanations in various studies, the effort is to interpret and organise the student's causal conception. We defer the discussion of various efforts in theorising the student's cognitive difficulties and the related curricular and instructional issues to other chapters.

Since the overall goal of this work is to explicate the problematic of evolution education as it concerns the cognitive difficulties in *understanding* the *theory* of natural selection, in this chapter I specifically review the evolution education literature that engages with students' explanations[38] of adaptive evolutionary phenomena, like the ones instantiated in artic fox's fur, cheetah's legs, bacteria's resistance, blind cave salamanders, deciduous trees, etc. We will come across a variety of conceptions students use to make sense of the instances of evolutionary processes. Our aim in this chapter is to study and characterise the diversity of causal-explanatory structures in these conceptions. I will extend and enrich this discussion of students' explanations

[38] This will have a limitation of leaving out some important works in the broader area of evolution education, like the works that employ concept mapping techniques and the ones like that of Anderson et. al. on the "Development and evaluation of the Conceptual Inventory of Natural Selection" published in 2002 in the *Journal of Research in Science Teaching,* Volume *39,* pages 952-978.

in the following chapter with the insights and ideas from my study of the students' explanations.

3.1 The necessitating necessity: the "need-driven" adaptive change

Very often, the student thinks that an organism "needs" to do an adaptive act (say, by repeatedly using a particular body structure) or "needs" to develop an adaptive trait, to survive and flourish in its conditions of life. To her, the "adaptive" response or the "adaptive development" is a necessity in the current conditions. This *necessity*, along with the conditions that have contributed to it, *necessitates the necessary adaptive evolutionary change*, and thus forms a major explanatory concept in the student's worldview. The explanatory conception of the "necessitating necessity" manifests itself in various causal-forms in the student's explanation of various situations; let's look for these causal-explanatory manifestations documented in the literature.

Demastes et al.'s study[39] (1996) clearly brings out a role that the conception of "need" plays in the student's understanding of the evolutionary change, particularly the role "need" plays in causing evolutionary change for better adaptation of the organisms to their environmental conditions. In fact, the authors of this study term the need based conception of evolutionary change as "controlling conception". They say that *need* "plays an important role in the learner's conceptual ecology for evolution" (p.416). For example, a student (student M) in this study gives following response to the questions about evolution of webbed feet in a population of ducks: "The trait of webbed feet in ducks… appear in ducks because they lived in water and needed to swim… webbed feet allows better swimming. It was an evolved trait, wasn't it? And

[39] This study tracks the patterns of changes in the conceptual frameworks of a few students over a period of one year. Its goal was to understand "how students come to understand evolution" (p. 410) during a year long biology course covering a variety of biology topics, but with a focus and a 10-day formal unit on evolution.

it's not a chance mutation, it was something *necessary*. [Things evolve] mainly as far as when they need to, ah adapt to certain conditions" (p.419; my emphasis). In this student's view, evolution of webbed feet was necessary *for* the better swimming and was caused "be*cause* [the ducks] lived in water" (ibid.; my emphasis). Thus here you find that, to this student, the "need" of better swimming would ultimately explain the evolution of webbed feet – organisms need to change to be better adapted to the existing conditions in which they are living; but this need has arisen due to the conditions in which the organism finds itself, and these conditions are said to be an immediate *cause* of the adaptive change. This student (Student M) gives a similar *need*-based explanation in the case of evolution of running species in a population of Cheetahs: "[Cheetahs] needed to run faster… It was necessary for them to catch their pray to survive… it occurred because of the need for the adaptation… they needed to run faster to catch food so it happened" (p.415). In this case, the necessitated adaptive act (faster running) has a particular goal – food! And the animal "had to" *develop an* adaptive trait if it is to survive.

This developmental-tone is apparent also in a student's explanation in Jensen and Finley's (1995) study[40]: "As means for survival they had to catch their prey (so) they developed and learned how to increase speed over a number of years" (p.156). Jensen and Finley call it an instance of "evolution on demand" conception. Such conceptions are evident when students are thinking in the context of plants. For example, Ferrari and Chi (1998) quote the following response: "If the tree is to survive in the environment of the field, *it will have to develop traits* that are conductive to the amount of sunlight, water, parasites, etc., so it can continue to flourish" (p. 1245; emphasis in original). Such need-based and goal-directed explanations are also classified as

[40] This study evaluates effectiveness of a "historically rich teaching innovation" (p.147), in changing the students' non-Darwinian conceptions of evolution to the Darwinian conception.

teleological or *functional*[41] explanations in the evolution education literature. Before we discuss the instances of these in the literature, let us see another causal-form that a need-based explanation takes in the student's thinking.

We saw a few instances of a student's need-driven-explanations where a *need*, created by the environmental conditions, necessitates adaptive *developmental* change in the whole population. A need can also necessitate the use or disuse of a body structure *causing* its modification and thus the evolutionary change. Examples of this are found in the student's explanation of changes in cave salamanders, in the studies of Bishop and Anderson (1990) [42], Settlage (1994)[43], and Demastes et al. (1996). Just to illustrate, let's again take an example from Demastes et al.'s study; when a student (student ST) is responding to a pre-test question "about the evolution of blindness in a population of cave salamanders". She says: "the salamanders live in complete darkness, light is not a *necessity*… the ones that originally went into the cave became blind and their offspring were born without sight and they became blind and may be the process just happened quicker because they could function without sight… they don't use it, they lose it… … [After five minutes she adds the following] ... they became blind just because [they] didn't *need* their sight. But I don't see how that could be passed on". But, when talking about the evolution of running speed in a population of cheetahs, she seems to

[41] There are, however, important differences between teleological and functional explanations. For example, in one interpretation, functional explanations are *non*-casual explanations (photosynthesis might explain the presence of chlorophyll in a plant, but it is not a cause of the production of the pigment). In another interpretation, functional explanations could be *causal* without being teleological (Chlorophyll pigment *exists* today because it has been performing the useful function of photosynthesis in all the past instances). For an accessible and elegant overview see, Psillos 2007, pp.97-100.

[42] Bishop and Anderson studied 110 college students enrolled in successive terms in their "nonmajors' introductory biology course" (p. 416).

[43] Settlage reports his study of 50 students (grade 9 to grade 12) done before and after a course titled "Evolution and Life on Earth". Each test had two similar essay questions.

be doubtful about the need-driven-change: "I really don't think we can form something just because we need it" (p.416-7). Even if this student is doubtful about the correctness of her understanding, we, at least, can safely presume that the need-driven-explanations are a kind of *default* explanations given by the students[44] – when no other convincing explanation is available to them, they are most likely to understand the change as necessitated by the "need" or the "conditions" of the time.

The examples in the preceding paragraph illustrate that the survival-necessity and the conditions contributing to it, are not distinct causal factors from the use/disuse of certain body parts; and hence I do not put "use/disuse" as a separate casual category in the student's explanation. Use/disuse could, however, be quite a dominant causal-explanatory factor in the student's view. In Bizzo's 1994 study[45], students had the option of choosing either selection or use-disuse as an answer and defend it. In one case an option of choosing artificial selection of the differences in the bone weights of the ducks, and in the other an option of choosing natural selection of a few faster felines present in some generations, was available to them. The author mentions the difficulty students face even after the apparent recognition that one of the options is Darwinian. For example a student is quoted as writing: "both [the options] are correct because one is Darwinism, but cheetahs had to improve in every generation a little bit" (Bizzo's 1994, p. 541).

The student, when asked about how of the evolutionary phenomena refer not just to the "needs" and "wants" and the physical changes in the environment of animals as a cause of the change, but also to some "internal force" (Deadman and Kelly, 1978). Thus in the student's explanations the causal

[44] The general idea that in the case of children a kind of explanation could be a *default* explanation is from Gutheil et. al (1998).

[45] Students in this study have already had formal instruction in the theory of evolution. They were aged between 15-17 years.

factors are not restricted to the external "forces". In Banet and Ayuso's (2003) study, Spanish students (Age 14-16) believed that mutations take place to help organisms survive in unfavourable conditions; organisms respond to the environmental changes by mutating and thus attempting to avoid the possibility of extinction. A similar finding was reported by Brumby in his papers (e.g. 1979). She studied 63 (age about 18 years) British students, 47 of which had studied evolution and heredity. The students categorized as having "poor" understanding of natural selection (65%) think that the environment induces individual change (or "mutations") that makes organisms "immune" (possibly to the antibiotics or insecticides), thus adapting them to the environmental changes. For these students adaptation is a *process* entirely governed by the environment. We should, hence, note that the *need* does not always enter into the student's narrations as a causal factor, neither is it always associated with the environmental conditions as a cause of adaptive transformation. Environmental factors alone are sometimes sufficient to bring up an adaptive change.

3.1.1 Teleological or Functional explanations

In section 3.1, I clarified that I classify the commonly referred category of the "change by use/disuse" under what I have called as "necessitating necessity" or the "need-driven" adaptive development. Similarly, a commonly used category of "teleological or functional explanations" is also entangled with what I have broadly delineated as the category of "need-driven explanations"[46]. The "necessitating necessity" could be conceived by the student as an *adaptive end* towards which an individual's development is directed. Such a conception has a teleological explanatory structure in which the end necessitates its beginning. For example, if having a thick furry skin is conceived by the student as a 'need" towards which the organism's

[46] Here the reader is reminded of footnote number 7. Though the categories of the student's explanation are overlapping with each other, there could be subtle and significant distinction among them.

development would be necessarily directed, she could easily be classified to have a "teleological" conception of organic change. An example of this, for instance is found in Clough and Wood-Robinson (1985a); they interviewed 84 English (UK) students (Aged between 12 and 16 years). Most of the categorized responses from the younger students and about half of the responses from 16-year-olds were anthropomorphic and/or teleological. For many of these students, adaptive change is a *conscious* response of the organism driven by the need to survive in the changing or drastic environment. For example, when asked to explain how the thick coat of the Arctic Fox, that "lives well at very low temperature", came about originally, a 16-year-old girl said: "Fox at first when it had shorter fur would have been cold so it … it knew that it had to change, really" (ibid., 127). A 12-year old girl said: "gradually… [Foxes] began to grow thicker coats until they were able to survive properly … yes, they were sort of determined to stay alive" (ibid., 127-8). Another 12-year old said: "[An individual fox] grows thick coat, so it can keep warm while it's out looking for food" (ibid., 128).

The last response could fit the category of "functional explanations" as well – an individual has a trait for the function it serves. One of the difficulties in learning natural selection identified by Bishop and Anderson (1990) is the student's inability to distinguish between causal and functional explanations. For them, explaining the function of an organ is sufficient to explain its evolution[47]. Section 3.1 should remind us that student's *need-based explanations*, though not purely mechanistic or natural, are still *causal* explanations, in which the external physical conditions or internal forces act to bring out the necessary adaptive transformation. In an elegant piece of work

[47] Being satisfied with the functional explanations can surely and significantly make the learning of natural selection difficult. Nevertheless, here I would like to mention that if one takes a full view of causality in natural selection, functional explanations do figure in it, and in an important sense. After all, a particular trait is selected for the function it serves and thus its *continual* existence is explained by the utility it has for the organism.

Tamir and Zohar (1991) pose a very interesting and important question: Do students use teleological and anthropomorphic terms just as convenient shorthand while they actually are aware of the differences between mechanistic-causal explanations, teleological explanations and anthropomorphic explanations? Or, anthropocentric-teleological answers do indeed reveal students' confusion between causal and teleological explanations? The authors randomly selected 12 grade 12 (Age 17) and 16 grade 10 (Age 15) students for this study.

When asked explicitly, many students in the study could easily recognise anthropomorphic formulations (especially in the case of plants) as different from anthropomorphic explanations. In fact, grade 12 students even support the inclusion of anthropomorphic *statements* in the textbook for the reasons of convenience and ease. But, at the same time it may be noted that, only 3 out of 28 students could give purely mechanistic explanations; and 62% of the students believed that, animals do "really wish, try and strive" (ibid., 61). Even when, a process or behaviour is re-described to the student by removing the benefit it earlier had, majority of the students still gave teleological or partially teleological (teleological but not in all the instances) responses. For example, the students were asked to predict whether or not a deciduous plant growing in a green house would shed its leaves, about 70% of the students gave teleological answers. For example: "Perhaps shedding the leaves is needed to complete the life cycle", or "perhaps without dormancy it cannot bloom" (ibid., 63). Thus, Tamir and Zohar found teleological reasoning to be more common among students than anthropomorphic reasoning. Teleological responses do not necessarily involve humanlike, *conscious*, goal-directed behaviour. Instead, they are based on "the belief in the functionality of the behaviours of living organisms, which is illustrated by major principles, such as the adaptability of organisms to their environment and the complementarity between structure and function" (ibid., 66).

3.2 Evolutionary change is necessary individual transformation

In Section 3.1 we saw that the *need* explains the adaptive change in an individual in two distinct but complementary senses: one, it could be taken simply as a *necessity* in the sense that the individual needs a particular trait or modification to adapt to and survive in the conditions; or two, it could be taken as a *necessitating* necessity, that is the *need* that somehow causes the individual to have or develop the necessary-adaptive trait. In the first case, the conception of causality could be more complex: in this complex causal form, the fact that some adaptive trait is "needed" is not sufficient to explain its development; need is essential in explaining adaptive development , but by itself it does not *cause* (that is necessitate) the individual to change. The *necessary* change is caused (or necessitated) by living-conditions, or the habits, or the use/disuse, or even through some internal force or mutations[48]: the cave salamander lost their *unnecessary* eyes but the loss is *caused* by disuse. In the second case, however, the necessity itself is deemed to be directly responsible for the necessary change: artic foxes developed think fur for it was a necessity[49] (See section 3.1.1). In either of the cases, irrespective of the student's causal conception of necessity in the evolutionary phenomena, the organic change is understood by the student as a necessary *individual transformation*. The student finds little difference between *individual* change and *evolutionary* change, and therefore the cause of individual change (i.e. individual variation) is the same as the cause of evolutionary change – origin of variation among individuals directly accounts for the origin of variation

[48] Again, it may be the case that the conditions that are said to cause the necessary adaptive transformation are the same that have contributed in creating that necessity – if being in water is causing the necessary development of webbed feet, the aquatic habitat has also contributed to the creation of the need of having webbed feet.

[49] The development of think fur in artic foxes was necessitated by the necessity of having it.

among species. This explains why the student sees "*need* as the [cause of] origin of variation" (Demastes et. al 1996, p. 413); and evolutionary change is seen as a transformation or development in the traits: it is "*gradual change in the traits themselves*" (Bishop and Anderson 1990, p. 423). In Jensen and Finley's (1995) study, the students often express the idea of an "individual 'evolving' with time" (p.163). Indeed it is paradigmatic to the student to understand "evolutionary" change in terms of *transformation* of individuals, rather than in terms of *selection* of individuals[50]: adaptive transformation is "getting used to", it is "an individual process of adjustment" (Bizzo 1994, pp. 542-3 & 544; also see a review by Wood-Robinson, 1994). For the student individual changes mean that the individuals evolve or adapt to the changing environment; and as we have already discussed, this deterministic adaptive change or evolution is understood to be due to the "need" of that change and/or due to the "changes in the environment" or sometimes even due to the subconscious efforts of organisms to improve themselves. In their excellent paper, Deadman and Kelly (1978) note that that the students in their study rarely recognized the significance of slight modifications and their adaptive value. Students do use the words "extinction" and "survival", but just as "shallow explanations", without linking them "in any deeper sense to selection mechanism"[51] (ibid., p.10). The problem is to be dealt with, in my view, by going to its roots, not by superficially telling the students that populations, not the individuals, change over time (after all, changes in population are contingent on changes in individuals). I argue that the students are to learn the distinction I develop in this work, the distinction between evolution by transformative action and evolution by selection. We will have many occasions to come across the student's responses wherein the evolution is

[50] The distinction between change by transformation and change by selection (that is originally due to Lewontin) is central to my work. It will be referred to again and again in this study and is discussed in detail mainly in the chapter on causal-explanatory structure of Darwin's theory of natural selection.

[51] A general discussion of "shallows" of explanation could be found in Wilson and Keil, 2000.

explicitly or implicitly understood as change by transformation. Below I quote a transcript of a typical response from Geraedts and Boersma (2006, p. 861; my emphasis): "[When the foxes move to a much colder environment] … their coat will gradually *become* ticker, to adapt themselves to the cold. To keep them warm, otherwise they won't survive … [And their children] will already begin with a thicker coat, and their coat will become thicker still". Last statement of this student leads our discussion of the causal structure of their explanations to a point where we deal with the conception of inheritance of acquired characters.

3.2.1 Inheritance of individual adaptive change

Various students conceive the causality of organic change differently. However different their conceptions be, if the organic change is to exist and amplify across generations then it needs to be transmitted across generations, and this brings us to the student's notions of inheritance. In general, *younger* children tend to think that characters acquired by an individual in its lifetime will be passed on to the offspring. Karbo et. al. have reported young Canadian urban children's (Ages 7 to 13 years) views about inheritance of characters. Younger children in this study generally believed in the inheritance of a character abnormality acquired by animals during one's lifetime, and for them the chance of inheriting an acquired character is more if the new character has been acquired by the animal in its younger age. Very few children, however, believed that plants inherit acquired characters. Significantly, many younger children thought the inheritance to be controlled by environmental factors (sun, water, food, parental care, attention) or body parts (blood, teats, brain) or even nature. Compared to the younger ones, older children have a much more nuanced notion of inheritance. In this study children aged above 10 yrs. thought the contribution of parental traits to be important – "it would depend on whom the child takes after" (ibid., p.144). For predicting traits of offspring,

older children wanted to know the traits of both the parents as well as of their ancestors.

In their study of 84 English (UK) students (Aged between 12 and 16 years), Clough and Wood-Robinson (1985b) found majority of the students thinking that the characters acquired during one's lifetime are *not* inherited. Many of these thought the inheritance of acquired characters to be simply "unnatural". For example, when asked to predict and explain if the baby of a normal mice whose tails are chopped off would have a tail or not, a "12-year-old said that the babies would have tails 'because it's not natural, nature didn't make it happen'" (ibid, p. 306). Another 14-year-old student said that the babies will have tails because mice "had tails until he chopped them off its … well … they were born with tails, so the other mice would be born with tails" (ibid., 306). About 20-25% students in this study did not believe in the inheritance of acquired characters because there is no genetic change in acquiring the character. A 12-year-old boy said in answering the tail task that "they'd still have tails because the chromosomes wouldn't have altered – it was just the tails that had been chopped off" (ibid., 306). However, interestingly – and in line with my data (discussed in the following chapters) – many of these students who thought that the acquired characters are not inherited, did say that if organisms in each of the successive generations keep acquiring a character, the acquired character *is* inherited: the cutting of tail in each generation would "work in the end, given time" (ibid., 306). A 12-year-old boy said that if tails are cut repeatedly over many generations, then mice "probably wouldn't bother growing their tails any more if they knew they were just going to lose them" (ibid., 306). The idea that given enough time, acquired characters are inherited was found to be quite persistent and prevalent among the students. This belief is also common among Botswana students (Wood-Robinson 1994, p. 40). In the case of inheritance of athletic ability, compared to 13% of the UK students' sample, 31% of the Botswana student sample believed in the inheritance of acquired athletic ability. But

majority of the Botswana student sample did not believe in the inheritance of the acquired characters. Thus talking about the farmer's calloused hands, one student said: "Children do not inherit features that the parent acquired, but only inherit those that they are actually born with. The parent's hands have nothing to do with what is in the womb" (Wood-Robinson 1994, p. 39).

From the student's responses, it is evident that whenever students have the standard concept of inheritance – whenever they think the structural gain or loss during one's lifetime is not inherited, the explanation is commonly *not* grounded in the understanding that the traits are dependent not on the living-conditions but on the "genetic" factors. The awareness of the characters being determined by genetic entities may not ensure us of the understanding of non-inheritance of acquired characters. Evidently, it is not very difficult for the students to entertain the possibility that just as body structures are, "genetic" structures could as much be adaptively transformed and inherited. For instance, in the Lawson and Thompson's (1988) study, when asked about the skin colour of the child of a fair-skinned girl, who grew up in Africa and then married a man of the same race, living in Africa thereafter, a student in this study said: "Probably somewhat darker because the mother's *chromosomes have adapted*" (p. 739; my emphasis). The changes could thus be acquired at the "genetic" level too, and leaving little doubt that the acquired skin colour is inherited. Even if students have an idea that the trait is not always conditioned by environmental factors and that they are in some way dependent on DNA, they accommodate this fact to the framework which predicts inheritance of acquired characters. A response by one of the students in Bizzo's (1994) study instantiates this[52]: "[In circumcision] having removed the DNA of that part for many generations, it disappeared" (p. 541). It is clear that having an idea of "gene" controlled inheritance is not enough, nor does it appear very useful, in

[52] Many students (about or more than half) in this study believed in the inheritance of the acquired characters.

understanding that evolution is *not* the inheritance of necessary adaptive transformations.

3.3 Summary

In sum, from this review, following is my characterisation of the student's causal structure. The student understands evolutionary change as an individual transformation. The individual transformation is commonly explained by perceiving its need/necessity – the transformative-change happens simply because it is a necessity. The perceived necessity, however, could assume a variety of causal forms in the student's explanations. In some instances, it could be perceived as an immediate *cause* of the change, but sometimes it is deemed explanatory without any reference to the cause. In other instances, the student does perceive the necessity of the change, but a distinct factor is identified as a cause of the change. The causal factors could be the physical conditions (the conditions that have contributed to the creation of the needs in the first instance), and they can bring in the necessary change by transforming the structural or genetic traits of the individual. Or, the causal factor could even be some internal force. Moreover there are many instances when the necessary change is caused by the corresponding use/disuse of the body parts. The adaptive individual transformation, achieved through the conglomeration of this variety of the necessitating/causal factors, could be inherited to the coming generations. But the inheritance again depends on a range of conditions like: the age at which transformation occurs, the number of generations that have been subject to it, whether or not chromosomes or genes are also transformed in the process, etc.

4 Causal Structure of the Student's Explanatory Narrative of Evolutionary Change: Class VII

In the previous chapter, studies on the student's understanding of evolutionary change were discussed. The aim of this review was to recapitulate various ways in which students understand evolutionary change. The studies reviewed were carried out with varied aims, and hence they do not (rather, they do not need to) always undertake detailed discussions of the *causal-structure* of students' explanatory-understanding. To diagnose, define and detail out the problematic of understanding natural selection, what is needed is a subtle picture of the students' causal-explanations that focus on the *variety* of causal-possibilities they think about[53]. With this aim, I now turn to the discussion of causal structures in the students' explanations. Before I do that, I provide methodological details of the study.

4.1 Methodology

The sample for this study consisted of a total of 83 students. They were a mix of secondary school students (Class VII-X), higher secondary school students (Class XI), and undergraduates (1st and 2nd year students who had opted for the Science streams). Each student had to respond, both in writing and in an oral interview, to 16 or 24 open ended descriptive-explanatory questions. Following is the number of students, in the brackets is given the questions to which they responded both in writing and during the interview[54]: Class VII 24 Students (A, C or B, D), 11 students (L, C, J, K, M, P); Class IX 11 Students (A, C or B, D); Class X 12 students (L, C, J, K M, P); Class XI 09 students (A, C or B, D); Undergraduates 1st year 08 students (A, C or B, D), 1st & 2nd year 08 students (J, K, M, P, L, C). The details are tabulated below:

[53] Recall that this is the main goal of this work.

[54] I have explained the details of the questions below. Please see the abbreviations given at the end of this Section, and the Appendix.

Students \ Description/ Questions		Either (A and C) or (B and D)**	C, J, K, L, M, P	Total	
Class VII S#18-41; S#73-83 (Mean=12.3 yrs.)	Male	10	5	15	35
	Female	14	6	20	
Class IX S#42-52 (Mean=15.0 yrs.)	Male	6	--	6	11
	Female	5	--	5	
Class X S#61-72 (Mean=14.8 yrs.)	Male	--	5	5	12
	Female	--	7	7	
Class XI S#1-9 (Mean=15.8 yrs.)	Male	4	--	4	9
	Female	5	--	5	
Undergraduate S#10-17; S#53-60 (Mean=18.9yrs.)	Male	5^	6	14	16
	Female	3^*	2	2	
Total		52	31		83

^ These students wrote about only one of the four descriptions (A, B, C, D), but during the interview they talked about at least two descriptions (either A & C, or B& D).

* S#12 - only interview, no written response of S#12 could be collected.

** These are the students who were part of both the written test and the interview, and whose understanding is analysed in this study. In these cases, all the students appearing for the written test were not interviewed. Written response of all the students were first screened for their variety and the student population for the interview was selected such that this variety is at least roughly represented in the interview sample.

Though the sampling in this study could be labelled as 'convenient' sampling, the students whose ideas are reported in this work come from wide socioeconomic strata of the society as well as from various geographical locations. All the secondary class students (Class VII, Class IX and Class X) that were interviewed in this study attend a government aided school (the school receives government funds) that mainly caters to lower middle class students. The parents of many of these students work as unskilled workers. The other higher secondary school from which about a dozen Class XI students were interviewed caters to the students whose parents hold various positions in a research and development institute. In the first round of data collection, when the school students were responding to either A and C or B and D (but not to J, K, L, M, P), the whole divisions (of about 40-60 students) responded to the questions in writing. The written responses of all these students were then screened for the variety of their contents. The interview sample was much smaller than the written test sample[55]. The student population for the interview was selected such that the variety of response from the written test is at least roughly represented in the interview sample. In the second round of data collection when the school students were responding to C, J, K, L, M, and P, the number of students appearing for the written test and the interview were roughly the same. In this case the students were selected based on their proficiency in English language. The proficiency was decided by the teachers based on the student's performance in the English language (one of the compulsory school subject). The undergraduate students in this study come from a wide variety of backgrounds that vary on academic, socioeconomic and geographical counts – at the time of the interaction they were studying different subjects (microbiology, biotechnology, etc.) to earn different degrees (in sciences and medicine). This variety in the sample was made possible by a talent nurture programme conducted by this institute

[55] See the table for the number of students interviewed from each of the Classes.

(HBCSE), in which these students were participants[56]. In the case of undergraduates, the number of students appearing for the written test and the interview was roughly the same in both the rounds of data collection.

All the students first responded in writing to the question-items given to them (often preceded by a short description, see the Appendix); and then during the following days, they were interviewed, one by one. Each interview lasted for about forty-five minutes. During the interview students were told to talk in detail about their written response, elaborate it, add to it and explain it. The interviews were audio-recorded and fully transcribed. The question-items to which students responded were labelled as A, B, C, D, J, K, L, M and P. Each question-item had a number sub-items, for example C had eight questions labelled as C1, C2… C8 (please see the Table and the Appendix).

The four descriptions of the evolutionary events – A, B C, D – and the question-items following them, were constructed to explore how the students view and understand individual variation. In the situation (or evolutionary phenomena) described in each of these items, the students were clearly told about the existence of individual differences. Each situation given to the students had the following structure: The existence of variation—Variation in a particular trait—Mention of a relevant environmental condition—Increase in the number of individuals having a particular variation in the trait. The situations were constructed to confirm with this structure, not necessarily to get the scientific-historical details right. The guiding principle for formulating these descriptions was: assuming that there have been these cases of evolutionary change, how would one make sense of it. Each situation was followed by a number of open ended questions (C1, C2… C8, for example) asking for descriptive-explanatory responses (see the appendix).

[56] In this programme, the students were involved in the experimental-project based work; it had no relation with this study.

The remaining descriptions and the questions following these descriptions, preserve the important purpose of A, B, C and D, but had their own utility too, in probing the student's understanding. J and K were specifically crafted for the study of how the student views adaptations, and how teleology plays out, if it does, in their causal-explanations of these adaptations. Unlike the previous instances exemplifying evolutionary change in animals, P chooses a plant, and was more comprehensive, as it aimed at bringing together various complexities of evolutionary change in a plant population through its interaction with the predatory-animal population. The aim of M was slightly different, it was designed to see if students think of selection as a means of modification, or if transformation alone is imagined as a possible method of desired modifications. The focus of questions in L was to locate the student's thought in a general cause/effect—artificial/natural—animate/inanimate framework of causal-explanatory understanding: it was to study how the student conceives and relates the change and its causes in inanimate world to the animate world.

If we want to study *how* students understand a theory in science, we study how they make sense of the phenomena explained by that particular theory. For example if we want to study how students understand a theory of inheritance of characters, we study how they make sense of the similarities and differences between parents and their offspring. Note that here we are not assuming that students will answer in accordance with some pre-specified, preordained categories of explanation. We are providing them with the set of phenomena that a particular theory in science explains. Thus we have an opportunity to contrast students' causal-explanatory responses with the scientific causal-explanation. This contrast is possible because both the student and the theory explain the same set of phenomena. Well described phenomena seek out the relevant and comparable explanations from the student as well as from the scientific theory, thus enabling the comparative contrast between the student's and the scientific way of causal understanding. Thus, the student's

understanding of a scientific theory is studied through the causal explanations she construes (in writing or during interviews) around the phenomena described to her, the phenomena that are relevant to the scientific theory.

During the interview students were told to talk in detail about their written responses, elaborate it, add to it and explain it. The interviews were audio recorded and the records were transcribed completely. Each of the students' written and interview responses were studied *individually*, to reconstruct their causal understanding of the given descriptions; that is, to reconstruct how the students describe and explain organic change described in the diagnostic situation, and probed in the questions following each of the descriptions. No specific causal-explanatory categories were presupposed. Categorisation, even when bottom-up, often fragments the complexity and heterogeneity of an individual's understanding of a set of phenomena (for e.g., phenomena instantiating evolutionary change and adaptation). The categorisation is not the aim of this work. The aim is to study: one, what are the various causal construals with which the student understands the organic (evolutionary) change; two, how these various causal construals contrast with the Darwin's construal of causality; and three, how the contrast between the student's and the Darwin's understanding helps us define and detail out the problematic of understanding natural selection.

What follows is the result of the analysis, presented in the form of a spectrum of the causal-explanatory frameworks of the individual students. I must mention that the word "framework" is not used to connote something that is *necessarily* fundamental and coherent. It is used broadly to connote something that captures the characterisation of the student's causal-explanatory understanding.

Before we begin the discussion of the student's understanding, note the abbreviations used: WR refers to a *r*esponse of the student to a *w*ritten

questionnaire items; IR refers to her *r*esponse during the course of *i*nterview; A, B, C, D, J, K, L, M, P label the main items in the written questionnaire; Except M and P, each main item had further sub-items, numbered K1, K2, K3…, for example, see appendix; all the students in the (entire) study were numbered sequentially, each one is thus referred to by a unique number.

In this chapter we will discuss the understanding of Class VII students. Organic evolution is taught formally in the school in Class VIII and Class IX. Hence, the students whose understanding is being discussed in this chapter, had no formal instruction concerning the *science* of organic evolution[57]. I will discuss the student's understanding (in this and the following two chapters) by presenting a spectrum (not categories) of causal structures of the student's explanations.

4.2 Impossibility of the evolutionary change-I

To think about and understand the theory of natural selection, and how natural selection causes evolutionary change, it is preliminary that we grant the possibility of evolutionary change. For the student, if the evolutionary change is a plain impossibility, then no question of how she thinks of the *how* of evolutionary change would arise. The question of how or why of evolutionary change would be insensible for her. For instance, S#18 takes long-necked and short-necked giraffes to be of different *kinds*. She does not think that before thousands of years giraffes had short necks. She recognises the individual variation among giraffes. The individual variation in giraffes is understood to be analogous to the human variation: one human being's neck is smaller than the other ones. "The same pattern is their… [in the] animals [too]" (WR). Indeed, individual variation seems to be a commonsensical fact for her – "If they [the giraffes] are having a smaller neck or a longer neck, what is the

[57] They however had studied the historical evolution of human beings in their Class VI history classes.

problem?" (WR to C3-4). It is impossible for her to think that in antiquity giraffes might have had short necks: "how it is possible that giraffes [are now] having long necks and first it was small? … Why… [is it the case that] years before giraffes neck was small? Why new giraffes neck is longer [than] that [of] the previous [one]?" (ibid. & WR to C2).

4.3 Impossibility of the evolutionary change-II: Essentialist understanding

In the preceding section we saw how difficult it could be for the student to think of the possibility of evolutionary change. We may not always be able to figure out why the questions concerning evolutionary change are insensible for the student. But, sometimes it is clear that the student denies the possibility of evolutionary change because she is an essentialist. For her different animals and plant species are so distinct from each other, each one having its own essence, that it is absurd to think that one could give way to the formation of another. For instance, S#28 seems to interpret DDT resistant mosquitoes and DDT sensitive mosquitoes to be two *kinds* of mosquitoes just as cows and cats are two kinds of animals: "No it could not be like that, that a DDT resistant mosquito gives birth to DDT sensitive mosquito. A cow gives birth to calf and not to kitten. Similarly, a DDT resistant mosquito can't give birth to a DDT sensitive mosquito" (WR to A5). Her essentialist commitments also come through her A8 answer – she seems to preserve the type over the transformation imagined in A8. Her human beings keep their qualities and limitations even after becoming mosquitoes. Rather human beings seem to remain human beings even after becoming mosquitoes and (as in the ordinary situation) are most likely to die due to DDT: "If human beings are imagined to become mosquitoes, all *human beings* will die due to DDT insecticides because [the DDT] may be powerful and may contain some chemical which may lead to their death" (WR to A8). It is *not* that S#28 is unaware of the individual similarities and differences, but these are thought to be the

hormonal differences having no link to the increasing number of DDT resistant mosquitoes. S#28 thinks that individual mosquitoes differ in colour and size; and "the hormonal changes in the body of the mosquitoes may be responsible for the similarities and differences in the mosquitoes" (WR to A4). Further, the hormonal changes are thought to be controlled by food one eats: hormonal differences depend "upon the things [mosquitoes] eat … and if that is good". For example, "in human beings, suppose, if we eat very good things which have nutrients in it… the hormones will be increased, so the height and all will increase"[58] (IR).

4.4 Evolution: A natural change

In the previous sections we discussed the student for whom evolutionary change is not even a possibility. Unlike these students, S#24 thinks evolutionary change to be a possibility, and the ape to man evolution seems to be a prototypical example of this change for him. Animals change as the time goes by: animals change with "changing time … [with] changing time changes the shape of the animal … [For example] apes [have] evolved [into] man" (IR). In fact, S#24 thinks this change to be so *natural* that it hardly needs any further explanation. He could not tell how or why the shape of an animal changes with time. When asked explicitly during the interview, he declines to entertain the possibility of environmental conditions as a cause of the change over time. For example, he says "no" when asked about the possibility of DDT sensitive mosquitoes becoming DDT resistant due to continuous exposure to DDT. Apparently, to him, the just said possibility does not explain much, and (in A2) he is keen to know "Why the (DDT) resistant mosquitoes [are] increasing due to continuous use of (DDT)?" (WR) (parenthesis in original).

[58] Hormonal differences play explanatory role in the understanding of other students also. E. g. S#27, see the Section 4.6.

Interestingly, S#24 recognises the benefit of having long neck and suggests the humans to have long necks "because [because] of long neck the giraffe can reach to the upper part of the tree and can justify his hunger by eating the leaves of the trees… [And also] because of its long leg and neck it can see the danger arriving to kill it" (WR to C8). This realisation of the benefit is essential for understanding natural selection, but merely realising the beneficial role of a structure is not enough (see chapter one). To understand natural selection the benefit of a structure is to be seen as advantageous to the individual having that structure (self-advantageous) and thus of great help in self-survival and eventually in self-selection.

Like S#24, for S#39 too, evolutionary change "is a *natural* change … Changes take place in everything, like man was first ape and then it has changed into man; first monkeys had the tails, now we are not having the tails, it has changed"[59]. In fact, for him these changes are so natural that it is insensible to ask *how* it happens. He says that he "can't get [the meaning] of [this] *how* [question]" (IR) (my emphasis). Both S#24 and S#39 think evolutionary change to be a natural phenomena, but with a difference. For S#39 the change is "according to our needs" and for the adjustment with the surrounding. For example, giraffes "have [had] to adjust… [to] changes in the surrounding" (IR). The explanation S#39 offers in the case of DDT resistant mosquitoes is also teleological. He thinks that "the resistance power [of mosquitoes]… increase[s], so they will have power to resist DDT"; and this resistance power is said to depend "on the food they eat" (IR).

4.5 Congenital defects explain the differences

We just discussed how the evolutionary change is natural or normal for the student. Another possibility is that the student takes the individual change or

[59] Students' responses are quoted mostly as they are, sometimes retaining the oddity of their constructions.

the individual differences as *ab*normal. The student understands the differences talked about in the given scenarios (for example, the differences in the mosquito's sensitivity to the DDT or differences in the giraffe's neck length) to be due to inborn defects. Each character is supposed to have some normal form and the variation from this norm is supposed to be caused by some defect during the reproduction. For S#22, DDT resistance is a norm among the mosquitoes. Normal and strong mosquitoes would generally be resistant to DDT. Indeed, he thinks that, defending themselves would be the "habit" of these strong mosquitoes. All the mosquitoes, however, cannot defend themselves. This dissimilarity in resistance against DDT is because "at the time of birth there would be some problems occurring" in some of the mosquitoes (WR to A4 & A5). The giraffe case is understood in the same sense by S#22. It seems that for him long neck is a norm and short neck a defect. Long necked giraffes have been in existence since antiquity. Because of the drought "some [of the giraffes] would not have been properly treated and therefore the growth of their neck is shorter than others" (WR to C4 & IR).

Again for S#23, like S#22, the differences in the "body structures" are "because of their birth" – "their growth will not be proper, during their birth some problem will be there" (IR). The short neck of the giraffe is thus an aberration caused by "some problem" during the birth. Congenital defects also explain the differences among the sibling giraffes: "though the giraffes are born from [the same] mother their growths are different" (WR). In the case of mosquitoes, S#23 understands the differences in DDT resistance to be due to differences in the "resistance power" (IR). Some mosquitoes "are strong, some are weak" (WR to A3). It is interesting to note that, while the differences are understood as congenital defects, the similarities are understood to be caused by the similar living conditions. S#23 thinks that "all the mosquitoes are black … because they [all] live in that gutters".

4.6 Internal working of the body explains the differences (transformation is not necessarily adaptive)

Apart from viewing the organic change as normal and natural, or understanding the individual differences as congenital defects, the student may think that the individual differences are controlled by the *internal* workings of the body. S#34 thinks that the organic change is explained by the "changes inside the body". She does *not* think that DDT sensitive mosquitoes could become DDT resistant because of continuous exposure to DDT (IR). Further, the change in the giraffe is understood by drawing an analogy with the change in the human being. "If a person's body… is working properly, then he will have a proper height. If the person's body is not working properly, then he will not have proper height … like that also in giraffe … So like that changes are there, changes of getting differences" (IR). Analogy with human beings is also employed to explain the continual existence of the giraffes: "Yes, there will be long necked giraffes after thousands of years from now. Like human beings will be there after thousands of years, giraffes will also be there" (WR to C7).

Some students also think something *internal* like hormones causes the individuals to change and differ from each other. S#27 thinks that, "the similarities and differences could be because of their [individuals'] own internal body problem (WR to D4). For example, it could be "because of hormones [that some of the individuals'] growth is limited" (IR).

Similarly, S#36 seems to understand the cause of the change to be *internal*, not external. She does *not* think that a light coloured moth could become dark in colour due to smoke and pollution. The colour is said to be dependent on the "hormones" which in turn "depend on the parent[al hormones]" (IR). Like S#30[60], S#36 also thinks of *behavioural* similarities and differences among human beings, like those in being polite and friendly. But, unlike S#30, she

[60] See the Section 4.18.

relates these to something internal. For, the reasons for these differences are said to be differences in "their mind's set up" (WR to D3 & D4). However, like many of the Class VII students, the cause of resistance to X-disease is not thought to be entirely internal. Resistance is thought to be due to the general health and nutrition, the existence of the virus is thought to be "because of the harmful chemicals and garbage" (WR to D5, D6 & D7).

4.7 Non-hereditary adaptive development via conscious efforts—and a story of "power" germs

We just saw how the student considers adaptive trait to be a norm, and how in her view non-adaptive organic change is understood to be caused by defect-prone reproduction. In a complete contrast to this nativist understanding, the student may think that adaptive change is a consequence of conscious efforts of an individual to develop itself. S#26 (Class VII, 11Y 09M) thinks that some giraffes are short necked and some long. "Short necked giraffes eat grasses and long necked giraffes eat the [leaves] of tall trees" (WR to C3). For her, a short necked giraffe can become long necked giraffe in its lifetime by "trying to grow the spinal cord" (IR to C4). Giraffes could do this "by lifting their body strait" (WR to C2), when they try to eat the leaves of tall trees. By thus "developing" the spinal cord (and the long neck) to eat the leaves of tall trees, "the giraffes are developing their survival" (WR to C3 and C4). Interestingly, for her, though the giraffes could acquire long necks during their lifetime, this acquired trait is not inherited to the next generation[61]. The offspring of those giraffes who have acquired the long necks during their lifetime will not be born with long spinal cords (IR to C5).

[61] The student's conception of inheritance of character, especially when she thinks a character could be acquired during an individual's lifetime, was often diagnosed by using some examples during the interview. Like by asking the student to consider a male and a female, with some specific neck length, to be stretching their necks to obtain the food, and then working out the example through the following generations.

In the case of mosquitoes, S#26's explanation is not developmental. Like a number of other class VII students, she too thinks that some mosquitoes are resistant to DDT because they have "power to live". But her explanation is distinct as there is an interesting turn in her "power" story – mosquitoes get the resistance power from the germs they suck from the blood: "We think that mosquitoes are having that power. But, mosquitoes don't have the power [of their own]. I think that the mosquitoes [have power] because of carrying the germs from the body of diseased person. The germs are powerful. So they [the germs being carried by the mosquitoes] are not killed by that insecticide. Some mosquitoes that do not carry the powerful germs… [die] due to the insecticide" (WR). Her answers to A6 & A7 complement this argument. She thinks that, since "in olden days there was less population [of human beings]", the DDT resistant mosquitoes were not there, perhaps because at that time there were not many people having power germs in their blood. But now the population has increased and so "mosquitoes can't die because they suck blood" from the people who carry powerful germs and hence there will be DDT resistant mosquitoes after hundreds of years.

4.8 Nature Divinised-I: Theistic—essentialist—teleological—developmental—nature's change

The student's interpretation of 'nature' and 'natural' is crucial in understanding Darwin's theory of natural selection. In natural selection, the 'natural' is understood in contrast to the 'artificial'. 'Natural' is not understood as 'nature's', and 'nature' is not seen as a causal-agency, let alone as a divine causal agency. The student may however view 'nature' as a divine causal agency, and interpret 'natural' as something that is normal and given or caused by the God. To see how such conception details out in the student's understanding, we will first study S#80's responses, followed by a more complex conception of S#78.

S#80 understands the artificial/natural distinction by distinguishing what is *nature's* from what is *man-made*. The 'natural' is not just something that is not caused by man, but it is something that has to be *in* nature, not in the human world: "The change caused *in* nature is called 'natural change'. The change caused by man is called 'artificial change'" (WR to L4 & L5; my emphasis). The change in 'nature' is caused by 'nature', where nature is understood as *God*: "nature means God" and natural change is "the change done by God" (IR). He seems to subscribe to a static worldview. He says that he does not know if the leaf eating insects were always green. When asked if these insects migrate to trees having red coloured leaves and start living there for many generations eating the red leaves, he rejects the possibility of their becoming red (IR). He also denies the possibility of changing a useful animal or plant so that it becomes even more useful (IR to M).

For S#78, both natural and artificial change is caused by some agency, the former by 'nature' and the later by 'human being'. Natural change as well as natural cause, she thinks, is something that is "been brought by nature" or "something which happens naturally", while artificial change and artificial cause "have been brought by human beings" (WR to L4 & L5). For example, growth of the seed is said to be a natural change and rain its natural cause. Some more examples of natural cause that she offers are "flood, cyclones". She contrasts the natural and the artificial pretty well, by contrasting the transformation of a seed into the tree with that of a wooden log into a furniture item: "when we sowed the seed, the seed grows into a tree, that is a natural… natural change, but if we take a wood and sowed it, it will not grow into a bench or desk, so this is not a natural change" (IR).

The biological *change* is understood (by S#78) as *development*, and the example of development she immediately thinks of is of human development in the area of education and technology: Change in the biological world "means that the change in the living world, like we have so developed in many

things. There is a development in our day to day life, like we have developed to learn and write and even developed in making artificial things" (WR to L3). Interestingly, not just the human development in these spheres, but the "natural" development of apes to human beings is also a prototype of change for her (IR to C1). The change in giraffes is understood on the same grounds. A notion of "natural change" becomes a focal point in understanding the change in the giraffe. The 'nature' has developed in such a manner that the present day giraffe has a long neck. In her words: change in the giraffe is "brought by nature", and "today's world have so developed that thousand years ago giraffe's neck is shorter than today's world giraffe" (WR to C1).

So, S#78 understands the change as natural, developmental change, where *natural* is understood as something that happens without the mediating agency of human beings or something that is "brought by nature". Now, she thinks it to be *natural* for the giraffe to have a long neck because "nature have given the giraffe the gift of long neck" (WR to C8). Every animal, she thinks, has some such characteristic speciality, "like cheetah can run faster than all animals", "like human beings are having a good brains", giraffes have long necks. For her then, it seems, it is the nature of, or it is natural for, an animal to have a particular defining characteristic. She says that it is difficult to define nature. And by nature she "means rain and all; rain, mountains, they are formed because of the nature, so nature mean something like *God*" (IR; my emphasis). It is "because of nature" that animals or plants have a distinctive special characteristic and it is pretty natural for them to change to come to have this characteristic. She clearly has an essentialist-theistic framework of understanding the specific characteristics and changes in some of them. The change in the L-plant fruit is understood on similar theistic-essentialistic lines: "'L' plants are [having] hairy [fruits] because of the natural change in the world. There are many animals or plants who have changed very much because of the nature" (WR to P).

She accepts the sentences given in J "whole heartedly" (WR to J1). She also thinks that green insects were always green, and the mottled grey ones, always mottled grey. Moreover they will not change their colour, she thinks, even if they begin inhabiting, say, a tree with red-coloured leaves. This static picture in the insect-colour case sounds complementary to her essentialist-theistic understanding. Why then, according to her, does the insect-colour is green? In response to this question, she offers both a non-teleological (and mechanistic, if you wish) as well as teleological explanation. Because she does not believe in the evolutionary change in this case, she doesn't have to think about the change from non-green colour to the green colour. She simply has to explain the existing colour. She does this in two ways: one, she thinks that just like we have the colour we do "because of the pigment in our skin", insects have the colour they do because "they would also have some pigments in their in their skin"; and two, they have green but not any other colour so that "they can hide themselves from their enemies" (IR). The case of aquatic plants is also understood teleologically: "aquatic plants have a waxy coating so that the preparation of food and respiration of plant is done easily" (WR to J1).

In spite of having theistic-essentialist framework of understanding, the student may still clearly recognise the individual variation in the present as well as the past populations (And you may recall from Chapter 1 that recognising individual variation is essential for understanding natural selection). S#78 clearly understands individual variation in the giraffes. Giraffes do not have the same neck-lengths just as "like all the human beings are not having the same face" (IR to C1). She even admits of slight individual differences in the neck-lengths of giraffes living in the remote past. When asked: thousands and thousands of years ago whether all the giraffes were having the same neck lengths or there were differences in their neck lengths? She replied that some giraffes would have had "a little tall neck" than their contemporaries (IR). The possibility of individual variation across generations is also well acknowledged by S#78. But, the sibling-giraffes will have individual variation

in the neck length *only* if their parents have had differing neck- lengths. The offspring's neck-length "depends upon the parents" she thinks, "if one is having long neck and other is having short neck, so their child can also have short or long. But if the parents are having, both are having, the same length of neck then their child will also have the same length of neck" (IR).

4.9 Nature Divinised-II: Living conditions—and God—determine the individual characteristics

In the student's understanding, a change in a characteristic is caused by the living conditions. Living conditions are thought to determine or to transform the individual traits. In this sense, such understanding is no different from the ones discussed in the following sections. S#32, for example, thinks that the resistance to the X-disease depends on health – on "cleanliness… food and all" (IR). Similarly, the colour of the moth is also thought to be determined by the moth's living conditions – moths are transformed by the conditions in which they live. "Due to smoke the tree bark becomes darker and the moths resting on it also become dark coloured" (WR to B1). But, apart from this simple causal relationship between the living conditions and the characteristics of the individuals living therein, the student also has a theistic understanding of 'nature'. 'Nature' and 'God' are synonymous for the student. For S#32, individual similarities and differences "are caused due to nature". When asked what she means by 'nature', she says: "God, God created these". Not all similarities, however, are created by God – colour, for example is God's creation, but the differences in body build-up (thin individuals and fat individuals) is the result of the food individuals eat (IR).

Like S#32, S#33 thinks that the differences and similarities are created by *nature* or *God*: The "similarities and differences are *made* by nature. If nature wishes, she could wish them to have similar[ties], or he could wish them to have differen[ces]" (my emphasis) (WR). Here, "nature means our God; if God wishes he could make them similar or different" (IR). Moreover, the

divinised nature is not the only cause capable of controlling the individual characteristics. Like S#32, for S#33 too, the moth could turn dark due to smoke. A light coloured moth, if exposed to a lot of smoke, can acquire dark colour and all of its offspring will also be dark coloured (WR & IR to B5).

Thus, S#33 thinks that acquired characters are inherited by the following generations. Further, it could be noted that, both S#32 and S#33 think that *all* the offspring of dark coloured moth would be dark in colour and of light coloured moth will be light in colour. For these students, the offspring will *not* vary from each other in a particular trait, if the parents had no variation in that trait.

4.10 Creationism-I: Creative God and clever scientists—increasing population explains increasing number of variants

Like S#32 and S#33, S#35 also thinks of the conditions in which mosquitoes live. The conditions, she thinks, are becoming more and more conducive for the mosquito growth. The number of resistant mosquitoes – which for her are simply big and strong mosquitoes – is increasing simply because the *overall* number of mosquitoes is increasing due to increase in "dirty places … garbage … [leading to their increased] reproduction" (IR). But, when it comes to the general question explaining individual differences, she refers to God, the creator: The reason for differences in size and colour "is that mosquitoes are God's creature. God created them in different kinds and way" (WR to A4). What we do is to study the God's creation: "God created mosquitoes [and] … man find[s] it out [that] it is resistant, it is sensitive etc." (IR). When it is pointed out to her that there are scientists who believe that mosquitoes as well as men are not created by God, but mosquitoes come from microorganisms and man comes from apes (by the process called 'evolution'), she says that she is "not cleaver, scientists are cleaver" and she "believes in both" the accounts.

In line with her answers to A, she thinks that giraffes are created by God, and just like in human beings a mother could give birth to a short child, so could be the case in giraffes – short necked giraffes could be a "birth problem" (WR & IR). S#35 finds no immediate conflict between her creationist explanation and the scientist's view told to her during the course of the interview.

4.11 Creationism-II: Creationist-essentialist understanding

For S#81 a *cause* is that "which affects" or "which creates" (IR). Natural change is the change "which occurs naturally" (WR), that is "it has been created by God not by human beings" (IR). In contrast, artificial change is "caused artificially", by human beings, not "by nature".

She thinks, it is only "*after* these severe storms, drought for many years, now-a-days we see giraffes with longer necks" (WR to C1; my emphasis; also WR to C6). Thus the rare events described in the C are taken to be unusual, perhaps disastrous and certainly forceful to somehow cause the said transformation in the giraffe's neck length. May be because of this strong association between causal power of the disastrous drought and the neck-length, other points in the description are interpreted (by S#81) to have little causal value for the neck-length change. For example, she does *not* relate the survival of tall trees with the eating habits of the giraffes: "During severe storms, winds and droughts… large trees give shelter to… [the giraffes] and survive them" (WR to C1). Further, her thought appears to be essentialist. For her, long neck seems to be essential if one is to be a giraffe: "Yes, I will suggest them to have long necks, because if they are really supposing to become giraffes for a few days… they should do it" (WR to C8).

Consistent with her theistic beliefs, she thinks that leaf eating insects were always green and bark eating insects were always mottled grey (WR to K3). And it was difficult for her to accept that the fruits of L-plant were not hairy in

the ancient time (IR to P). But, she does not deny the possibility of organic change. As we have seen, she admits the giraffe-neck transformation due to droughts. Similarly, when asked, she thinks that green coloured insects become red coloured if they start living on a tree that has red coloured leaves. To begin with, they are green because they eat the green leaves, "if they will eat red leaves then they will become [red]" (IR). Thus, in her understanding, though no (evolutionary) change is postulated in the past, and the cause of natural change is thought to be God, she (unlike S#78 and S#80[62]) does not deny the possibility of transformative change caused by the factors like droughts and food. (You may recall that S#78 and S#80, who also have theistic understanding, deny this possibility).

4.12 Creationism-III: Theistic, physicalist, progressivist conception of change

The student may be creationist in thinking that God causes the organisms to be the way they are and this could even be pretty miraculous, like it is for S#81[63]. But at the same time she may believe that God manipulates the living world only through the material, and *not* through (completely) mental, means. For S#74, the leaf eating insect are green "because they are eating green leaves" and the bark eating insects are grey "because they only eat bark" (IR), and these insects were and will remain of the same colour "because they eat the same things and going on eating it" (WR to K3). Similarly, in the case of giraffes, individual similarities are caused by the similar eating habits. The reason individual giraffes are similar to each other "is that they are herbivorous animals". But, in the first place, the giraffe is herbivorous "because the God has made them like that" (WR to C4). God clearly has a central role in S#74's conception of change. We now see giraffes with much longer neck because, she thinks, "something… some magic must [have]

[62] See the Section 4.8

[63] See the previous section.

happened" during the period of drought. This magic is understood to be mediated by God. *But*, according to S#74, God could not act through pure magic, and droughts are essential if there is to be the change in the giraffe's neck length. The change could *not* have happened without the drought, she thinks, because God "wants some excuse". He does not want us to know that. He is the cause, as "all should not believe in magic". This is because people's (blind) belief in magic may bring harm to them. For example, instead of taking medicines, some people "thinking that magic will happen… don't want their children to go to the doctor" (IR to C1). S#74 seems to think that, for our good, God always acts through some physical cause.

In fact, the notions of "good" and "progress" occur consistently in S#74's explanations and these are even related with science and scientific progress. "Living world" for her is related with "good mind" and progress, and the progress is supposed to be the result of "believing in science" or in "scientific reason". In fact, it seems that for her science and life are strongly related: "science is that from which we are living and [for example] because of science we get medicines" (IR). She writes: "We understand that the world who do not believe in science and just having an orthodox mind are the non-living world. The living world is the opposite of that non-living world. Living world is that which are progressing due to scientific reasons" (WR & IR to L1). This is how, she thinks, life is sustained by science: "because of science the pesticides are invented and because of which the plants can grow nicely" (IR). Even the biological change is understood in terms of progress, and progress is "because the world is living and starting to understand the meaning of science" (WR).

4.13 Creationism-IV: Theistic conception, where individual transformation is caused by the efforts and practice, or by the food

In the preceding section we saw how the student's understanding is grounded in the physical causality, even if her conception is explicitly creationist.

Similar is the case of S#76. She is a creationist in thinking that God is the creator of living entities, and God is pretty powerful for her. But she does *not* explain the change in the giraffe or in the insect by referring to the supernatural cause. She explains these changes as transformations caused either through practice and efforts or because of the food one eats. Let us discuss the details of S#76's conceptions.

S#76 thinks that an earthquake is an example of natural change. For her, "natural change is the change which occurs naturally" (WR). It "occurs [by] itself… for example earthquakes" (IR to L4). And, for her, "natural cause means the cause which causes naturally" (WR to L6). "Like earthquake can take place anytime, so we don't know how it is, it takes [place] naturally and it comes very fast … we are not aware of that" (IR). Here the natural is understood in contrast with the artificial. Artificial change, she thinks, "is the change which does not occur naturally, but it is the change which is made by the man itself" (WR to L5). Fans, for example. If we put "on the fan[s], they give us wind so we can be fresh" (IR). In contrast to natural cause, "artificial cause means the cause which causes artificially. Like bomb blast etc." (WR to L7).

She understands the *natural* in contrast to the *artificial*, but not in contrast to the *supernatural*. For, 'natural' for her means something that is not 'artificial', but it does not exclude the 'supernatural' element. The artificial change is *artificial* when *we* are the cause of the change, when we know the cause. In contrast, the natural change is *natural*. Here, we neither cause the change, nor do we always know that the change is coming. But God does, thinks S#76: "God knows the cause" of all changes in this world and also "has the power" to cause the change. We come to learn about the "power" of God "by seeing the things happening around us naturally, like earthquakes and all" (IR). "The non-living things are mostly made by man", she thinks. Living things, on the

other hand, "are not made by anyone. They are made by God" (WR to L2 & L3).

S#76 uses God's causal powers in understanding the 'making' of living entities. But, to explain the giraffe's long neck and the insect's colour, she uses the typical causal-framework of the (transformative) change via effortful use of a structure and of the transformation in colour caused by the food. In the case of giraffe, she thinks that, during the droughts, giraffes "were not able to eat the leaves for their survival. So it is after severe droughts that the necks of giraffes were very long" (WR to C1). This happened through practice. "They were trying to eat the leaves from the tall trees and they were practicing how to eat… They stretch their necks for catching that [food], so their necks must be growing" (IR to C1). The acquired trait is not immediately inherited to the next generation. The offspring of these giraffes, who have acquired long-necks by stretching, will not have long-necks. The offspring too will have to practice stretching to acquire long-necks. It is only after acquiring the same character again and again in a couple of generations that the trait will be inherited, that is the offspring will have longer necks even without practicing stretching. While the change in giraffe neck is explained as the transformation caused by the neck-stretching exercise, the insects colour is explained by "the food they eat" (WR to K4). The insects were not always green and grey, S#76 thinks, "because it is not necessary… Like human beings [are] with many varieties" they could have been of different colours in the past.

Thus, S#76's understanding of the instances of organic change is *not* theistic. The change in neck-length is grounded in the individual efforts, the insect colour change in food habits, and the L-plant fruit skin change in the changing climate. None of these organic changes are thought to be caused by the God's causal-power. God explains the creation and existence of living beings, not the change in some of its characters. So, the question of future existence of long-necked giraffes is left to the discretion of the God: only "God… knows…

because he only has made them" (WR to C7); but, not the question of the neck-length changes in the giraffe.

Like S#76, S#79 understands God as a cause of natural changes while the change in giraffe's neck is thought to be caused by the individual efforts to eat the leaves from tall trees. But, S#79's understanding is deeply teleological. She clearly construes usefulness of the effect as the cause (of that effect). She thinks that *cause* is understood by "tell[ing] the reason for why it [or something] is caused like that". Her example: "the tree… branches are changed into the desk and benches … because we can make many useful things which are physical but from the [living] trees we can get it" (IR). Her teleological thought is illustrated again when she justifies her acceptance of the statements in J, by referring to the usefulness of the structures in performing the specific functions. She thinks that lack of these structures would mean lack of the function they perform: "I accept these statements" in J, she writes, "because if the birds have heavy weight then they fall on the earth and because of air filled bones… it becomes easy for them to fly" (WR to J1). Similarly, "aquatic plants are having waxy coating on their leaves to protect them", or another possible cause could be that only the waxy coating "helps them for their respiration" (IR to J1). Further, according to her, L-plants now have hairy fruits to protect themselves from the cold and snow (IR to P).

S#79's theistic thought comes forth when she thinks about the natural/artificial distinction. She thinks natural change to be a "change that occur[s] naturally and which are not man made" (WR to L4). Here "naturally means… we can't make it, we get directly from the God" (IR). In contrast artificial changes "do not occur naturally and are man made" (WR to L5). Artificial causes "are not gift of God" (WR to L7). Human being is an example of the 'natural': "they are not made, they are, we are from the God only, we are the gift of God" (IR). But, the change in giraffe's neck is not the God's gift, she thinks. the increase

in neck length is caused by the efforts giraffes put in obtaining the food. "To eat the food the giraffes used to jump and so because of that today we can see giraffes having long neck" (WR to C1). She thinks that "while jumping something must have happened" (IR). Further, "because females can't jump that much", the male's neck lengths would generally be longer than females. She also thinks that the long-necks, thus acquired by jumping, are inherited to the coming generations. The logic behind this is simple – offspring are like their parents: "if the parents' neck is longer, then their children's neck may be longer as how their parents are having"[64] (IR). Similarly, long necked giraffes would be there for thousands of years to come "because of the generations that occurs in them… because of the parents" (WR to C7). And the same reason explains the differences among individuals. But at the same time, she thinks that the offspring will slightly differ from each other and from their parents, in all the cases (IR). The student's experience of individual differences in human beings guides her to this conclusion. The sibling giraffes differ from each other in neck lengths "because when human beings are born some are fat and some are thin. Some are fair and some are dark. Same in the giraffes" (WR to C5).

Though she thinks of change in the giraffe's neck length and sees its cause in the giraffe's efforts in food gathering, for her long necked giraffes have been here on the earth since "there was life on the earth. The reason is that without the life no one could survive"[65] (WR to C6). Similarly, she thinks that green insects were always green. When asked if their colour will change in case they migrate to the trees having red colour leaves, the answer was negative: "the insects will remain of the same colour" (IR). In response to M, she can't think of a possibility of changing an animal or plant so that it becomes even more

[64] Compare this with S#76's conception. She thinks that the long neck is inherited only if acquired again and again over a few generations.

[65] During the interview she says that to begin with the difference between individual neck lengths was not large.

useful for us. She says: “we can’t make something more useful…, we can use many things from [a plant or animal], but we can’t change that… [so that it] become more useful” (IR to M). All these responses, of assuming the existence of present animals and plants and denying the possibility of our ability to make useful changes in them, are not surprising given her belief in God as a cause of living things. Thinking of God as a cause or creator of living beings supports thinking of the long-necked giraffe’s existence since the beginning of life, and all this thought is not (immediately) antithetical to thinking of change in (some of) the giraffe’s neck-length during their efforts to obtain food in the time of crisis.

4.14 Habitat is thought to transform the residing individuals: Plain (i.e. not necessarily adaptive) individual transformation caused by pollutants like DDT, drought conditions, or the food

Change could simply be understood as an individual transformation caused by the conditions in which the individual is living (conditions of life!). S#31 thinks that by living on a dark coloured tree bark, a light coloured moth becomes dark coloured. Thus, as the air pollution is increasing, many more trees become darker and “as a result more dark coloured moths” are found (IR&WR to B3&B4). If a moth which has acquired the dark-colour in its lifetime, reproduces on (and only on) a dark coloured tree, then its offspring will also be dark coloured (IR). Otherwise, light coloured moths will have light coloured offspring and dark coloured moths will have dark coloured offspring (WR to B5). It must be noted that here and in all the transformationist explanations, the focus is not on the being but on becoming – not on the darker *beings*, but on *becoming* darker.

For S#73, the change in the giraffe’s neck length is caused by “horrible [drought] conditions” (IR to C1). “Giraffes had short necks. Because of many dangerous things happened during that time, we find… giraffes with longer

necks" (WR to C1). He however was unable to tell how exactly the "horrible conditions" could have caused the change from the short neck to the long neck. In the case of moths, S#73 offers a simple transformationist explanation. Insects have the colour they do, he thinks, because of the food they eat: "The leaf eating insects are green because they eat green colour leaves and those eating bark are grey because they eat the barks of the trees" (WR to K4). Moreover, he thinks that "they will be of the same colour for many more years because they are eating their particular food" (WR to K4). As we will see below, food becomes the causal-locus for a number of other student's also. The changing conditions are thought to be the cause of change in the case of L-plants by S#73. He thinks that the temperature in which L plants have been growing have changed from hot to cold and hence the plants now have hairy fruits: "Because of the colder winter we find only hairy fruits" (WR & IR to P).

In assigning the causal role to an individual's habitat, the student may focus on reproduction. S#41 thinks that "dark coloured moths are pollution / smoke born" (WR to B4). In her understanding, when moths reproduce in the polluted environments, most of the offspring are dark coloured. They are light in colour if the reproduction is in the 'pure' environments: "When the parent moth lives on [a light coloured] tree bark, they give light coloured moths and when because of pollution the tree barks become dark, they give dark coloured moths" (WR to B5). Yet, it must be noted, the S#41 does recognise the possibility of the individual variation in the moth colour. Offspring of dark coloured moth could "be light coloured also, its not necessary" that it only be dark coloured, and vice versa (IR).

Just as S#41 thinks that the moth's reproduction in smoke rich environment produces dark coloured moths, S#20 thinks that mosquito's reproduction in DDT rich environment "gives rise to… resistant mosquitoes". Resistance, he says, is "because of the reproduction" in DDT rich environments. If a DDT

sensitive mosquito pair is reproducing when DDT is present in their environment, most (but *not* all) of the offspring will be DDT resistant, whereas if the sensitive pair is reproducing in a DDT free environment almost all of their offspring will be sensitive (IR). In the giraffe's case, S#20 relates the droughts with the "coming in" of long-necked giraffes, but with no specific focus on reproduction. Long-necked giraffes are found, he thinks, only since "the severe droughts appeared". Before these droughts there were no long-necked giraffes (IR to C6). But, exactly how he relates droughts with the neck length could not be elicited during the interview. When asked explicitly, he said that he does *not* think that continuous use or stretching of necks by short-necked giraffes to reach leaves of tall trees could lengthen their necks. Though S#20 thinks that DDT could transform sensitive mosquitoes into resistant ones, continuous use of a neck, according to him, cannot transform the giraffe's short neck into long one. Thus, the student may think that the external condition like droughts could be causally effective during the individual's reproduction. But, at the same time, the student could be sceptical to think that the giraffe's stretching of neck to obtain food, for example, could (substantially) change the giraffe's neck length.

Change could also be understood to be caused by various specific *external* factors including quality of food the individual eats. Food, for example, is the sweeping cause in S#25's (Class VII, 12Y 09M) understanding. Amount and quality of food an individual is willing or able to find for oneself determines the amount of growth – and hence the amount of change – in that individual, and its offspring. Individual differences and similarities (including those among the siblings) as well as the given instances of (evolutionary) change are understood by S#25 as instances of individual transformation caused by the kind and amount of food the body gets. For example, in his words, the description given in C, "says that Giraffes in olden years didn't know how to get their food and grow their body. But in recent years giraffes get their food and understand how to get the food and grow [the] body" (WR to C1).

Moreover, the differences in the neck lengths are explained by the differences in what the giraffes get to eat. “What is needed for their height is not there in the body”. And every giraffe does not get to eat what is needed for their neck-height and so all of them “don’t have the same height”. Similarly, if “the giraffe’s mother is not getting proper nutrients like food and proteins” then its neck will be short, but “if the mother is getting all the nutrients then the neck of the giraffes will be big [or long]” (WR & IR to C4 & C5).

S#25 also thinks that the “strengths and weaknesses” of the parents and the conditions in which they are reproducing affect the well-being of the offspring. In the case of mosquitoes, for example, some of them die due to DDT because they are “very weak”. Those “who are very strong don’t die”. “If the mother is not too strong … [and] if [she is reproducing]… at a bad place then [the offspring] will not be too strong” (WR & IR to A4 & A5).

S#19’s understanding is not very different from that of S#25. He understands the individual differences in resistance to the X-disease to be due to physical and mental health and strength gained by eating nutritious food. The food is thought to make people resistant to the disease. Thus X-disease resistant people were there before thousands of years because “people that time were very healthy and strengthy. They were morally plus mentally and bodily powerful”. And, even today, people know this – “they know the importance of eating meat and other things, [they know that it] is necessary” to be resistant, and hence they will be resistant for years to come. Moreover, if some of the animals become human beings, they “would be X-disease resistant because animals are powerful… specially carnivorous animals”. S#19’s understanding of D is not very different from his understanding of B. In the former case food causes the transformation, in the latter smoke-pollution is the cause of light moths’ becoming dark. The increasing number of dark coloured moths is said to be “due to high smoke” content in the air. Once the smoke particles settled

on the tree barks transform the light coloured moth into dark coloured, it can never regain its light colour and all of its offspring would be dark in colour.

The dark colour of the moths could be seen not merely as a consequence, but also as a contributing part, of the increasing pollution. In S#29's overall scheme of understanding, dark coloured moths are harmful and dangerous pollutants and this dark-moth-pollution is increasing because of the increasing smoke pollution. For example she (S#29) writes: "Smoke is harmful for human beings, trees, animals etc. Some times more smoke causes air pollution, water pollution etc. And when pollution of smoke increases, pollution of [dark-coloured] moths also increases. … To avoid more amount of moths, first more amount of air pollution should be avoided… only [in this way harmful dark coloured] moths may [be] avoid[ed]" (WR to B2, B3 & B4).

To understand natural selection of dark-coloured moths, we would expect the student to see that in the given circumstances being dark-coloured is advantageous for the moths in avoiding the predators. But it is clear that S#29 has not recognised this. She seems to think that birds are equally dangerous for all the moths whatever might be their colour: "birds [are] dangerous for all moths -- whether they are dark coloured (harmful) or they are light coloured (not harmful)" (WR to B3). Thus though the individual variation is recognised by the student, this variation is seen to have little consequence in the moth's survival.

4.15 Time, teleological responsiveness of living things, their effortful use of a structure, and factors like food and climatic change, explain adaptive transformation

In the previous section, we saw that for the student organic change could be an individual transformation caused by the changing living conditions, but she may *not* always understand the change to be an *adaptive* change. The student could, however, also understand the change to be not only a transformation,

but also an *adaptive* transformation. In fact, the student often thinks adaptive-response to be a mark of living, but not of non-living, things; it is a part of an individual's responsiveness to the changes in its living conditions. S#77 expresses this understanding in a characteristic manner: "physical or non-living world [or things]… do not correspond to the events in their surroundings… Whereas… biological or living world… correspond to the events in the surroundings" (WR to L1). The so called "correspondence" between the living things and their surroundings, she thinks, is maintained because of the responsiveness of the living things: unlike the non-living world, living "things respond to the surrounding" (IR to L1). We should note that, in S#77's understanding, this so called "correspondence" is *not* caused by the natural selection but by teleological transformation.

Transformation is indeed a prototype of change for most of the students in his study (as well in other studies; see Chapter 2), not just S#77. But S#77 explicitly talks of transformation in both artificial as well as natural cases. By "artificial change", he understands the transformation of non-living things: "non-living things are constantly transformed by man. E.g. – The machines such as computer are transformed by man because of his ability to discover to think to make something new" (WR to L2). His examples of biological change are of behavioural transformations that are thought to be caused by "scientific attitude", or of structural transformations that are thought to be caused by changing climatic conditions. The example of the former is man's "changing behaviour… [and] a way of living": "in the stone age period, the man was living in a cave. Afterwards because of the increase in his scientific attitude, he discovered fire, wheel and other such useful things that play an important role in our today's life" (WR to L3). The examples of the latter are the changes in the length or size of animal structures like teeth; "At first animals like elephants have long tusks, but at present it has… tusks measuring [only] 1.5 m to 2m in length because of the climatic change" (WR to L3).

As I have already mentioned, the transformation is understood by S#77 as teleological or adaptive transformation. The sentences in J, for example, receive teleological explanations – explanations where the existence of a structure is explained by pointing to its necessity for the organism in performing some vital function. "Plants have waxy coating on their leaves because if it would have not been there, the plant will drown in the water. As everybody knows wax floats over water"[66] (WR to J1). Similarly, "tortoise has a shell for its defence" (WR to J3). The explanation of insect colour (in K) is given on similar grounds. The colour of the leaf eating insects is green "so that while they are eating [their] food the enemy cannot find them". The leaf eating insects could afford this protection "because they have the ability to camouflage themselves" (WR to K1). S#77 thinks of this of this ability as "adaptation". He takes the colour of barks to be brown, and hence thinks that, unlike the leaf eating insects, the bark eating insects are *not* capable to have the adaptive colour: "mottled grey coloured insects are not able to change [their colour as per that of their surrounding]; they are not able to adapt themselves to the barks of the trees, that's why they are mottled grey" (IR to K1). The colour-adaptation is understood not only in terms of the ability to adapt. The adaptive transformation in the colour of the insects is thought to be caused by the food they eat: The leaf eating insects were not always green, they became green "because slowly the chlorophyll in the leaves started entering their body"[67] (IR).

S#77 cites two causes of change in the giraffe neck length. The first one is simply "time, period of time" (IR). Apparently, he thinks that so much time has passed that the changes like the one under discussion are to be expected. The second cause that he talks about is stretching of the necks while eating the

[66] Note that the explanation in the case of waxy coating is justified by referring to an everyday observation – that wax floats on water.

[67] Do these insects know that their colour is changing? "If they are vertebrates they can understand, but if they are invertebrates it is impossible" and so, he concludes, the insects are not aware of the adaptive change (IR).

leaves from tall trees: “trees are also growing much more longer and they have to stretch their necks and this also causes sometimes their necks to get longer” (IR). He also thinks that the characters acquired by the stretching will be inherited to the following generations.

The change in L plants, like the one in the case of giraffes, is partly understood by referring to the passage of time. His general perception seems to be that “as the time goes living things start changing themselves” (WR to P). The prototype of this change-with-time is of the change from ancient to modern man: “first man was eating only fruits, bulbs and roots. But now he started eating vegetables; he started cooking, because of his scientific progress… and other minerals are also discovered such as oil, which helped him in producing fire, rather than making trees as the fuel of fire” (IR to P). But time is not the only explanatory element in his narrative. In the case of giraffes, with time, stretching explains the increased neck-length. Here, in the case of L-plants changing climatic conditions cause the change in the fruit skin. The climate becomes colder and causes the fruit to *adapt* by developing the hairy skin: “first Sahyadri mountains were not as high as they [are] today and there were only few mountains. But because of the pressure exerted inside, the earth crust made forming of many more mountains in the Sahyadris. And so first it was a very hot climate in Sahyadris, but now because of the hilly region clouds stay over there… and so to adapt itself the plant has hairy skin” (IR to P).

4.16 Transformation of the “old” into the “new”: The (quality of) available food and the amount of genetic factor determine the individual differences

S#38 thinks that all the giraffes that were in existence in the distant past “have gone [died] completely… because of the drought … [and] now they are completely new”. When asked from where these new giraffes have come into existence, she says: that exactly is “the question in [her] mind”; and the

possible answer to it is that, "it may be genetic factor… [that] caused [the] height; … tall necked giraffes [are tall necked] because of the genetic factors, [they have more genetic factors], past giraffes do not have more genetic factor" (IR). Thus, the 'tall' necked giraffes are tall necked because they have greater *amount* of neck length causing genetic factors.

Even if S#38's explanation is non-teleological, completely physical and genetic, it is not very different from the student who bases her understanding of the neck-length variation on the food giraffes eat. This is because, S#38 also relates the amount of genetic factor to the type of nutrition the giraffe gets. She thinks that during droughts, giraffes "must have… [migrated or] gone to another place because of climatic conditions … As the climatic conditions change, the vegetation will [also] change, [and] the new vegetation will have [a different] nutritious [value]. Because of that reason … all [the giraffes migrated to this new place] must be today's [long-necked] giraffes". The neck-length of a giraffes depends entirely on the amount of genetic factor it has; but nonetheless, this giraffe can acquire a long-neck during its lifetime by feeding on appropriately nutritious vegetation. The acquired character of long-neck is, however, not necessarily inherited to the following generations. The offspring of this giraffe, which has thus acquired a long-neck, could both be long necked and short necked "because some [of them] will have more and some will have less [of] the genetic factor" (IR). Along with the amount of genetic factor, the offspring neck length is also thought to be dependent on "the care taken by the parents… [and] the presence of hormones" (WR to C5).

DDT resistance of mosquitoes, S#38 thinks, also depends on the "genetic factors present in them" (WR to C5). Moreover, she thinks that a DDT sensitive mosquito cannot become DDT resistant due to the exposure to DDT. But, just as in giraffes the neck-length is related with the food, in mosquitoes the DDT resistance is related with the DDT. Interestingly, S#38 thinks that DDT "is not harmful for resistant mosquitoes" and it must be responsible "for

the growth of resistant mosquitoes" (IR). She sticks to this answer even when it was reminded to her that DDT is an insecticide and is supposed to be harmful for the mosquitoes.

4.17 Simple evolutionary world view-I: Change is because of evolution

The students may understand change as a consequence of evolution. Evolution is thought to be a common phenomenon, told to us by scientists. But the student may talk little about the causes of evolution. S#83 thinks that living things "can respond… reproduce… respire" and "scientists… believe" that "first, the living things… had evolved in water" (WR & IR to L1). The living things, he thinks, "have evolved from unicellular protozoa". And, seconding scientists, he thinks that there "were only microorganisms, first" (IR). Unlike some students (S#32, S#33, S#78, S#80), he does *not* divinise 'nature', but thinks of it as 'surrounding' in which things evolve. Some physical things, for example, "are made by nature like stone… sand"; for S#83 not *all* physical things are made by man. Here, by nature he understands the "surrounding", "they are made by surrounding", that "means they are evolved… they are formed" (IR).

We saw that while thinking about the characteristics of living beings, he mentions *biological* evolution in some detail, but while thinking about the change the living world, his thoughts are primarily focused on what could broadly be called as *cultural* human evolution: "first… human beings were living in caves and they were eating raw animals… Now they know how to cook and they have built many buildings and towns. First they use barks of trees for their clothes, now they use cotton or any type of cloth. So this change has been taken by biological world". The cause of this change is: "[is] able to think about all [this]" (IR). When asked to think about changes *in* the living beings, he talks about the change from apes to human beings: "first they were not talking, now they can talk; first they were apes, now they had been

evolved in man" (IR). "Evolution" is understood as the cause of this change: "first they were apes, then they became Homo erectus, then Homo sapiens, then Cro-magnons man" (IR). Thus, two different descriptions of the same process – the process of human evolution – one more specific (acquisition of language) and one more general (Homo erectus to Homo sapiens), are understood such that one becomes the cause of another (Human evolution explains the language acquisition). In the case of giraffes too, 'evolution' is cited as a cause of change in the giraffe's neck length: "because of evolution now giraffes have long neck" (WR to C4). In the case of insects too, he entertains the possibility of evolution and thinks that the insects "will not remain same, their colour will change" (WR to K3). This is because "in future they can evolve" (IR).

In S#83's conception, evolution occupies a central position. He, however, could not think about the *how* of evolution in any of the discussed cases. He could not think, for example, how the insects would evolve or change in future. Like a number of other students being discussed here, his causal explanations refer to the transformative action of food or climatic conditions. He explains the existing colour of the insects by referring to the food to they eat. Pigments present in the leaves and bark are thought to affect the insects (WR to K4 & IR). Just as food explains the insect colour, climatic conditions explain the hairy L-plant fruit. The change in the L-plant fruits is "because of climatic effect on them … their environment change[ed], so they have became hairy" (IR).

4.18 Focus on the behavioural-I (with little reference to the physical)

The student focuses on behavioural similarities and differences, with little discussion of the physical characteristics. S#30 writes only about the behavioural similarities and differences, like those in people's "choice" and in "their behaviour". The reason for these differences is said to be the particular

instances of behavioural differences that are observed by her in their "choices of colour, clothes etc." (WR to D3 & D4) and also in the way they talk; some of the people are "very polite' while some could be "talking very harshly" (IR). Apart from the focus on behavioural characteristics, note that the generalisation that people's behaviours are different is 'explained' in terms of particular instances, like different people like different colours and different clothes; or some of them are more afraid of talking harshly than others. When it comes to characteristics like disease resistance, she thinks that "it depends on the parents". She, however, thinks that offspring will *not* vary in a particular trait unless the parents have variation in that trait. Thus, if both the parents are sensitive to the X-disease, then *all* the children will be sensitive; and similarly, if both the parents are resistant, then all the children will be resistant (IR).

S#30's understanding of the moth-description (given in B) is not very different. In the case of moths too, she thinks that offspring will be like their parents, unless they behave differently; unless they get attracted towards smoke, for example. So, all the moths living in an area without any smoke-pollution (in jungle, for example) will be light in colour. In cities too, if the parents are light in colour, their offspring will also be light in colour unless the young ones get "attracted towards the smoke" and become dark. The offspring of these moths, which have acquired the dark colour during their lifetime, "will be light in colour. [*But*] it can happen that some [of them] may be dark in colour" (IR). Thus, for her the characteristics of an individual are mostly dependent on their parents, and a particular behaviour of an individual in particular condition may transform the individual and the transformed character could be inherited by some of the offspring.

Like S#30, S#40's understanding (S#40-VII, 12Y) is also focused on the behavioural aspects of the individuals and he also attributes causal-significance to them. He understands the situation D, in terms of knowledge of

'right' and 'wrong' acts and its consequences: "There are differences and similarities between persons because they don't know what is right or what is wrong. That is why they act like a mad. [A]nd [those] who know what is right and what is wrong, they don't act like a mad person… There are children "who don't listen to their parents and do whatever they like to do. Sometimes the children may play at a bad place and [this] causes [them to be] X-disease sensitive" (WR to D4 & D5). The theme of the knowledge of right and wrong, that causes right and wrong acts, which have comparable consequences, continues through the rest of his answers. He says that "thousands of years ago there were no schools" and "people… [were] unknowledged [not knowledgeable]"; but now situation has changed, "now the persons are knowledge [knowledgeable] and they also know what is right and what is wrong and they do all the right things" and hence they will be disease resistant (WR & IR to D6 & D7). In fact, the theme of the knowledge of right and wrong dominates S#40's thinking so much that he begins confusing the *existence* of things and events with our *knowledge* of them. For he thinks that one cannot *be* disease resistant without having the necessary *knowledge*: we [do] not suggest that there is X-disease resistance in animals because there is a difference between animals and human beings. God had not given brain to animals to know what is right or what is wrong and they do what they want to do" (WR to D8). In the case of moths, S#40 seems to take increasing number of dark colour moths to be a function of the increase in the total number of moths (both dark and light).

4.19 Summary and conclusions

In chapter one, we discussed how the individual variation[68] is necessary for natural selection. The student with a static (non-evolutionary) understanding recognises the individual variation. But this variation is of little causal significance in her explanations. For this student animals and plants fall in

[68] That is variation in the various characters that individuals of a population posses.

different *kinds*, and she sees neither a necessity nor a possibility of imputing any significant change (across generations) in these kinds. The impossibility of the change across generations could chiefly be because of the student's essentialist commitments. She thinks that the reproduction is true to its kind. For her, it's insensible to even suppose that an animal or a plant could reproduce something significantly distinct from its own kind. Rather than change, reproduction is perhaps seen by the student as a means of maintaining continuity and stability.

Evolutionary change is *not* impossible for all the students. A student may take the evolutionary change to be possible, and even "natural". In fact, the change is considered as a normal (i.e. routine) part of the natural world and the natural things, and its understanding needs no further explanation – no further cause – in the student's thought. Ape to human evolution is prototypical example of this change, and the change is often an adjustment with the prevailing natural conditions. All the organic change is, however, not always viewed as natural and normal. It seems that sometimes only an adaptive change or an adaptive character is viewed as normal and natural. For example, DDT resistance or long neck is thought as normal. Whenever the reproduction and development leads to such adaptive characters, it is a normal and natural individual change. The variation in these normal characteristics is of course possible, but is understood as *ab*normal. It is thought to result from *ab*normal reproduction or from *ab*normal development. The student may think that the variation from the normal and the natural is an inborn defect or is caused by abnormal/inadequate nutrition. The theme of understanding individual differences as deviations from the normal continues when the student understands the cause of organic change[69] to be in the defective internal workings of the body or in the hormones present in the body. In all these cases, the cause is *internal* to the

[69] Organic change here encompasses both the individual (ontogenic) as well as evolutionary (phylogenic) change. As we could see, the student rarely distinguishes between the individual change and the evolutionary change.

individual and the variation is variation from the normal. It is always thought as unnatural deviation or defect and hence it is *necessarily non*-adaptive. The student is aware of the individual variation in such cases, but for her the variation is always non-adaptive, and hence it will be of little casual value when it comes to understanding the change by natural selection.

We saw how, for the student, the cause of change is physical and internal to the individual. For her, the cause of change could as well be non-physical and external. For example, the individual's conscious efforts to develop a body structure for survival, could explain an adaptive change; or, some external agency, often understood to be divine "nature", causes the change. In the latter case, the student is *agenciating* and *divinising* the nature; for her, the "natural", the "nature's", and the "God's" are synonymous. In natural selection, you may recall (see the Sections 1.4 and 1.5), the natural is defined by *contrasting* it with the artificial and it is neither agenciated nor divinised. The student, defines the "natural" by *analogising* it with the "aritifical", and in the process agenciates the nature: just as the artificial is caused by the "human being", the natural is caused by the "nature". In fact, the meaning of nature and natural is sometimes so conflated and compounded in the student's understanding (e.g. S#78) that, she may at once understand it as natural development (again in analogy with the human development), the changes brought by 'nature', changes brought by natural forces like floods, or the God given specific adaptive characteristics. The student with such nuanced understanding of natural often subscribes to a static world view in which, for example, the green insects were always green. The student with the static-essentialist picture (and almost all other students studied in this work), however, has a (more or less) detailed appreciation of the individual variation both within and across generations. Moreover, it must be noted that not all the instances are explained by referring to the divinised-agenciated-nature. The 'nature' is not called in, for example, to explain the characters like health and body-built; such characters are easily explained by referring to the individual's

living conditions and nutrition. Sometimes even the moth colour is explained by the moth's living conditions. As mentioned, the student may have appreciation and recognition of the individual variation, but the variation she thinks of is not always physical variation. The student could have her focus entirely on the behavioural variation.

Apart from divinising nature, the student may think about another non-physical cause: the supernatural causal agency, God. The theistic student thinks that God is the creator of the natural (living) world and hence, unlike human beings, "knows" about *all* the natural causes. Like the students who divinise nature, the theistic student, along with her supernatural creative cause, also thinks that living conditions affect the individual and could transform it accordingly. Indeed, the student may even think that the God acts generally via physical causes and these physical causes could transform the individual according to its necessities. Thus, God explains the creation and existence of the living beings, but not the change in some of its characteristics[70]. Theistic student understands the natural by distinguishing it from the artificial, but for her the natural does *not* exclude the supernatural. Moreover, she may not only think that the immediate cause of individual transformation is physical, she may even appreciate the scientific progress and the views of practicing scientists.

The student's understanding of the organic change could also be based completely on the physical causes (without any supernatural causal elements). The student may, for example, think that the external conditions could transform the individual living therein (e.g., cold transforms the L-fruit skin from smooth to hairy). The action of external conditions is thought be

[70] But, the student may sometimes deny the possibility of evolutionary change in the past.

particularly effective during the reproduction. For example, reproduction in DDT rich environment produces DDT resistant mosquitoes. Here the student also allows for the possibility for individual variation across generation. Thus, not all the mosquitoes reproduced in the DDT rich environment will be DDT resistant. However, the student does *not* seem to recognise potential advantage of a variation for the variant's survival (e.g. S#29). And, when the student *does* recognise this, she often thinks teleology; she thinks that the living beings (and only the living beings) could be responsive to their conditions of life and could transform themselves in accordance with their living conditions. The teleological transformation is indeed paradigmatic to the student. The student thinks that living things generally have the *ability* to adapt to the existing conditions and they generally change with time. Compared to the student who has a static view of the biological world, for this student, the change-with-time is intrinsic to the living entities and is one of the chief explanatory elements in her understanding. Sometimes the evolutionary change may even occupy a central position in the student's understanding, where the student may think of life evolving from simple organisms in water, but without any idea of *how* of the evolution.

It is possible, it seems, that the even without the formal school instruction in evolution, the student may refer to the genetic factors in their explanation of evolutionary change (e.g. S#38). The student here thinks that the long neck giraffe is a completely new (type) of giraffe and this transition from the "old" to the "new" could perhaps be explained only by referring to the corresponding change at the genetic level. Interestingly, the (class VII) student does *not* think about the qualitative change at the genetic level. For her, the said change is a *quantitative* change, where the amount of genetic factor determines the difference (of the kind). This reference to the genetic factor as a cause of change is not an indication that here the student's explanation is fundamentally different from other class VII students. For, the amount of genetic factor is further determined by the quality of food available to the

individual. The ultimate explanatory factor is thus the food, which is pretty common among the Class VII students.

Finally, a note on the student's conception of inheritance of the acquired character: the concepts of acquisition of a characteristic within one's lifetime and the concept of inheritance of this acquired characteristic to the following generation, do not necessarily go together in the student's thought. That is, the student may think that the character is acquired by an individual through various means, but she may *not always* think it could be inherited by the following generations. Moreover, the cause of acquisition of a characteristic does not necessarily determine whether or not the characteristic is to be inherited. For example, some students may think that, when a characteristic is acquired via conscious self-development (e.g., S#26) it is not inherited, and when it is acquired due to the effect of living conditions it is (S#33); while some others may think that the characters acquired due to the effects of living conditions are not necessarily inherited (e.g. S#20; also see the following chapters).

Before closing this chapter it must be noted that the Class VII student studied here had no formal instruction in the science of organic evolution. Hence, the causal-explanatory understanding discussed in present chapter is the understanding the student brings in when she begins learning the science of organic evolution.

5 Causal Structure of the Student's Explanatory Narrative of Evolutionary Change: Class IX, X and XI

In the last chapter we studied the student's understanding of Class VII students. In this chapter we will discuss the understanding of Class IX, X and XI students. Class IX and X students had studied organic adaptation, natural selection and evidences for the theory of natural selection in their Class VIII, and again various instances of organic adaptation in their Class IX. These students come from a school which follows the state (education) board curriculum. The Class XI students studied in this work come from a school that follows the national (education) board syllabus. There is not much difference between the *extents* of content studied in these two curricular systems (the state generally models its curriculum on the national curriculum). But, whereas Class IX and X students have studied natural selection once, Class XI students have studied it twice, for they revisit the topic again in Class XI curriculum.

The spectrum of these students' understanding falls across the following causal-explanatory frameworks.

5.1 Impossibility of the evolutionary change-III: Insensibility of the how of large scale evolutionary changes

We have discussed how S#18 and S#28 find it *im*possible to think *about* the evolutionary change[71]. S#28 thinks that the evolutionary change is impossible because of her essentialist understanding. S#49 is not an essentialist. In fact, at one point, she (indirectly) thinks about the possibility of ape to human evolution: "According to me", she writes, "a human being cannot be a giraffe. It can become an ape or a monkey because they are our ancestors" (WR to C8;

[71] See the Sections 4.2 & 4.3.

emphasis in original). S#49's impossibility stems from her difficulty to imagine *how* evolutionary transformation could actually happen, if at all. It is insensible for her, for example, to think that the evolutionary change in the giraffe neck-length could be caused by extensive exercise of the neck: "If a human become a giraffe it will have short neck because humans have a short neck and if you stretch it anyhow, it can not become long. If it is stretched the animal will die due to the pain caused by stretching" (WR to C8). She also doubts whether droughts can cause the increase in the giraffe's neck length: "how can because of drought the short necked giraffe have turned into long necked giraffe?" (WR to C6). Since, to her, such possibilities that could cause the evolutionary change seem almost impossible, she thinks that giraffes have always been as they are now – long necked: she does "not think [that] they were short necked" (WR and IR to C6).

S#49 recognises the slight individual differences in the case of both giraffes and mosquitoes (WR to C4 and A5). She also traces the individual differences and similarities to the parents and is aware that individual characters are dependent on the genes that one has inherited. For example, differences in giraffes "are because the genes of their parent might be different from others" (WR to C4). Moreover, "some of the children will get the genes of his mother… or [some will get the genes from] both [the father and the mother]" (WR to C5). Thus, S#49 not only has an idea of individual variation and its genetic basis, but also does *not* think in terms of change-by-transformative action of habits and habitats. Due to these reasons one can expect that S#49 may find it easier to understand the idea of evolutionary change by natural selection.

Before we close the discussion of S#49's understanding, I must mention how she confuses between what we can call an epistemological issue and an ontological issue. It is an indication that such confusions could be antithetical to the understanding of evolution. S#49 thinks that it is only "after the use of

DDT on them [i.e. on mosquitoes], they have *proved* to be DDT resistant or sensitive" (WR to A6; my emphasis), and hence since DDT was not there thousands of years ago, there was no question of the existence of DDT resistant mosquitoes at that time. This could be considered as a case of confusion between what we have come to know (epistemology) and what has been in existence (ontology). Since we came to know of DDT resistance in the mosquitoes only after the use of DDT, the student mistakenly thinks that DDT resistant mosquitoes must have come into existence only after the discovery of DDT. This confusion between an epistemological claim and an ontological claim should however be distinguished from another commonly found conception – a conception where students think that DDT resistance is somehow caused by DDT (in both the cases the student will think that DDT resistant mosquitoes are found only *after* the DDT use had begun).

5.2 Creationism-V: Evolution? Nonsense!

S#08 explicitly talks about her beliefs and, in light of these, finds the theory of evolution completely nonsensical: "Though it is believed that thousands of years ago, giraffes had much shorter necks, I do not believe such NONSENSE. I do not believe the theory of evolution itself. I consider the facts written in the HOLY BIBLE as true and follow them. Hence it is difficult for me to believe that giraffes may have existed that had shorter necks and that now they have longer necks" (S#8-XI, 16Y; WR to C1; all emphasis in original). The student asks: "How can *a* giraffe's neck that has been short, after a period of time increase in length? OR How does a *whole* species of giraffe undergo changes when man himself is not undergoing many changes?" (S#8, WR to C2; my emphasis). Note the assumptions in her questions. First, she thinks that *a* giraffe undergoes the neck-length change. And second, the *whole* species changes at a time, not some individuals of a species.

She acknowledges that offspring may vary from each other, but within limits. For her, individual variation does not exist necessarily, but is just a common, well known and inconsequential phenomenon: "[In a single family] some [of the sibling giraffes] may be long necked and some may be short necked… In humans also, some are tall and some are short, so why can't this happen, it may happen but *not necessarily*… Even in giraffes also that some kind of range will be there, not very short necked giraffes will be there and not very high necked" (WR to C5; my emphasis). When asked specifically if continuous use of neck could lead to the increase in the giraffe's neck length, she says: "why don't we become taller if we do such things, if I go and do some pull ups, I don't think I will grow taller than how I am" (IR).

She thinks that giraffes have long necks "since when they have been created". And hence, she says: "I do not accept any other explanation" (WR to C6 & C7). Indeed, for her, it's "obvious… [that] they have been created like that" (IR). She says that she believes in the genesis chapter of bible but partly, and also in the theory of evolution but partly or marginally. For example she doesn't believe in the "seven day procedure", she does not believe that the God created everything in seven days, "God can create everything in one day or one moment". The bible was written "by people or the sages or whatever. They have been thinking, reflecting and then writing it, based on the experiences or revelations given to them by God… somehow given to them. So may be… they have been writing it partly right or partly wrong. I don't think fully wrong, it won't be [fully wrong], and nor… it be fully right" (IR). She "feel[s] that that God must have created each and everything according to its importance", and "think[s] that man was created on the sixth day or the last of all the [days]... that must have been true" (IR). Here, according to her, the account in the Bible coincides with the theory of evolution: "when you say man was evolved last… it is somewhat coinciding with the Bible". Another coincidence is that both the Bible and the theory of evolution claim that everything had begun and developed from the water. So may be, she

continues, “Darwin got his theory from them [the Bible]”, as Bible was written much before Darwin was born (IR). When asked why she considers what is written in the Bible as “facts” (as she wrote in response to B1), she said: “may be because… my mother was a staunch Christian and… she had brought me up [on] these values. May be like that. Or may be I am wrong and you are right, may be. [But] most probably I will be right. … Actually I believe that God is existing and he is he is creating these things. Because of my experience with, what you say, relationship with God or something like that, you can say. … From childhood I have been taught like this” (IR).

She does not accept the change in the neck length of giraffes, but thinks that “the facts of the mosquitoes becoming DDT-resistant [and] increasing [in number] can be true and proved”. Indeed, she writes, “this case is similar to how human beings become disease resistant. Human beings over the years have acquired resistance to many diseases… e.g. A man/woman who has contracted chicken pox in his/her childhood will now be able to resist bigger forms similar diseases like small pox and measles”. This difference in acceptability of change in the case giraffes and change in the case of mosquitoes could be attributed to the differences in the ways these two situations are described and understood. The neck length change in the giraffes was viewed as evolutionary change – a change from ancestral short-necked giraffes to the present long-necked giraffes. In contrast the DDT-resistance in mosquitoes is taken as a case of individual change, not evolutionary change, and it is accepted to be true by analogy to the common human experiences of ‘acquiring’ disease resistance.

5.3 Creationism-VI: Genes & God; God is the ultimate cause—Activation of the existing genes caused by the 'desire', and 'trying' to accomplish the desired end, is the proximate cause

S#01 refuses to *believe* that the ancient giraffes were short necked. Her theistic commitments compel her to claim that the long necked giraffes have been always present on the earth; and if evidence from the past presents a picture of the past with only short necked giraffes, it is a problem with the evidence, not with her belief. She asks: "On what basis it is believed that the giraffes found thousands of years ago had small neck? It is possible that thousands of years ago there existed both giraffes with small neck and long neck. May be the proof we have got is of the existence of giraffes with only small neck" (WR to C2). S#01's creationist commitments get modern renderings. God must ultimately be the cause of the characters living beings have. But the God is not conceived as the *direct* cause of the existing adaptive characters, the cause is thought to be an activation of existing genes. This is well illustrated in S#01's C6 response: "Suppose a person has a gene to become tall, it is not necessary that he will become tall, unless and until he gets a proper environment or situation. Gene will not be active till the external situations also become favourable. Therefore, may be the giraffes with shorter neck also had a gene but the environment was not proper to make it active. But when the environment became favorable and the giraffes tried to acquire the leaves of tall trees, evolution took place. Their neck became long. So it is since the time when giraffes themselves had a desire to eat the leaves of tall trees and also when the environment became favourable, they had long neck" (WR to C6). Note the genes are already there (perhaps since the divine creation of the animal), but not the corresponding character as these genes are not active. Evolutionary adaptive change, for S#01, consists in the activation or expression of the existing genic[72]-potential. The gene-activation is caused by

[72] I use genic in a simple and general sense of "of or relating to genes".

the change in environmental conditions *and* the related desire and efforts of the organisms. In the case of giraffe, only tall tress survived and the giraffes (which already had a gene for long neck) "were like forced to take leaves from there for eating, then tried try to elongate their necks and hence it became long". When asked what this "trying to elongate" does, she said "they tried, it was a desire". She was then asked: "desire, ok so that desire can change their genes?", her reply was interesting, according to her the desire does not *change* the gene, but just *activates* it: "it activated the genes which were present…", and this happens "over a period of time", or "may be" in the same generation (When asked, can the elongation of neck happen in the same generation, the answer was "may be"). All the offspring of these (acquired) long neck giraffes will also have long necks according to this student. It is worth noting that though the character is acquired through environment induced desire and subsequent trying to fulfil it, this desire and trying accomplishes the elongation through the activation of the existing gene, and since the active gene is already present, it is not surprising that the trait is passed on to the next generation.

Unsurprisingly, S#01 shows inklings of essentialist thinking. The individual differences are due the differential activation of the existing genes, but the similarities often are the essential characteristics of the species – in S#01's terms the similarities are the "characteristic features" of the giraffes. Each species is said to have a number of characteristic features, features that are common to all the individuals of a species. Thus, two individual giraffes are similar (each one has four legs, for example), because these similarities are "characteristic features" of giraffes and these characteristic features, it seems, are caused by similar eating habits and similar use of organs. The differences are attributed to the "different genes", but the expression of these, specially those controlling adaptive traits, depends on whether or not the genes "get the favourable situation where [they] can exhibit" the adaptive trait they control.

The differences are also caused by the process of crossing over during meiosis (WR & IR to C4 & C5).

5.4 Creationism-VII: Genes and God; genes themselves are strong/weak, or they are transformed due to the external physical factor, like smoke

Again, a discussion of a static essentialist worldview, now of S#06, in which various species are created by God. Our body, for example, "is God gifted" (WR to D3). Each species is different from all the others so that each one has its own identity – that is the reason we could call a dog 'dog' and a man 'man': "to distinguish them, means this is a dog and this is a man, to distinguish them, God has created this" (IR). "If all look same then no one will ever be able to distinguish [one individual from the other]… So differences [are] necessary" (WR to D4). Similarity among the individuals, for example human beings, is because "they are all human beings and belong to same species" (WR to D4).

This student thinks that individual characters are controlled by genes that we inherit from our ancestors and that they generally do not undergo any changes. She also recognises the variation among offspring in each generation. Offspring differ from each other. Even if both the parents are sensitive, or both are resistant, to the X-virus attack, among their offspring some could be sensitive and some resistant. The sensitivity or resistance depends on the genes that each of them gets from their ancestors. Though both the parents are sensitive, some of their ancestor could have been resistant and that brings in the individual variation in each of the generations. "Genes are present in the body and our body functions because of genes" (IR). Resistant children "will have more power to fight against virus. Their genes [have] got the power of fight and [thus] their body [has] got more immunity". [Some children] are X-disease sensitive because may be these children are weak and their immune power is less" (WR; emphasis in original). These children are said to have

genes that are "not so strong to fight". Moreover, X-disease sensitive people become X-disease resistant if living in an area full of X –viruses, because "they have got attacked by this X-virus so many times, so their body [gets] use[d] to that attack, so they will be resistant after so many attacks". We may think that since, for S#06, genes themselves weak or strong, this acquired disease resistance will be hereditary, but it not the case always. If both the parents have this acquired resistance to the disease, it is "not necessary" that *all* their children will also be resistant. This is "because earlier… [the parents] were sensitive and after [X-virus'] attacking so may times they [have] become resistant, so some [of their children] will be sensitive and some will be resistant" (IR).

In the case of moths too, genes are supposed to get affected by the smoke, transforming the moth colour. According to S#6, when the moths "come in contact with [the] smoke … their genes will be affected by the smoke". If both the parents have the "affected" genes[73], then *all* the offspring should be dark coloured. But, just like in D, this is not the case in moths too because dark coloured moths, before "become[ing] dark in colour because of the smoke. So before that they were light in colour. So if they give birth to the [offspring] some will be dark [in colour], some will be light because before [becoming dark] they were light … [Only] after [being] affect[ed] by the smoke, they become dark" (IR).

We may expect that the student who appreciates variation and its genetic roots will also have an appreciation of an evolutionary worldview. However, this appreciation is not enough to see the world with an evolutionary framework. For example, here S#6 has a gene-centred conception, but for her, the genes are labile; the genes themselves are either powerful or powerless and they are directly affected (e.g. by the smoke). Thus the organic change, even if genetic,

[73] This student was aware of the idea that genes determine the characters and they are transferred from the parents to the offspring

is not stable enough to be preserved across generation and result into the genetic change. For evolution to be possible (from whatever cause it may be), the individuals have to vary and the variation has to be inherited across numerous generations.

5.5 Creationism-VIII: Theistic-essentialist teleological transformative action

It should be clear from the Chapter one that (among other things), a fair understanding of the distinction between the artificial and the natural, recognising individual variation within as well as across generations and questioning the possibility of inheritance of acquired characters, are potentially fruitful for understanding the idea of natural selection. S#63 understands the artificial/natural distinction, variation and inheritance in a way that could be potentially useful for understanding natural selection. Her understanding of the natural/artificial distinction is what would be ideal for understanding the distinction between the artificial and natural selection. It contains both the defining distinctions: autonomy/dependence and man/non-man: for her, "a 'natural change' is a change brought about naturally due to the various natural factors and changes. It is not done by man but a change that takes place on itself and continues. 'Artificial change' is a change which is done due to various techniques. It is not natural and hence does not take place on its own. It is artificially done to make something possible" (WR to L4 & L5). She also recognises the individual variation very well. For, she writes: the given "description describes about giraffes. It explains that of all the human beings or animals born on earth, no one is similar to each other and has various differences" (WR to C1). This is a very significant interpretation of the given passage because she not only zeros on the individual variation but generalizes it to be a statement concerning all kinds of animals, inclusive of human beings. Moreover, she not only recognises the individual variation within the generation, but also thinks about the variation across generation,

and has an idea of gene based inheritance. For her, among the giraffe offspring "some can be short necked… [and some] long necked depending on the type of genes he has got. It is not always that all animals have same length or height" (WR to C5). Nevertheless, S#63's understanding is theistic—teleological—transformationist.

S#63 thinks that the individual similarities could be natural or God given, but the individual differences could be explained *without* referring to the divine agency: "The similarities are due to nature or are readily given to them by the God and one cannot bring about a change in it. Differences are due to the conditions existing around it and the way the animal tackles it and their capacity" (WR to C4). During the interview, she clarifies that, not all similarities are God given: only "some of the similarities are given" by God and some by nature. Nature for her is "surroundings, which is created by God" (IR). She also adds that differences depend on the "type of genes" (IR).

Her overall thought is primarily teleological. She thinks that the physical world "is a world which has no human characteristic, no feeling". It exists for "some reason or other". Biological world, in contrast, is: "active", full of feelings, "living" things and "expressions" (WR to L1). Further, for her, "natural cause means a natural reason due to which the cause is done. It is naturally done for some true purpose and for a good purpose" (WR to L6). "It brings about a good change which is beneficial to all … [For example] the growth of trees… is beneficial to us … [Whereas the trees growing in jungles are] maintaining the environmental conditions… the ecological balance" (IR). S#63's explanation of the giraffe long necks, bird bones and aquatic plant wax, is teleological. The necessity of these things for the organism explains their existence: "Giraffes have long necks since there were droughts in the country and they were not capable of getting their food from trees and *had to*

rise higher"[74] (WR to C6; also similar IR; my emphasis). "Birds are animals which have to fly in air and therefore have a low body weight … Aquatic plants have waxy coating so that they can float on the water and not sink" (WR to J1; my emphasis).

In addition to being teleological, her understanding of the organic change is primarily transformationist; various causes are thought to bring about the transformation in the biological world: "A change in biological world is the change *brought about* in the living beings… This change is sometimes natural or sometimes self-done… [For example:] change is brought about in trees due to its growth, ability to grow etc. Human beings change due to various things taking place in and out of the body" (WR to L3; my emphasis). Further, she thinks that the organic change is brought about "by an action". For example: the growth "brought about in trees" by "watering… means maintaining it". But, what about the tree that grows in jungles? There "the climatic conditions" like "sun's radiations" and the internal "aspects present in the plant or tree … [like] the enzymes" are said to cause the growth of the tree (IR). Another example of transformation is found in her explanations of insect colour and L-plant fruit skin. The food they eat, transforms the insects into what they look like: "The leaf eating insects consume leaves which contain chlorophyll and therefore are always green. While barks of trees contain algae and as the [insects] feed on them they are of mottled grey colour" (WR to K4). And, in the case of L-plants, the living conditions is the cause of the transformation:

[74] But the offspring of the parents who have acquired longer necks through these means do not have equally (or more) long necks – they also show a variation as wide as the one in their parent's generation. For example if both the parents initially had 100 centimetres long neck that becomes 105 in the process of having the food from tall trees, then the neck lengths of their offspring, according to this student, could vary from 80 to 95 centimetres. Thus she entertains the concept that the external conditions could act on the individual to transform them; or the concept that if the need for the food is to be fulfilled then the organism is ought to "rise" to the occasion to survive. But, she does *not* entertain the concept of inheritance of acquired characters. She consents that a few individual offspring "may" have a character same as the acquired one in their parental generation, but certainly it is not a routine phenomena.

"The fruit of 'L' plant is hairy because it is posed to various different climatic conditions, pollution and various other changes which have been there now and were not the same earlier… [The conditions] have changed from ancient time to the present" (WR to P).

5.6 Focus on the behavioural-II: God, habit as well as habitat explain the similarities and differences

We discussed how S#30 and S#40's understanding is focused on the behavioural characteristics with little reference to the physical (see Section 4.18). Similarly S#48 focuses on the behavioural, but he also refers to the physical. In D3, he writes about physical differences and behavioural similarities. The differences he mentions are in height, voice, eyesight, hearing power and strength. The human beings are thought to be similar in being "fond of cool and pleasant places", in being "of good nature", and in sharing the liking for eating the same things.

He understands the similarities or differences as God's creation. But, he also lists a number of external factors such as living conditions, behaviours of family member, friends and relatives (WR). During the interview he explains how behaviour of others towards a person can make a difference: "If suppose 2 children are there … Suppose if one child is born in one family and other child is born in a different family. They are going in different schools … [One of the children is] treated like animal means everyone [is] saying that and other [one] is treated with good manners. Then, the one who is treated with bad manners will become bad … His brain will be engaged in different work, means bad work; and the one [who] is treated by good manners, his brain will be engaged in good work". Thus according to him differences are created by different external conditions. However, according to him, these acquired behavioural differences are not necessarily inherited by all of the coming generations. Because children of a 'bad' person (who has become bad due to bad treatment) could be bad as well as good, again depending on the

'treatment' they receive from others. The explanation in D5 also uses the behavioural differences. The children could be disease sensitive as well as resistant because they "have different behaviour and different tendency to eat food and live" (WR). For example if one of the children has "angry behaviour… he is always angry, then his blood pressure will increase and he may have some disease due to that" (IR). In this case, behavioural differences account for differences in resistance to the disease. In the case of moths, however, the similarities and differences mentioned are physical – "size; colour; wings; spots and margins", and the cause of these is thought to be their habits and habitat, that is "their way of living and their resting places" (WR to B3 & B4). In fact, in S#48's understanding, habitat overrules heredity: the colour of offspring could be different because "it does not depend on the colour of the parents, [but] it depends on the surroundings" (WR to B5).

5.7 Nature's (not natural) selection-I: Nature, conceived as God, selects the capable

S#71 does not link the individual variation in the neck length is caused either by stretching or by nutrition. The neck-length differences (as well as other similarities and differences) primarily "depend upon the qualities that the [offspring] acquire from their parents": "if most of the genes in the children are of the father, then father will be the dominant [in contributing to the offspring's trait], and if most of the genes are of the mother, then mother will be the dominant". She thinks that even in the ancient giraffes there were differences in their neck-lengths – the variation is common to "all the giraffes", and the neck-length variation is not caused by the droughts or the necessities created thereby: it "depends upon [the] parents" (WR to C1, C3, C4 & IR). Further, she connects the survival to the existing-variation: "During severe droughts only large and tall trees survive. The giraffes who had longer necks were able to eat the leaves of the trees [survive] and giraffes who had

shorter necks were not able to eat the leaves died. So it is after severe droughts for many years we see long necked giraffes" (WR to C1).

In all these aspects her understanding is similar to the (standard) Darwinian understanding (discussed in chapter one). She even says that her response is "based on the Darwin's theory of evolution". However, according to her Darwin's theory says "that those who have *ability* to adapt to the given environment survive and which do not [have the ability] die" (WR; my emphasis). Thus, when it comes to her conception of the Darwin's theory, like S#68 and S#70, she too believes that, in Darwin's theory, what matters is the *ability* to survive – the ability that can be *actualised* on demand. One need not necessarily have to actually *have* the variation that could sustain the organism in the current conditions, but it is enough to have the capability that others don't have and that could be realised for the survival in the adverse conditions. The fallout of this *ability-based-conception* of selection is immediately apparent. Because, for the student, it is not necessary that the individuals have to actually vary, and have advantageous variation that could cause their *natural* selection, they face the questions – "why is the nature selecting only those who are *able* to face the given environment and not those who are *not able* to face it?"[75] (WR to C2; my emphasis). Because organism is *not actually* varying, they are not *naturally* selected; but the ability (or potential) to vary adaptively is being tapped by the "nature", and it is the nature that is selecting the organisms.

By *nature*, other students (e.g. S#68, S#70) generally understand the environment and the external physical conditions. But when S#71 says "nature", she means "God" (IR to J). In the case of giraffes, she has accommodated her partly-Darwinian explanatory framework with her conception 'God', by seeing the "nature" as the "selector". But, in the

[75] Here by "nature selecting", S#71 means "selection by nature" (IR to C2).

remaining responses, she conceives the "nature" as "God", who either adaptively transforms the individuals or creates them so that they are adapted to the given conditions. And hence, the following responses: "nature has made the birds to fly in the air… to adapt them to the environment the nature has given light, air-filled bones" (WR to J1). In the case of leaf eating insects the colour is also attributed to "the leaves they eat… [and the] chlorophyll in it", but then the colour is to enable them to 'camouflage… and protect[ion] from the predators" (WR to K4 & K1). "The fruits of all the L-plants are hairy to protect them from the given surrounding conditions and also… beetles" (IR).

5.8 Nature's (not natural) selection-II: Nature selects the capable

We have discussed how the student *agenciates* and divinises the nature[76]. S#68 does *not* divinise the nature. Nature, for her, is neither conscious nor divine. By "nature", she means "natural conditions": "the climate, the humidity level, famines, floods all these are natural conditions" (IR). But nonetheless, she does agenciates nature. She casts the nature in the role of the *selector* in natural selection.

She thinks that different individuals, giraffes for example, have differing "capability[ies] to adapt to the surrounding"[77] (WR to C3). Only some giraffes are thought to have the "capability" to "adapt" to the adverse conditions like droughts. This capacity, S#68 thinks, comes partly from the parents, and hence not everyone has it. The "capacity to adapt" simply means the capability "to live in that surrounding, to do everything in that surrounding". "Nature" selects only those individuals who have this *capability* to adjust to the surroundings, who are the *fit or healthy* ones, and this process of selecting the individuals capable of sustaining the calamities is, she thinks, called *natural*

[76] See the Sections 4.8 & 4.9.

[77] In the case of giraffes these differences, S#68 thinks, "may be due to some change either in the physical or biological world" (WR to C4).

selection: "Nature selects the one who are capable to adapt in that surrounding, so they [i.e. the selected and capable giraffes] are changing their neck lengths to adapt in that surrounding" (IR). She also thinks that the capable individual "does not depend on someone else for that capacity to adapt in that surrounding".

For S#68 then, *nature* selects those with the *potential* to adapt. She is not thinking of those who already have the advantageous traits, and hence are *naturally* selected. "Nature", which to her is external conditions, selects those who have a potential to sustain those conditions; and this potential is realised when the selected individuals transform or develop the traits – or adaptations – that will sustain them through the external adversities. For S#68, nature selects the "healthy" or fit individuals for the "struggle", and these individuals, as they have the capacity, adapt to the conditions.

It is *not* that she does not understand the variation in the giraffe's neck length independently of these climatic conditions: even before droughts giraffes "were not all same… all were different. They were of the same species but their characteristics were different, their qualities were different, I feel so; and their necks will also have different lengths" (IR). She clearly states that ancestral short-necked giraffes had a variation in their neck-lengths[78], but perhaps her focus is not on the slight individual variation; and the survival of the longer necked giraffe is not combined with the slight individual variation in the neck lengths in successive generations to yield the concept of natural selection. Rather, those who survive are said to adapt, where to *adapt* is akin to the individual adaptive transformation.

In fact, all her explanations do not call for nature's selection of the capable individuals. In the case of L-plants the cause of adaptive variation is seen to be

[78] The long-necked one among them is understood (by her) to have the neck length that is considerably shorter than that of the modern giraffe

in the necessity to adapt to the prevailing climatic conditions. The change in the L-plants is caused because it was necessary for them to adapt the changing climatic conditions – the conditions "force them to bring a change in their life and adapt in that surrounding" (IR to P). She even thinks that the transformation of individuals are sometimes directly caused by the food they eat: "those insects which are living, eating on green leaves are green because of the food which they are eating, because of the nutrients which they are consuming… and those which are mottled grey [have that colour] because they are consuming the bark of the tree, which is brown in colour" (IR to K).

5.9 Essentialist understanding, with an appreciation of the adaptation: Put the existing characteristic to adapt

We have seen how the student understands the variation (for example) in the neck length or the DDT resistance to be variation of kind, not variation of degrees[79]. Like these students[80], S#43's understanding seems to be essentialist and she seems to understand the variation (discussed in the descriptions given to him in C and A) to be of *kind*. For example, she interprets C5 as asking about the possibility of the offspring having a very large variation in the neck length, as large as that between ancestral and contemporary giraffes. Because of this, her answer to C5 is "no" as "we now see giraffes having [only] much longer necks" (WR). Her essentialist understanding is also apparent when she is talking about individual differences in C3 and C4. Here, instead of comparing two individual giraffes, she compares a giraffe with other animals and offers an anthropocentric justification of the differences: "all the animals should have different body structure, different behaviour and so on, that could

[79] See, the discussion of S#18, S#28 and S#53 (Sections: 4.2, 4.3, 5.1; 4.10 to 4.13; and 5.2 to 5.5.

[80] Not only the student with essentialist (explanatory) frameworks, but sometimes the student with evolutionary framework is also seen interpreting the individual differences to be differences of kind, see the discussion of S#44's understanding in the Section 5.10.

be [to] differentiate those animals and identify them"[81] (WR to C4). The giraffe is identified by its long neck, and she takes these long necks to be already in existence in the species (IR to C5). When asked explicitly, she could not think about the origin of the long necks, and rules out the possibility that giraffe could have acquired the long neck because of climatic conditions like droughts.

S#43 evidently has an essentialist understanding. Hence it is difficult for her to think about change in the existing characteristic feature of the organism. Change in the giraffe's neck length for example. But she thinks of the advantage long necks have for the giraffes. When "giraffes have much longer neck then they had a good advantage to eat leaves of trees" (WR to C1). During the interview, she also refers to the long necks as an adaptation. The giraffes who have long necks "adapt that long neck to eat their food". Thus, the long neck that "their species already" have, had become an adaptation for food eating (IR to C5).

S#43's understanding is a good illustration of how far or how close an essentialist student could be from understanding natural selection. S#43 thinks about the advantage a particular character could have, and how that character could be put to function usefully in the present conditions. That is, how the (individual) organism could *adapt* using an existing characteristic. But, being focused on the character, and *not* on the *intra*-species slight individual variation in that character, the student is not thinking about better and better functioning variant of that character. The advantageous character (and hence its advantage for the variant individual) is static for the essentialist student. It is not the locus of change. In natural selection, the character in question varies across the individuals (of a population), and is the locus of change. Better and better individual variants of the (hereditary) character are naturally selected in

[81] It is not that different animals do not share some characteristics. She thinks that, "they must also have similarities [in] for e.g. eyes, legs, ears, mouth etc." (WR to C4).

successive generations. Thinking about the advantage of a character is essential, but not enough, to understand natural selection. The student has to couple the advantage a character has with the concept of intra-specific individual variation. This is what the essentialist thought seems to lack in.

5.10 Simple evolutionary world view-II: Individual differences (and similarities) arise mainly during evolution, or else are caused by the varying (or similar) teleological response of various individuals to their habitat

Like S#83[82], S#44 thinks of evolution without much focus on *how* of evolution, because for both (to some significant extent) evolution itself is an explanatory concept. In fact, S#44 explicitly thinks that C is about evolution: "This passage tells us about the *origin of giraffes* during the course of evolution" (WR to C1). "First the earth was hot sphere. Slowly vegetation and lakes and sea bodies have started to… form on earth, and that amoeba was formed … Amoeba then… fishes were formed. After that… they started to came out, reptiles were formed. Then slowly *because of evolution* they got a back bone but it was not erect. Later the backbone was erected…". S#44 thinks that this evolution is very slow and we come to know of it only after a very long time interval (IR). You must note that, for S#44, evolution is slow, *not* gradual. Giraffes do not evolve gradually from their ancestors, for example. They are thought to *originate* directly during the evolutionary process, and this explains why they are like they do. For example: since the "first origin" giraffes have long necks (WR to C6), "means during the evolution when first giraffe was born from that parents [it was long-necked]" (IR). Hence, when it comes to explaining similarities and differences in giraffes, S#44 refers to the process of evolution which has given rise to the giraffe species: "The reason for their similarities [is that] they belong to same species (WR to C4)… [that is] a group … [or] a class (IR)". The "differences

[82] See the Section 4.17.

are because of their habitat. Some differences are there [since the] origin, but some differences are there because of nature and [because] they [the giraffes] could not adjust to the surrounding" (WR to C4).

In the preceding response of S#44, you must have noted that along with evolution, similarities and differences are also explained by the individual's responsiveness to its habitat. Some giraffes could adjust to their habitat while others cannot, and this results in the differences among them. In the case of mosquitoes, S#44 thinks the similarities among individual mosquitoes are caused by the similar "adjustments to the nature" (WR to A4). In all these cases, for S#44, "nature means surrounding … climatic factors, abiotic factors" (IR).

Given that in S#44's picture of evolution the change is *not* gradual, it is hardly surprising that he interprets long necked and short necked giraffes as well as DDT sensitive and DDT resistant mosquitoes to be two very different *types* or *varieties*. If this is so, there is no question of parent of one type reproducing the offspring of another type. For example, if the parents are having long-neck, "all the offspring will have long necks. It is the feature of giraffes" to have long necks (WR to C5).

5.11 Teleological adaptive transformation

We have been discussing a number of instances of the student's teleological thought[83]. We now discuss the understanding of S#67 as it helps us further in characterising the student's teleological thought and provides us with some of its prototypical instances.

S#67 seems to have a clear understanding of the natural change and natural cause: "The [natural] change occurs … *gradually and steadily*… we are not

[83] See, for example, the discussion of S#77's understanding in the Section 4.15.

doing anything in that… [For example] 60 crore years ago, there was a ocean… because of the sediments deposit, it grow into the mountains and it is one of the biggest [mountains now – Himalays], and now also it is growing steadily, mountains are growing steadily … [Example of natural cause is] trees grow, survive, we don't do anything there… The cause [here] is they get the sufficient nutrients from the soil and sunlight" (WR & IR to L4 & L6). From these responses, it seems that her teleological thought (to be discussed below) does not originate in ambiguities concerning the basic idea of cause and effect. In fact S#67 often seems to understand the teleological change as a natural change and both are thought to be "gradual and steady". Giraffes have long necks, she thinks, "after many drought years, when giraffes adapted to survival and [to] the changes occur[ing] in nature. … Because of the gradual increase in the tree length … due to natural change … the giraffes used to not get their food and they used to stretch their necks … to have the food …; and because that they *gradually* increase their necks" (WR to C1, C6 and IR). This adaptive individual change is so perfect for her that "if the height of trees goes on decreasing, the neck length of giraffe goes on decreasing" (WR to C7). This gradual teleological change is not the only explanation that helps her understand individual similarities and differences. She thinks that apart from the "eating habits", the differences are also caused by "mutations of genes" (WR to C5).

Her understanding in all of the other cases is also distinctly teleological. She writes and says during the interview that the birds have light air filled bones "to adjust with the surrounding" (WR & IR to J1 & J2). Insects too have to adjust the colour with their surrounding for protection: "leaf eating insects were not always green and the bark eating ones always grey… [These] changes occur due to change in surrounding and physical world… [The insects] had to adapt according to the surroundings… to protect them from their enemies" (WR to K3-4). It is important that *unlike* a number of other students, she does *not* think that the insects change (from the non-green to

green) because of their feeding on the green leaves. But, she thinks that the change is done "internally" (IR). Just as insects change for protection, the plants change, she thinks, to save the depleting nutrients: "It may because of the changes in the soil, supply of water, nutrients, climatic conditions. First… the climatic conditions of that area would be good. The rainfall was quite good, so the fruits would get water and in the soil the nutrients were available more than required. So it was possible to have fruit trees having smooth fruit. But now due to many fruits grown, the nutrient in soil decreases, the rainfall has also decreased. So in order to save water and nutrients, they convert the outer covering [to] hairy" (WR to P). Hence, hers is a typical teleological transformationist explanation, where the individual is adaptively transformed to achieve certain ends, but not exactly by the external conditions (to which the individual is adapting).

5.12 The amount of genes inherited from the parents explain the individual differences, while the individual's adaptation to the living conditions explains the (evolutionary) change

We discussed how the student conceives the evolutionary change as an individual (teleological) transformation, meant to adapt the individual to its living conditions. For example, the student thinks that the individual's responsiveness to, and reproduction in, the external conditions determines the course of change (cf. S#77, S#41)[84]. Similar is the understanding of S#50. He thinks that "because… they [i.e. the moths] are living in a smoke… the[ir] children would get adapted to that smoke and therefore they would be dark" (IR to B5). But he does not understand the individual similarities and differences in terms of the individual's adaptive responsiveness to the living conditions. He understands the similarities and differences to be due to the similarities and differences in the *amount* of genes one inherits from the

[84] See the Sections 4.15 & 4.14.

parents: "The reason for above similarities could be… the genes present in them. [For example] from their mothers and fathers they get genes and because of that they get disease resistant … [Differences could be because] there might be some less amount of gene transfer [from parents to offspring]" (WR & IR to D4). Thus, for S#50, in the case of humans, the amount of genes the individual inherits causes her to differ from her parents; but in the case of moths, their adaptive responsiveness causes the offspring to differ from its parents.

I should mention here the comparison of S#50's understanding with that of S#38. Both of them think that the variation in the *amount* of genes each individual has, causes the variation among them. But, according to S#50 the amount of gene the individual has is contingent on what she inherits from the parents, whereas S#38 thinks the amount to be contingent on quality of nutrition available to the individual.

5.13 Genetic transformation by direct action: DDT affects the genes randomly, while prolonged exercise of a body part affects the genes in it

We discussed how the Class VII student often explains an adaptive character, like DDT or disease resistance, by thinking in terms of resistance-capacity or capability. The student thinks that the organism resists a disease or DDT, or camouflages itself from the predators, because it has the ability or capacity to do so[85]. S#42 also refers to abilities and power of organisms that confer them the useful characters they have. He thinks that DDT resistance depends on the 'resistance capacity-power' and neck-length' on the 'stretching ability'. But, his explanation does not end there. The resistance capacity of the mosquitoes

[85] See, for example, the discussion of the following student's understanding: S#39 (Resistance power, depends on food; Section 4.4); S#23 (The strong has resistance power, the weak does not; Section 4.5); S#26's story of power germs (Section 4.7); S#19 (X-disease resistance due to physical and mental health and food; Section 4.14); S#77 (ability to camouflage; Section 4.15); S#25 (strong and weak; Section 4.14)

is said to depend further on the mitochondria. In addition to all this, S#42 understands the change (in the mosquito and the giraffe) to be caused by genetic transformation due to effects of DDT and neck-exercise. Hence, for S#42, the organisms have a particular trait, either because of their ability/capacity, or because they "have [it] from heredity".

According to S#42, DDT 'affects' genes. Due to this there is a *chance* that, if a mosquito population is exposed to DDT, some of these mosquitoes could become DDT resistant (WR to A1). Genes, he says, "cause the hereditary characters… means some diseases, resistance power, any height … [DDT] directly concentrates on genes… [of] the mosquitoes, which give birth to… younger one. [This offspring] may be resistant to DDT or it may not … [Sometimes the DDT affected gene of a parent mosquito] gives its characteristic [to the offspring], but sometimes it does not" (IR). Thus, for him, *some* of the DDT affected sensitive mosquitoes can become DDT resistant due to the direct action of DDT on the genes, and this genetically acquired character could be transferred to the offspring. But, again, this transfer of genetically acquired resistance may or may not happen, because "it's not that genes give all the characteristics to younger ones" (IR). Thus, S#42 thinks that DDT "accumulates" on the genes, transforming some of them such that the mosquito becomes DDT resistant. But, this whole process is random in the sense that DDT does *not* transform the whole mosquito population, and only some of the transformed individuals transfer their resistance to the following generations.

Thus S#42 understands DDT resistance to be caused, either by the resistance power the individual has, or by the effect DDT has on the genes. These different notions are used by him to explain his two different assertions. To explain the presence of DDT resistant mosquitoes in the ancient time (when DDT was yet to be discovered), he uses the notion of resistance power: in ancient time "some of them might have [had] the resistance power high. If at

that time they were attacked by the insecticide DDT, they could have escaped from it due to high resistance power" (WR to A6). And, to explain the anticipated existence of DDT resistant mosquitoes in the distant future, he uses the idea of heredity: "Yes, DDT resistant mosquitoes would be there after hundreds of years [b]ecause it [that is the resistance] is carried out by the means of genes (WR to A7).

In the case of giraffes too, one could have long neck, either "because of heredity characters, or [because of the] stretching ability" (WR to C5). The "stretching ability" is said to be dependent on the genes one has; and like the mosquito, S#42 thinks that the giraffe could also undergo genic transformation[86] through the effortful and continuous use of the neck: "Before many years, giraffes had a short neck. But [during the droughts], due to the food was not there anywhere below [on the ground], they tried reach at height [to reach the leaves of tall trees]. While doing this, their neck used to get stretched. This daily routine had made their neck longer" (WR to C1). During the "continuous exercise [of neck] … the [neck] muscles [may] be loosing up … [affecting] the genes" (IR). Even if he thinks of this exercise effected adaptive genic transformation, he does *not* think that the thus acquired genic character is always transferred to the next generation. Since parents "give only a limited number of characteristics to [their] young one", only those children who get the 'gene-characteristic' of long-neck from the parent would have long necks.

I would now like to discuss the understanding of another student – S#62 – who, like S#42, thinks that stretching of neck causes it to elongate and in the process could also change the related genes. But, again like S#42, he thinks that the elongated neck length is not always inherited to the coming generations. In response to C1, S#62 writes: "Long long ago giraffes had neck

[86] But, *un*like the mosquito case, the genic transformation in the giraffe cannot possibly be random.

not as big as they have now. When there was a drought condition, the long trees would survive not the short bushes. Giraffe is and was an herbivorous animal. They eat plants and leaves of the trees. During droughts there were only tall trees. They have to stretch their neck to eat these leaves. During the course of time their neck becomes longer and longer. As there were droughts they used to eat in the same manner" (WR to C1). During the interview he said: Giraffe acquires a longer neck by stretching and passes on this character to the next generation, but not to all of the offspring – may be just about half of them. If both the parents had acquired longer neck by its overuse before they reproduced, then why not all their offspring have longer necks like their parents, why some of them have shorter necks? Faced with this question, the student attributes the differences to the presence or absence of genes for the long neck; some offspring get it from their parents, others don't: "genes are transferred from one generation to the other therefore… children with longer necks have the genes", while others don't get it from the parents. Does this mean that the parents' (who to begin with had shorter neck) genes change when they are acquiring a longer neck through stretching? Yes "a little bit", he thought (IR).

Unlike his giraffe neck length explanation, S#62's other explanations are *plainly teleological*. He thinks that the organisms *have* to have some traits, when it is *necessary* to have them. For instance, birds have light bones because, light bones are necessary for flying and are needed to fly-light over long distances. Similarly, aquatic plants should have waxy coating to prevent decay of the leaves: "Birds have to fly over long distance. If they have heavy, non air-filled bones, they would be unable to fly in air as their body weight would increase. They have light air-filled bones to maintain a balance in their body which is *necessary* for flying. Aquatic plants have a waxy coating on their leaves because the water *should* drain from their leaves. If water gets accumulated on the leaves, it would decay the leaves… [and they] would not float on the water" (WR to J1). The change in L-plant fruits is also understood

teleologically: He thinks that, the hills have low temperatures and the plant "*should* become hairy to avoid that [low] temperature" (IR)[87]

5.14 Individual adaptive-developmental response, and the eventual adaptive gene transformation, or adaptive gene activation, explains various adaptations

Like S#42 and S#62, S#03 too thinks of adaptation as an individual genetic transformation, but his explanations are subtler compared to the ones just discussed. They include the individual's developmental responses to various external conditions eventually leading to either the adaptive gene transformation or adaptive gene activation. We will now discuss S#03's understanding in detail.

S#03 thinks that the reasons for individual differences are "mostly" the reasons for "evolution".[88] For him, like for all those who understand the various instances of organic change (being discussed in this work) as instances of individual transformation, an explanation of individual differences is the sufficient explanation.[89] S#03 thinks that, here are differences in mosquitoes because "[t]hey [have] evolved in different environments, so in order to suit the environments they adapted to it; like we have. Like if we have any disease, suppose we have cold we adapt to it by developing the antibodies. So eventually they did develop it and it got imprinted on their genes and it [got]

[87] During the interview, he was asked what will happen if the L plants are grown in a room for generations at a low temperature (the temperature which is similar to what S#62 thinks to be the plant's natural climate).

[88] S#03 mentions the following differences among the mosquitoes: differences in body size, presence or absence of stripes on the body, feet lengths; "some living in a corner without any water and some only around water bodies"; some cause malaria (only females) some, some other diseases (WR to A3).

[89] Evolutionary explanations, they think, are meant primarily to explain the origin or cause of adaptative traits/adaptive differences. For them, adaptation is explained by *individual* adaptive change.

carried on"(IR). Thus, the adaptive individual transformation is thought to be the adaptive genetic transformation, and it is understood in analogy with the human defence system. Interestingly, he thinks of one more mechanism that could explain the differences in DDT sensitivity – adaptive gene activation. This adaptive gene activation is also understood using the human analogy. Just as is the case with humans, the individual differences depend on the genes that are present. "If the father is resistant then the boy will get the father's genes". And, "all the genes [in the individual] are not active [all the time], all the genes are not performing their functions continuously; whenever the conditions come they start… they show their properties like [DDT resistance]" (IR). As the adaptive trait acquired by the individual mosquitoes during the adaptive developmental-response is genetic, it is inherited to the following generations. If DDT sensitive mosquitoes grow in an environment which has DDT, the sensitive mosquitoes can change into resistant mosquitoes and *all* the progeny of these changed mosquitoes will have resistance to DDT. This is because "they have got the property, they have got the adaptation of resistivity, which is imprinted in the genes and genes will only pass onto their offspring" (IR). Since the adaptive traits are "imprinted in the genes" the mosquitoes will remain DDT resistant for the generations to come, irrespective of the presence of DDT in the environment. Moreover, if a mosquito population is never exposed to DDT, then there will be no DDT resistant mosquito in that population. The student was asked: "suppose you go to a jungle, deep inside the jungle, there are mosquitoes, many mosquitoes, but no human being has [ever] reached there, ok… No human being, no question of DDT… will you find there some sensitive and some resistant mosquitoes or will all be sensitive or will all be resistant?"[90] To this the student said that "all will be sensitive". Similarly, hundreds of years ago, since there was no DDT, the DDT resistant mosquitoes were not there.

[90] It should be noted that this question was often used to probe the student's conceptions concerning individual variation and its inheritance.

Not just DDT resistance but other traits too are explained (by S#03) to be adaptations to different environmental conditions: "Might be that the different mosquitoes breeding in different environment[s] and different parts of the world have adapted eventually to develop camouflage, arboreal adaptations and immunity against plasmodium protozoa"[91] (WR to A4). Also, all the differences need not have teleological origins. Differences, like the differences in the patch pattern on the bodies among mosquitoes, are explained by him as the errors in DNA copying during reproduction: "In the gradual reproduction (copying and printing of their DNA) some sort of error could have happened and they might have developed patches on their body" (WR to A4).

Not just the external adversaries like DDT pollution causes the mosquitoes to respond adaptively. S#03 thinks that competition also forces the competing organisms to develop adaptive traits; and those who do not develop these, die due to the severe competition, while those who do, survive. Here, it should be noted, competition is *not* a contributor to the process of selection. On the contrary, competition heightens the need of the animals to have, or to develop, the adaptive trait that will help them survive through the current competition and environmental conditions: "The conditions and environment of their [giraffes'] living are different. Thus they might have to compete with different situations for which different adaptations might have developed in them" (WR to C4). Like the mosquito case, in the case of giraffes too, the gene-activation is supposed to support and explain the adaptive development: offspring get genes and "with the genes the characters" from their parents, "some [of these] characters might be dormant and some might be active" and this explains the differences (as well as similarities) between the giraffes (IR to C4). When the

[91] Another possibility S#03 thinks of, that could explain the differences is that mosquitoes might "have communicated different methods of doing things among themselves" (WR to A4). The student's inference that mosquitoes can communicate with each other comes from the information he has about "some instruments [that] are there to kill the mosquitoes. They emit some sound, low frequency sound by which they get disturbed. So there must be some sort of communication between them because they can communicate with sound" (IR).

adaptive developmental change is happening "the genes having the characters of long neck… get activated" (IR). When asked, can the genes change due to the wish of a giraffe to reach for leaves of tall trees, the answer was: "yes, [but] not because of wish but because he wants to survive, that is why". When it was suggested to him that "wanting to survive" is also a wish, he repeated his answer but added the condition of long time: "[the genes can change but] not suddenly, it will take time" (IR).

5.15 Multiplicity of causes explain the (individual) change-I

The student makes sense of various aspects of the organic change through multiple causes. S#47 is a case in point. He lists various similarities among the mosquitoes: "Mosquitoes have six legs and four wings. They can fly, walk… They have needle like small mouth through which they suck blood… and pass some germs carrying illness. They are found at marshy land, near garbage bin and waste materials. All of them breed in dirty and stale water" (WR). To him, these similarities among mosquitoes are because "their habitat, their food and the genes present inside their body [are similar]. Or they may breed in a similar manner in the same place". And, similarities could also be due to shared parentage, he thinks (IR). Differences are "because of their different habitat and food they eat. Or they may breed in different places in different way" (WR). He also entertains the possibility of there being "some chemicals… inside that DDT… that [will] cause" some growth and resistance in mosquitoes (IR). In the case of giraffes too, S#47 thinks that the individual similarities and differences depend on "their surrounding, their parents and their food" (WR).

Along with all these causal factors, the effect of efforts and use of a body part enters S#47's explanatory narrative while he explains the change in the giraffe neck length. It must be noted that what he explains here, he seems to take it to be happening on the evolutionary timescale as he refuses the possibility of this

happening in a single generation: "Giraffes were having some small necks. Because of severe droughts, only tall trees survive, and therefore they tried to feed on [those] trees… therefore the giraffe started slowly growing their neck, their neck started becoming long… Because there may be the branches of the trees which are at short places, so some giraffes' neck may be grown to a short distance only; and some who tried to get the long, means to feed on the longer branch, their necks started to grow longer" (IR to C4). This does *not* mean that he has little idea of the genetic basis of inheritance. For, he also attributes the individual differences in neck length to be due to genes: Some of the offspring "may have short neck [and] some may have long neck. This would happen because of genes present inside their body as well as inside their parents' body" (WR to C5). Thus, S#47 has multiple causes in mind while explaining various aspects of the organic change: food, chemicals like DDT, habitat, habitual use or disuse of body parts, breeding places, parentage, and genes.

5.16 Multiplicity of causes explain the change-II: Teleological inheritance

Like S#47, S#51's explanatory narrative invokes a multiplicity of causal factors like habits, habitats, food, the strenuous use of body parts, etc. For example, similarities and differences among individual mosquitoes are thought to be because of similarities and differences in "habit and food[92]… [and their] style of breeding" (WR to A4). He also seems to have some teleological notions explaining the individual differences: "big mosquitoes are because they can fly in the sky, they can bite more, they can suck more quantity of blood and they can spread… very fast the diseases" (IR). Further, he talks about blood-based inheritance of the DDT resistance: offspring have "the blood of their parents. If their parents are resistant then they may be resistant,

[92] "Some mosquitoes feed on the human beings' blood and some feed on the grass" (IR)

or if their parents are… DDT sensitive, they may also have DDT sensitivity" (IR).

In the case of giraffes. S#51 thinks that the individual differences "depend on the climate [in] which they live". The differences may also depend on the parents, he thinks. But, "climatic conditions… bring a number of differences" among the offspring (IR & WR to C4 & C5). He explains the structural similarities in the body parts by referring to their necessity for the individual: "they have four legs, because they want to walk, they cannot balance their body on the two legs so all the giraffes [have four legs]… They have a longer neck to reach at the top of the tree and to eat… And their colour is to protect them from the wild animals" (IR).

In response to C1 (without much detail of the *how*), he writes that the droughts cause the death of giraffes, but (somehow) long neck giraffes survive it: "It is said that several years ago giraffes had shorter necks… [Then] there was drought because [of which] giraffes died and only longer necked giraffes survived" (WR). When asked (during the interview) if giraffe's neck could become longer due to stretching, he says that if the giraffe "stretches [the neck] for all the time… then [it] might [happen that] a little bit of his neck-length is longer". But, their "necks are not naturally [long]…, they have developed [the neck] themselves for reaching their food, [it is] because of their habit [that] their neck has become longer". Thus, because the neck length of parents is not *naturally* long, this trait will not be inherited to their offspring. They "will be having short necks. If they try the same thing, what their parents did, they may also have a longer neck" (IR). However, it is significant to note that, when he was asked how is it that today giraffes have long necks, he began to think of the possibility of inheritance of characters acquired for the survival in extremely unfavourable condition. For, before droughts the longer necks acquired through habitual feeding from tall trees was surely unnatural and hence not inherited to the next generation, but during the droughts "in

order to survive [the giraffes] started stretching their neck up to the top of the trees to get their nourishment" and in these conditions, some of the offspring "got same long neck" (IR). Thus, in normal circumstances it is *not* natural for the acquired traits to be inherited, but in the difficult time such inheritance is thought to be possible to enable the survival.

5.17 Multiplicity of causes explain the change-III: The change is understood as natural, non-teleological, individual transformation

Most of the students have a clear natural/artificial distinction[93]. S#69 is a typical example. Natural change to S#69 is a change "occurring due to change in nature… [where there is] no interference of man… [N]atural calamities like volcano, earthquakes are the natural changes" (WR to L4). "The 'natural cause' is [a] cause for natural changes, like the cause for occurrence of volcano is the increasing pressure from inner crust of earth which is a natural cause" (WR to L6). On the other hand, he thinks that "artificial changes are changes by the man… Pollution [for example] is a artificial creation" (WR to L5). Also, he does not *agenciate* nature. To him, "nature means environment or nature means the surrounding in which we live" (IR).

When it comes to understanding biological change he thinks of individual transformation: "The change in the biological world is the change in living beings". E.g. the physical change in a living body is a biological change" (WR to L3). The cause of the individual transformation could be under-nourishment: "when the child is born it is normal, and when its deficiency develops it changes… [due to] deficiency in something [like] nutrients" (IR). The nourishment continues to the cause that explains the change in the giraffe

[93] Recall that sometimes the distinction is blurred when the student divinises or *agenciates* the nature. I should also mention that S#56 questions the human centred artificial/natural distinction: "The distinction between artificial change and natural change is artificial because man is also a product of nature" (IR to L4).

neck length. The long neck of the giraffe, he thinks, is caused by having enough water and proper nutrition: "giraffes have longer necks if their requirement of drinking water is easily fulfilled… [and if] there nutrition of leaves of tree is proper" (WR to C1). He thinks that giraffes initially had much longer necks before the droughts begun, but during the droughts they get much less nutrients and hence their neck lengths became short. Once the droughts were over, the giraffes again got all the proper nutrients and their neck lengths became longer and longer. But, when it was brought to his notice that they had short necks before the droughts and in fact it is after the droughts that today we see long necked giraffes[94], he changed his explanation to the following: "then this might be a change… due to artificial things… many forests have been cut down… the giraffes are getting proper nutrition but the nutrition which is supplied would contain some chemicals and so this would be a deficiency which has resulted in increase of the length of the neck in present era" (IR).

In J, he "agree[s] with the statements". He thinks that light air-filled bones "is the modification due to living in air". Similarly, waxy coating "on the leaves [of aquatic plants] is also a modification as they live in water" (WR to J1). In the case of aquatic plants, the change is directly caused the aquatic conditions, aquatic conditions *make* the waxy coating on the leaves, which enables the plant "to carry out the photosynthesis process in water": "the change has occurred due to living in water, the conditions which were supplied to them while living in water… made the waxy coating on the leaves" (IR).

But, in the case of birds, the conditions are not the *direct* cause, but in those conditions the bird's use the bones in particular ways transforms them into light and air-filled: "the ancestors of the bird would have [had] heavy weight of the bones … they were not able to fly in the air due to their heavy bone…

[94] He was told that here we are comparing ancestral giraffes with the present day giraffes and are talking about the change in their neck lengths across generations.

They practice types of flying and so their bones had become hollow". Due to the "practice", the bird's "body, for flying, would have started modifying…, as [in] if a person is wounded the blood comes out, but the proteins in the body after some time block the overflow of blood, this is the change in the body… for stopping the overflow of blood. Same in this way, the body of the birds has evolved the change in the body for they can fly in the air" (IR).

But, before he thinks that it is the "practice" of the birds that has caused the body to have lighter bones, he entertains another allied possibility: because the birds found it difficult to fly with heavy bones, they "neglected" or 'ignored" the bones and this could have resulted in their becoming lighter. Thus, he asks in J2: "Is this modification due to the ignorance of particular organs by the organism". During the interview, he thinks that the bird's losing the weight of their bones is analogous to the human being's losing of the tail: "I can explain this [i.e. the bird's case], by the example that…: the ancestors of the human beings had tail but due to… the generations started going on [and] the tail was not used so frequently, and so now the human beings, of which ancestors had tail, are not having tail because they were not using the tails; and the human being has that tail bone at the back but not as a tail because it was not used in the primitive period" (IR).

Thus in the case of giraffes the evolutionary transformation is caused by the direct action of the kind of available "food" consumed by the animal, in the case of aquatic plants the living conditions make the waxy-leaf-coating, and in the case of birds the "practice"/use/disuse to fly in the air causes the body to respond by appropriately transforming the bone structure. In L-plant fruit case too, he thinks of a number of possible causes (and all of in one go!), but all of them causing the *transformation* of the fruit skin, and none causing the *selection* of the hairy fruit skin: "The change in the fruit skin of L-plant "might be due to the change in the conditions of ancient times. It can also be due to deficiency or due to some shortage. It might be due to overdose. Also beetles

may have enriched the plant with some product which made them [their fruits] hairy" (WR to P).

S#69 could not have come to think of the possibility of selection of slight variation because he does not recognise the *existence* of these, independent of the living conditions. Even the clue given in the situation P was of no help to him. The sentence given in the situation, "All the fruits of a plant are not identical", is immediately[95] interpreted by him as a prompt for thinking about the *cause* of individual variation in the fruit. And, for him, individual variation (that is individual change) is no different from the overall evolutionary change that is being considered in the situation: "while [for] the growth of a particular fruit… the nutrition was sufficient, but while the 2nd fruit was growing the plant lack sufficient nutrition due to which the first and the 2nd fruit would not be identical" (IR to P)

Thus S#69 understands all the given instances of organic change as the instances of individual transformation either caused by various factors. But, you should have noticed that the individual change is *not* understood by him as a teleological transformation. S#69 never refers to the beneficial function of a structure as a cause of its adaptive transformation; his explanations have little teleological tone. However, lack of teleology does *not* mean gain in the selectionist explanations. Lack of teleology may ensure us that the student is offering *naturalistic*-explanations, but it is not a surety that the student is offering natural-*selectional*-explanation. The naturalistic explanations could well be the natural-*transformationist*-explanation (as is the case for S#69). For example, in the case of leaf eating insects S#69 explicitly denies that the change from non-green insects to green insects is caused for the benefit of the insects: "I don't think it is the modification developed in the insects for their own benefit" (WR to K3). It is not the benefit but the "components" in their

[95] and, of course, spontaneously (that is without any explicit instruction or clue)

food that make them green: "they depend on the green leaves for their survival and so as the green leaves have the component of chlorophyll which make them green, and due to the consumption of these green leaves they may also have been turned green" (IR+WR to K1). But, once these insects "turn green… it would be easy for them to hide in the green leaves, and the other insects which depend on these green insects would not be able to eat them and hence they can protect their life" (IR). He thus acknowledges the use of being green for the insects, but does not think that the use has any causal value in the insect's greenness.

5.18 Selection without evolution: Causally empty selection

A quick recall of chapter one will tell us that for natural selection to be casually effective in effecting the evolutionary change, at least two conditions have to be met – individual variation and inheritance. The population must have individual variation that is inherited from generation to generation. Unless the variation is inherited across generations, the naturally 'selected' variant will not 'accumulate' to produce the evolutionary effect. Selection without *hereditary* individual variation is possible, but will be causally sterile. It will *not* cause evolutionary change. When S#52 thinks of the moth description, he does think of variation in moth colour. But, this variation is because, S#52 thinks, some light coloured moths *become* dark coloured: "When smoke… produced from the industries… settle in the moths and they look dark in colour" (IR to B1). This transformation of light coloured moths is irreversible (for, when a moth, which has become dark due to smoke, is drenched in heavy rains, it will not become light again)[96], but it is *not* hereditary. In fact, for S#52, the moths are only of one kind – all of them are light coloured. It is only "when the smoke gets settled in their body, some of

[96] During the interview, when S#52 talks about her conception of light coloured moths *becoming* dark coloured, she was asked about this possibility to probe whether or not the transformation she is talking about is permanent or temporary.

them become dark coloured" (IR to B4 & B5). Thus, S#52 thinks of irreversible but non-hereditary transformation of moths. S#52 then seamlessly blends this transformationist explanation with the selectionist explanation: When the moths that have become dark coloured "settle on the bark of the trees [that are already dark due to smoke], they are not visible… while the other, white moths are visible… So the white moths are eaten by the birds … so their number decreases while the number of black moths increases" (IR to B1). This looks like a typical Darwinian selectionist explanation of how the number of dark coloured moths increase. But, this explanation will not help us in making sense of the evolutionary change, because the surviving dark coloured moths will not inherit their colour to the following generation: "light coloured moths which have become dark now, are not dark from their birth, because of the smoke they have become dark, so their children will be light coloured only" (IR to B1; WR is similar).

5.19 Fragments of selectionist explanation, with (enough) scope for suitable adjustments with the surrounding and teleological transformation

Unlike the student (S#44 and S#83, e.g.)[97] who, without referring to the *how* of evolution, thinks of the instances (described in A, B, C, or D) in terms of evolution, S#45 thinks of the *how*, but without referring to the overall idea of evolutionary change. In other words, her explanation is fragmented from (or unconnected to) any overall idea of the evolutionary change. S#45 understands the given description in B as follows: "Moths are of two colours i.e. dark coloured and light coloured. It seems that when [from] the industries smoke comes out, the bark of the trees is coloured with black colour, so that the dark coloured moth is camouflaged as the birds feed on [them]. And then the light coloured moths fall prey to the birds" (WR). From this, it is clear that, at least in the case of moths, she has a selectionist understanding of changes in the

[97] See Sections 4.17 & 5.10.

moth population. But, her understanding could at best be characterised as skeletal or fragmented, not complete and connected, because she does not refer to *slight* individual differences and their *gradual* accumulation in the population, let alone its relation with natural selection and consequent evolutionary change[98].

For S#45, heredity explains the colour differences in the moths, both within and across the generations. The colour difference is "due to their parents… due to hereditary factors … [Among the offspring] some of the characteristics are of their own and some… are from their parents… For example, now the moths, some are white in colour and some are black in colour… Now suppose both the parents are black in colour, but still [some of the offspring] will have their own characteristics, some will be white in colour and some will be black in colour". Even if, for S#45, heredity explains the individual differences, sometimes the differences are thought to be due to differing individual teleological responses: "sometimes environment is not suitable, so they have to adjust for themselves. So sometime the characteristics and the habits both are changing according to [the environment], so that they can survive in the environment" (IR). Thus though she offers a fairly correct explanation of the increase in the number of dark coloured moths in industrialised cities, and though she seems to know that characters are somehow dependent on the hereditary factors one inherits from parents, her understanding still has a scope for the change caused by an individual's adjustments to the surrounding conditions.

Like S#45, S#46 also understands the change in the moth population as caused partly by the individual adjustments for survival and partly by a skeletal selectionist framework that refers to the differential survival of light and dark

[98] I will come to the detailed discussion of these points while characterising the understanding of the students who could be said to have a reasonably complete understanding of natural selection. See the discussions of the understanding of S#53, S#54, S#56, in 6.9.

coloured moths. Perhaps the former cause plays a stronger role in her understanding of change as it is perceived as a more general and "natural" cause of change: "the colour of the moths is changing… they are growing darker … This condition is because living-organisms always try to adjust themselves and save their life" (WR to B1). During the interview she adds: "every living being has its nature like that – to protect itself from its enemies" (IR). Thus, the moths are thought to be "affected by the environment" (WR to B3), necessitating the adjustment for survival.

However, in spite of all these answers where the "natural" need of animals to "adjust with the environment" is said to be the cause of change, there are three distinct fragments, one during the interview and two in her written responses, where her explanation resembles the skeletal selectionist explanation referring to the differential reproduction. At one point, in the beginning of the interview, she says: "…those light coloured moths, because they have been eaten away by the predator, their number has decreased; and since the smoke is there black coloured moth cannot be seen so they have increased, the number has increased" (IR to B1). Similar explanation is found in her written response to B6 and B8: "According to me dark coloured moths were almost not present hundreds of years ago… [O]ur environment was clean very clean and free from pollution … And therefore the barks of trees had not become darker. So these dark coloured moths could be easily caught by the birds. Therefore dark coloured moths were not there hundreds of years ago" (WR to B6). Moreover suggestion in B8 is to become dark coloured moths, because "if they are not dark-coloured they will not be able to survive in this [highly] polluted environment [where tree bark will be becoming more and more dark]" (WR). But, these responses find little resonance with her other explanations. Perhaps for her, the teleological explanation of individual adjustment and the population-level explanation of differential survival, do not contradict each other; on the other hand, for her, they may indeed seem to

complement each other[99]. For, living beings like moths could very well need to adjust to the changing environmental conditions – sometimes by adjusting their colour; and at the same time, those who have dark colour may benefit by being able to escape from the predator because of having the colour matching with the tree barks on which they typically rest. For her, the former might be a general fact applicable to all the animals (and may be plants?), whereas the latter might be a specific explanation of what is happening in the case of moths.

Like S#45 and S#46, S#64 explains the increasing number of dark coloured moths with a selectionist explanation: "The change in the biological world refers to the changes in the biotic components… For e.g.: Moths in Birmingham are of 2 kinds, black and grey. Before the industrial revolution due to presence of more fungus and algae, the grey coloured moths were being protected from predatory birds. But, now because of industrial revolution mainly fungus and algae production has decreased and has also been covered by a black soot on those trees. This has protected the black moths and the grey one's fall prey to birds" (WR to L3). But, this selectional explanation is perhaps not the part of evolution-by-selective-accumulation framework. This is evident when he explains the case of insect colour. The statements in K, S#64 thinks, "say about the protective means of insects which they use to protect themselves … from the predator birds" (WR & IR to K1). Moreover, he does *not* think that the green insects have *become* green. They must have been always green "because of nature" or "because their ancestors must be green in colour" (IR). Moreover these insects should remain green, even if the conditions they live in change. In fact, in his K2 response, he asks: "If the leaves were other than green colour then what may have happened [?]. If barks were not of such colour then…" (WR to K2). During the interview he asserts that, even if (for example) the leaves were to change to have red colour, the

[99] We will have other occasions to discuss this complementarity again. See, for example, discussion of S#59's understanding in the Section 6.8.

leaf eating insects "can't become red" (IR). He, however, amends his essentialist-inclinations, when told to suppose that the ancestors of the green insects were not always green. Under this supposition then, being green cannot be the nature of green insects; they have not always been green. Now he could no longer explain the colour by referring to the nature and to the immutable ancestral lineage. Having lost this explanation, he turns to the transformationist explanation – the one he uses in the cases of giraffe, mosquito and L-plant (see below). He thinks that, the transformation to the green insects is caused by the food they eat: "[If their ancestors were not always been green] then they must be green because of their food. They always eat green leaves; it [the green colour] might be because of that" (IR). And if they start consuming red leaves then, when asked this he says: "they can become" red too (IR). But, the change in colour is not caused by the external factors like food alone; the insect's internal structures like the "digestive parts" also have to contribute in the change. Thus teleological transformationist explanation seems to be a default explanation for S#64. Though he is thinking of selectionist explanation in the case of moths, it is connected neither with the evolutionary change in the moth colour, nor is generalised to the similar case of insect colour. When he is taken to think of change in the insect colour, he thinks of change by transformative action of food.

The transformationist teleological thought is also evident in S#64's other explanations. In the case of giraffes, the only possibility he thinks of is that the elongation of neck is caused by the use of neck during the search for food; and the acquired longer necks are inherited in the next generation. The necessity of food and the efforts to fulfil it is the cause that explains the change. But, he is not sure of his explanation – he takes it to be a possibility: "they in search of food for their own daily needs… will be going a little… would see a little high, so the neck of the giraffes would be elongated". Or, he "thinks so", but only "in some [not all the] cases"; it is a possibility, of which he is "not sure"

of (IR). In the case of L-plants, he thinks of two causes of change. One, the catalytic action of the insect excreta and two, the necessity of the plants to protect their fruits form the insects: "The fruits of L-plants have become hairy because the insects may have some excreta… which they have excreted on them and due to catalytistic action it must have formed [the hairs]… to protect themselves from those various insects" (WR to P). When asked which of these causes is a primary cause of the change, he chooses the "catalytic action of the excreta of insects". He seems to think that if there are no excreta that could cause the smooth fruit skin to become hairy, then there will perhaps be no change. But then, the plants have to still protect themselves; how do they do this then? The plants, he says "might change in other way… like ripening [the fruits] before the insects can eat them" (IR). We have two significant lessons to learn from the preceding discussion. The first one concerns all the students discussed in this Section. It is that the selectionist explanation, when unconnected with the larger explanation of accumulative evolutionary change, and when is limited to just a single instance, cannot evidence the conclusion that the student understands the evolutionary change by accumulative selection. On the contrary the student's understanding may primarily be transformationist—teleological. The second thing that we could learn, specifically from S#64's understanding, is that: more often than not, the student's causal explanation is not purely teleological or functional – the change is not caused to achieve certain end that is deemed as a necessity for survival. The student's explanations are not limited to this simple teleology. They often have a physical causal factor that naturalises the teleological/functional explanation. But, at the same time, it must be remembered that the physical cause is invariably *acting* to transform the individual to a necessary adaptive end (See the Section 2.3).

5.20 Selection complemented (and dominated) by Transformation-I: The environment selects as well as contributes to the fitness for survival

S#66's explanation of how in the present we see only long neck giraffes begins with the existing variation in the neck length and explains *how* a variant individual does or does not survive due to the variation it has. She even names her explanation as the one in Darwin's theory: "[In] earlier times there were giraffes having both long as well as short necks. As the tall trees survive, the short necked giraffes did not get their food, therefore they died and the long neck necked giraffes lived; and due to that process now we see giraffes having long neck, because the short necked giraffes have [gone] extinct. [This] is based on Darwin's principle, Darwin's theory of evolution" (IR). Placing the onus of the individual's survival or death on the variation it possesses is undoubtedly a distinctive mark of Darwinian explanation and she clearly states that, "the fittest one who has the ability, some extra ability than the others will grow and will survive, while the rest will die" (IR). Her selectionist explanation is not limited to the giraffe case; she understands the evolution of DDT resistant mosquitoes in a similar explanatory narrative, in which DDT resistant mosquitoes were present, though in a very small number, even before the invention of DDT.

She does *not* think that the relevant individual variation is caused by the individual's necessity to have them for survival. For her, individual variation is "natural" phenomena[100]. It "is a natural process [that] we can't question" … the "Mother Nature" gives [the individual] its special characteristic" (IR to C1). *Nevertheless*, according to her – and here comes her transformationist understanding – the environment contributes to the "fitness" of the variation: "the environment… contribute[s] to the factors [characters]". For her, "the process of natural selection by the environment… contribute[s] to the fitness

[100] Natural change, she thinks, is a "change occurring naturally without anyone doing anything" (WR to L4).

for survival" (IR to C1)[101]. Thus, she has seamlessly incorporated the *word* selection in her explanatory narrative, a narrative which in significant parts *is* indeed Darwinian. But, by "selection by the environment", she does not understand what a Darwinian would standardly do. For her, the contribution of the environment is not in the process of natural *selection of* existing fit traits, but the environment is said to *contribute* to the fitness *for* survival.

S#66's understanding is Darwinian in so far as the existence of individual variation is not *necessarily* linked to the conditions in which it is of use in the individual's survival[102]; and in so far as the increasing number of particular variant individuals is attributed primarily to the process of survival by virtue of having a particular variation. Her understanding is *non*-Darwinian as long as her conception of selection is not in effect a conception of *selection*. That is, her conception is *non*-Darwinian as long as, in her view, the environment contributes not in *selecting* but in *transforming* the not so fit into the fitter one[103] (e.g. DDT sensitive to DDT resistant one). In fact, during the interview, she was explicitly asked whether the transformation of DDT sensitive mosquitoes to DDT resistant ones "forms a part of natural selection", to which she responded affirmatively.

---

[101] These are the responses the student gave while explaining her written response. Hence, "IR to C1" means, interview response to the student's C1 written response. This is generally assumed throughout the text. This note is to remind the reader that in the interview, the student is mainly involved in explaining her written responses.

[102] No doubt that the giraffes with longer necks did exist even before the severe droughts, but yet the stretching of necks does lead to the heritable increase in the neck length[102]. No doubt that the DDT resistant mosquitoes were present even before the invention of DDT, but yet the exposure to DDT does transform the DDT sensitive mosquitoes to the DDT resistant ones.

[103] Here one may argue that for Darwin too the environmental conditions did play some part in causing the individual variation. True, Darwin was indecisive concerning the cause of variation. But, we have to bear in mind that Darwin's indecisiveness was limited to the issues of *origin* of variation. He was not indecisive when it came to the *evolution* of variation.

Her conception of the evolutionary change is *non*-Darwinian in one more significant way. When she talks of adaptation, she is thinking of individual adaptive transformation, not of the evolutionary adaptation by natural selection. For example, when she explains how the offspring of a short necked giraffe could come to have a longer neck, she explains her understanding of the adaptation: "due to the adaptation one of the parent had long neck … [That is] for the survival they had to eat the leaves and so while eating one of the parent must have got the long neck than the other, and that characteristic must have passed to their children … [Thus, the adaptation process is] adapting with nature, the condition that nature has provided, surviving in that conditions" (IR to C5). Further, in Darwin's theory the adaptation is a continual process; the possibility of *the* adaptation does not exist as long as the heritable individual variation exists in the web of dynamic ecological relationships. In her conception of adaptation, in contrast, the process of adaptation, and the "struggle" to acquire it, ends once the individual is adaptively transformed: since birds have "light and air filled bones, they now can adapt to that aerial atmosphere and so they no longer have to struggle for their survival… they are properly adapted" (IR to J1).

Further, for her evolutionary adaptation is not contingent on individual advantageous variants: "*all* organisms adapt to the changes in the environment… for [their] survival" (WR to P; my emphasis). For example, L-plants had to *develop* hairy fruits for the survival: "earlier there were smooth skinned fruits, but insects used to eat them, so for survival, gradually they developed hairs on their skin" (IR). You must note that, here she is *not* missing on the individual variation; in this case, like in all the other cases, she knows that the individuals vary from each other and some of the variants (having a particular variation) survive while others die. To begin with she asserts that "amongst [the L-plants] there must be some fruits which had small hairs and could resist insects". But, in her understanding, this selectionist explanation is immediately complemented by the transformationist-

teleological explanation. She immediately thinks that those who struggle and survive the adverse conditions or enemies would further be adaptively transformed by various means. Why this is so? Why the transformationist-teleological explanation immediately takes over her selectionist explanation? One main reason for this could be her apparent failure to run the selectionist explanation across generations, postulating in each one, the existence and survival of better and better variants. To use Darwin's words, she fails to "sum up in [her] mind slight differences accumulated during many successive generations" (Darwin 1859/1964, p. 29; see chapter one). Instead of explanation by accumulative selection, she takes recourse to explanations like: "gradually… the same plants [who to begin with had slightly hairy fruits], having that characteristic, must have developed them to suit the environment and now they have hair … to protect themselves … [This adaptive development] can be because of climate; to survive the harsh climate they may develop hair … Or, [simply because] the body of the plant responds… so it undergoes a change, but they don't understand, they don't know that" (IR to P).

5.21 Survival of the fittest: The survival of the capable, of adaptive adjustments, of struggle, or of genic activation and development

We discussed how for S#68[104] Darwin's theory is "the *nature's* selection of the capable". Along with conflating the notion of capability of the individual with a notion of selection, S#70 understands Darwin's theory as a theory of "survival of the fittest". The given description in C, he thinks, "tells us about the *natural* change in the body of giraffes. It tells us that… the length of the neck differs in two giraffes … Those [giraffes] who have longer neck are fit to live in this nature … According to Darwin's theory of evolution, the fittest one survives, those who are not fit die" (WRs to C1, C4, C5 and IR). Thus, like a

[104] See the Section 5.8.

number of students, for him too, Darwin's theory is not about the *existing* individual variation. Rather, he thinks that Darwin's theory *predicts* "the survival of the fittest". But, in the case of giraffes, he does not complement his understanding of Darwin's theory with a typical *non*-Darwinian transformationist explanation. He does not think that these fittest individuals undergo the necessary adaptive transformation once they survive or are "selected" (cf. S#68, e.g.). He never refers to external conditions or the necessity/need imposed by these on the giraffe as a cause of the increasing neck length. Thus his giraffe length explanation does not consist in the transformation of neck lengths by the external conditions, or the necessity of the change arising out of these conditions, or the stretching and overuse of the neck. Even the cause of individual variation in the neck length is not said to be any of these; the cause of individual variation, according to him, is the differences in "hormones in the body" each individual has, and the hormonal differences are "because of their parents" (WR and IR to C4 & C5).

But, this understanding is limited to the giraffe situation. In the case of birds, he thinks that they "always had light bones", and hence there is no question of evolutionary change and its causes (IR to J). He writes that he "accept[s] these statements [in J] because a bird cannot fly with heavy bones" (WR to J1). In the cases of leaf and bark eating insects, and of L-plants, his understanding is distinctly different from what it is in the case of giraffes. In the case of giraffes he is not invoking any explanatory *transformation* of the short necked giraffes into the long necked ones, caused by the adaptive ability they have. He does *not* think, for example, that only the "capable" giraffes survive and whenever necessary, by virtue of this capability, they *become* long necked giraffes (cf. S#68. e.g.). In the insect case, however, he *does* think that way: "Leaf eating insects were not green in colour. [B]ecause of their ability to adapt [to] nature they have become green … [E]arlier [many] leaves were not of green colour, today many leaves are of green colour, that's why on eating [these], they have become green in colour … It [has taken a] long time for them [to] become

green". In fact, there is one more reason for their becoming green: "they also become green to protect them from other insects, so that they can they cannot be determined on the green leaves" (WR & IR to K3 & K4).

In the case of insects, we saw that how, for S#70, the *able* insects are adaptively *transformed* by the food they eat for the protection from enemies. It is a typical case of how a supposedly Darwinian explanation enshrined in the slogan of "survival of the fittest" is complemented by partly transformationist, partly teleological explanation. S#70's understanding of the evolutionary change in the fruits of L-plants is another clear instantiation of the seamless conflation of these different kinds of explanations where the organisms try to be fit to survive, in fact "they adopt the ability to survive", and the fittest ones among these survive: "Today the fruits of the L-plants are hairy because… there has [been] a tremendous change in the nature and to survive in the nature this [change] has taken place and according to Darwin's theory 'only the fittest one survives, those who are not fit die'. So to survive this change has taken place" (WR to P).

In the preceding sections, we have been discussing, how the student's various interpretations of Darwin's theory are conflated in various ways with their theistic, teleological, transformationist and (most importantly their) *ability-based-conception* of natur*e's* selection. We will now discuss the understanding of S#02 and S#72. They also understand Darwin's theory as the selection of the fittest, where the 'fit' is the individual capable of the adaptive transformation. But, the conceptualisation of the selection-of-the-fit is different in these students.

S#02 recognises the individual variation among the mosquitoes, and then she writes: "Resistant mosquitoes do not die because they have genes which help them to adapt to the toxic environment and survive. Sensitive mosquitoes lack that particular gene. But with course of time, the next generation [will] try to

evolve it as it is the survival of fittest and they have to adapt [to] the environment. Therefore the scientist studying mosquitoes have discovered that due to continuous use of DDT, the number of DDT resistant mosquitoes is increasing" (WR to A1). Look at what happens to those who do not have the gene that enables the individual adaptation to DDT? As it is the survival of fittest, the mosquitoes have to adapt, and so their next generation tries to evolve to adapt to the environment, and therefore the number of DDT resistant mosquitoes is increasing. During the interview, to make her elaborate on the written answer, when she was asked the possible reasons of increase in DDT resistant mosquitoes, she equates evolution with development of the gene: "because they are developing; actually the evolution is going on, so they are evolving the genes that would help them adapt [to] the environment containing the toxic DDT, so that the coming generation would be able to resist the DDT more efficiently… they are trying to develop the genes" (IR). This raises the question -- can mosquitoes consciously develop or evolve their genes to suit the need of the day? Interestingly, the student is also puzzled over this issue, she asks in A2: "How do sensitive mosquitoes come to know that gene is required to resist DDT?" (WR to A2). At one pint during the interview, while answering to the question A8, she thinks that, "I don't think mosquitoes can decide… basically genes [decide]". But, she also thinks that: "with the passage of time [DDT] can [change the genetic code], but not [suddenly]…, suddenly it won't change…, if the generations would try to adapt so DDT will definitely affect the genes". When asked what she means by "trying", she said: "they try to develop more resistance towards DDT in unity". (IR). Thus to be 'fit' and to survive in the DDT pollution, mosquitoes have to evolve by trying and struggling to develop the resistance genes; DDT may also be of help to them because "DDT makes the gene being more adaptable" (IR). When she was asked what she understands by the "development of a gene", she said: "gene may be actually giving them some kind of protection, and developing some… something that they can resist the DDT… [may be a] new protein, new protein combinations in the chromosomes" (IR).

Note that, in S#02's conception, the surviving mosquitoes have to adapt to the environment, they do not survive because they already have slight resistance. They have to try for their survival by developing the already the gene into a more adapted gene.

S#02 is aware that the characters are controlled by DNA or genes -- you have to have a gene to have the character. She is also aware of the phenomena of genetic recombination and crossing over that result into the differences among the offspring (WR to C5). But, though she is aware of the genetic basis of variation, the struggle to *become* fit to face the environmental condition and the survival of the fittest is dominant in her explanations.

In the giraffe case too, S#02 understands the adaptation to be a response of animals to the changing habitat. Those who adapt survive, others die out: "Giraffes have different lengths of neck depending on their habitat. Some have longer necks, especially [those] which live in forests having tall trees, and others from forests of short trees have shorter necks. During severe droughts only large and tall tress survive… during droughts those who could *adapt and have long* neck to feed on tall trees could survive and others died out. As a result generations have long necks even if drought has passed" (WR to C1; my emphasis). So if the individual giraffe is successful in adaptively developing itself, then as a result, it has a long neck. It is not that the giraffe already has a longer (longer than others) neck and, as a result of having a long neck, *is* adapted.

Like S#02 whose understanding we have just discussed, S#72 also recognises the individual variation in the giraffes – "the passage [C] says that the individuals of the same species are always different… from each other … [Even before droughts] we will find differences [in the giraffe's] neck lengths… [and the differences] will be small… because they belong to same species" (WR& IR to C1). The individual differences across the generation are

also recognised: “In some cases we find that a child is similar to his father and mother, but in some cases we do not find that he is exactly same” (IR).

But, for S#72, the individual difference in the neck length – and the giraffe’s having longer necks – is caused by the giraffe’s stretching of the necks to survive during the droughts: “The giraffes first had very short neck. There were droughts in their place and so only the fittest trees survive. So there was nothing to eat, [so] they stretched [their necks] themselves and now they got long necks”. Giraffe’s effort to survive is not unusual in her understanding. She thinks that: “When any problem in the surrounding rises, one should always face that problem. Because we have to always remember that only fittest one survives and move to next generation” (WR). In fact, she seems to readily reconcile all this with her understanding of the Darwin’s theory. Among the giraffes, the “fitter” ones “faced” the droughts (bravely!), stretching their necks and elongating it and eating the leaves from the tall trees. For her, what Darwin thought appears to be pretty coherent with her just explained conceptions: “According to Darwin’s theory, only the fittest one survive. So at that time also when there was severe drought, the giraffes with long necks only can survive, because at that times the trees were long and so only the giraffes with long necks can eat the leaves and therefore they only survive; and short neck giraffes, they did not survive; and because of that today we see that giraffes have longer necks” (IR). In her understanding, her assertions about Darwin’s theory are not isolated from her conception of the efforts of the ‘fit’ individuals to survive in the adverse conditions. Nor is her conception of evolutionary change completely naturalistic. During the course of interview she realizes that: the longer neck acquired through stretching is to be inherited if the change is to continue through the generations, but she does not think that characters acquired in this way are inherited. Having realized this, she gives up her explanation that the present day giraffe’s long neck is caused because some of them were fit enough to elongate their necks by stretching. Now, it was difficult for her to see how the giraffes come to have

longer necks that are so necessary to survive, and she slips into explaining this by invoking the divine agent – "God has made [the neck] like that" (IR). Her belief in the divine agent must be helping her in answering the following questions that she raises in C2: "How the giraffes got long necks? What happened actually with them?" If what happened to them is not explained in the framework of "fit individuals facing the droughts by stretching their necks", then her understanding is in trouble; and the trouble is overcome by the rise of her commitments to the explanation invoking the divinity. Her understanding of Darwin's theory as the mere "survival of the fittest" is of no help to her here. Had her understanding been complete with the concept of accumulative change, it might have formed a meaningful alternative to her theistic-explanation. But, this is not the case; her current understanding blends the belief in the God given adaptive traits, with the idea that only the individuals with these adaptive traits survive.

Recall that S#72's conception of change also has a component that *agenciates* the Nature and conflates it with the a sort of selectionist understanding. For her adaptive transformation is the adjustment with the nature, and those who are fit to adjust with the nature survive: "Every individual should adjust itself to the surrounding. If it [does] not adjust, the nature will also not adjust with it" (WR to J1). Her following example of dinosaur extinction illustrates this: "in [the time] dinosaurs and all… earth was very suitable… but after [a period] changes came in the earth and therefore they did not survive at that, and so therefore they are not surviving today" (IR to L3). Contrary to the dinosaur's fate is that of the yak's because they adjust with the nature: "in yak and all, they have hairs on their bodies to prevent from that severe cold and so the nature also does not harm that yak and the yak has also no problem with the winter, cold there" (IR to J). The change in the biological world is seen as an "adjustment" to the changing physical condition: "there are many seasons like summer and winter… the climate and temperature changes, we have to adjust to it, so there is some change in us and which is brought by nature …

[For example in] summer we feel very much thirsty but in winter we don't feel so much" (WR &IR to L3). The light-weight bones of birds, and the waxy coating of aquatic plants is the mark of this adjustment. The case of the change in L-plants is no different: "As the nature changes, we too have to change with it. There is severe cold there and so in order to get rid of that cold, they have hairs' (WR to P). The situation is slightly different in the insect's instance. There the adjustment is the consequence of the food they eat – "because what individuals eat also makes a great thing … The leaves are mostly green in colour. So the insects which eat these are also found to be green in colour" (WR to K3 & K1).

5.22 Summary and conclusions

Some of the themes, like "impossibility of evolutionary change", continue to recur again, when we characterise the understanding of Class IX, X and XI students. The Class VII student, we saw, may explain the change in the giraffe neck length as individual transformation caused by the effortful use of the neck or by the forceful drought conditions. But, Class IX student may find these of no causal-explanatory value, at least in explaining large scale evolutionary changes. In the absence of a (convincing) transformationist causal explanation, the student is seen, either denying the very possibility of evolutionary change, or resorting to the theistic explanations. The student thinks that the individual transformation is the sole alternative to the creationist explanation and such transformations seems insensible to her. In addition to citing the insensibility of transformationist accounts, the creationist student cites similarities between the biblical and the evolutionary accounts, and the ancientness of the former, to support her theistic understanding. She thinks the ancientness and similarity evidences that all other accounts of the evolution ultimately borrow from the biblical account.

The student's creationism is supported, not only because the transformative cause is thought to be insensible and implausible by her, but also because sometimes the student completely gives away the necessity of evolutionary transformation. This is because she questions the very notion that once the organisms were so different from what they are today. She doubts the very evidence that says so. Indeed, she places her doubt in the framework of genes and gene activation. For, the genes for long neck were always in existence, possibility since the creation of the giraffes. The short necked giraffe's desire and efforts to circumvent particular conditions merely activates the preexisting genes for long neck. This tells us how a creationist student grounds her theistic explanation in the physical world by using a genetic paradigm. The student, however, does not always ground her theistic explanation in her views of genetic changes. The theistic-essentialist student is also seen thinking that genes themselves could be weak or strong and could be affected by external agents like smoke, but without linking it explicitly with her theistic explanation of individual similarities and differences. The theistic-transformationist student also seems to have some idea of genes in thinking that differences are determined by the type of genes individuals have and the conditions they are exposed to, and yet she thinks that similarities are God given and the natural causes often operate to bring in the good of the beings.

It is interesting to see how in the case of some of the students, the gene-centred understanding supports their theistic explanations, while in other cases it supports their transformationist explanations. In the latter case, the student causally connects the adaptive transformation with her genic-view in various ways. The student may think that the adaptive (individual) transformation casually depends on: the amount of genes one inherits; the direct effect of, chemicals or individual effortful-habits or the individual's adaptive responses, on the genes; and the activity pattern of the adaptive genes. The student is also seen relating the survival competition with the genic activity, where she thinks the competition to be the cause of adaptive gene activity. Here, the

competition is *not* the contributor to the process of selection, but a cause of the process of adaptive transformation. It must, however, be noted that in the gene-centred understanding that we are discussing, the student often preserves the possibility of random, non-adaptive genetic changes. That is, for the student, *not* all of the gene-controlled change is necessarily adaptive. So, when the student thinks about the direct effect of various conditions on the genes, she preserves the possibility of randomness in the process. Because, for her, genes are affected and transformed randomly and not all of the transformed genes get transferred to the following generations. The transformation of genes by direct action of various factors is, hence, not *necessarily* an *adaptive* transformation. Moreover, for the student, all the individual characters need not have *teleological*-genic causes; a number of characters are thought to be the result of *non*-teleological genic causes. Further, genic transformation is not the only cause of adaptive individual change. The student, who understands individual change as genic transformation, also explains individual change as caused by the *ability* of the individuals. This causal-ability is rarely a non-physical construct; in the student's view it depends on the mitochondria, for example.

The *ability* conception appears in various causal forms in various students. We just saw that the individual adaptive transformation is explained by the *ability* to change. The student here is coupling the concept of *ability to adapt* (let us call it adaptive ability) with that of *adaptive individual transformation*. Student also couples the concept of *adaptive ability* with the concept of *selection*, where she thinks that "nature" selects only the individuals with adaptive abilities. In such cases, the student could either have naturalistic or super-naturalistic conception. Whether the student who has a naturalistic conception of nature, but who thinks that the nature-selects-the-capable, has understood the idea of *natural* selection? First, she does not see the conscious selector in nature, but the "nature" is supposed to "select", and she is unclear on what exactly does this mean. Second, the natural selection is not

understood to be a consequence of *actual* survival of the individuals caused by the *actual* variant traits, and adaptation is not understood as a consequence of such survival events of the better and better variants in the successive generations – adaptation is not understood as an evolutionary adaptation. On the contrary, the nature or natural conditions are supposed to select the *potentially* fit individuals who would survive by individual adaptive transformation, and so the adaptation is understood as an individual adaptation. Her conception of the evolutionary change is undoubtedly a *naturalistic* conception. However, it is not a conception of the evolutionary change by accumulative selection, nor of the evolutionary adaptation.

If the student understands natural selection merely as the survival of the fittest, then she has even more reason to conflate *adaptive ability* and *selection*. She thinks that fittest in Darwin's theory are the ones who have the ability to struggle and adapt to the adverse conditions, may be though the adaptive transformation. Hence the *fit* in Darwin's theory are the ones who have *adaptive abilities*. The student may also think that adaptive abilities have genetic basis, and over generations the struggling organism could "evolve" to have the genic adaptive abilities, which it did not have earlier. Here the "evolution" is equated with the "development" of genes that could confer the coming generations with the adaptive ability. Sometimes the living conditions could also contribute to this genic development, according to the student. The student, who thinks this, is aware of the genetic basis of individual variation (indeed most of them are). Yet, her intuitive teleological understanding, that the change happens to fulfil some needs, remains dominant even after learning the genetic basis of the individual variation. The student may find it difficult to understand how could randomness in individual variation gets translated into not so random adaptive change in which the number of only those having an adaptive character increases. The explanation of adaptive change, for her, seems to be that the number of individuals with adaptive traits increases because those who do not have the adaptive trait (but either had the adaptive

ability or evolve it) get transformed into the ones who have these traits and thus the number of individuals having adaptive traits increases. Though they recognize the genetic basis of individual variation, it seems to remain an isolated fact with no causal-explanatory connection with the evolutionary adaptive change.

The student's various interpretations of Darwin's theory are conflated in various ways not only with their *ability-based-conception* of natur*e's* selection, but also with their teleological and transformationist explanations. The student (discussed in this and the following chapter), understands the changing moth population using a selectionist explanation, but neither connects it with the overall adaptive evolutionary change nor generalises it to other similar examples of evolutionary change. In the student's thought the (skeletal) selectionist explanation is complemented by the teleological—transformationist explanation. In the preceding paragraphs, we saw how, in the student's thought, the "selected" individuals are adaptively transformed (because of their adaptive ability). Here, the student thinks that the individual adjustments for survival cause the adaptive change, and thus adapted individuals survive better than others. Thus, the adaptive transformation could complement the selectionist explanation in two ways. In the student's thought, either the "selected" individuals are adaptively transformed, or the adaptively transformed individuals are "selected". In both the cases, the transformation thus complements the selectionist explanation. This individual transformation is often understood teleologically and does most of the work of explaining adaptive evolutionary change, leaving little role to the skeletal, fragmented selectionist explanation[105].

When the student thinks of a selectionist explanation where the variation is acquired by the individuals, this selectionist explanation could be causally

[105] Recall the detailed discussions in the main text Section 5.19.

sterile as far as the evolutionary change is concerned. Because, the student may think that the individuals having the acquired adaptive variation survive better than others, but she may also think that the acquired variation is *not* inherited to the following generations. If this is the case, the student's selectionist explanation could never explain the accumulative change across generations. Hence, the student's conception, in addition to being conflated with the transformationist conception, is causally-empty.

In the preceding case, the student thinks of the individual acquired variation that is not hereditary. The student, when essentialist, thinks of the adaptive advantage of the existing (*not* acquired), hereditary character. But, because of her essentialist thought, fails to focus on the slight individual variation in this advantageous character, and hence she would be unable to construe the selectionist explanation. Thus, the selectionist explanation fails to take off, in one case because the individual variation is not inherited, and in the other, because the specific inheritance is entertained too much to focus on the individual variation.

We have been discussing how the student's selectionist causal-explanation is skeletal, fragmented and conflated with her teleological—transformationist explanation, and how variously the student interprets "natural selection". To add to the student's various interpretation of selection: she could even think that the environment, understood by her as the "mother nature", contributes to the fitness, of the struggling individuals, for their survival. The struggling individuals thus adapt to the nature, and adaptation is understood by the student as a process of surviving in conditions that nature has provided.

All the preceding discussion of the student's understanding tells us how strong the transformationist thought – manifested variously in various students – is

when the student understands evolutionary change. In fact, as one of them (S#03) happens to put it pretty explicitly, for the student the cause that explains individual differences (i.e. individual transformation) is the cause that explains most of the evolutionary change. That is when thinking about adaptations and adaptive evolutionary change, the student is mostly thinking about adaptive *individual* transformation. And, as it will be even more apparent in the coming chapter, when you progress from Class IX-X-XI students to the undergraduates, genes and their activities play a pretty dominant role in the student's understanding of the adaptive change.

6 Causal Structure of the undergraduate student's explanatory narrative of evolutionary change

In the last two chapters we have been discussing the understanding of middle and high school students. In this chapter we will discuss how undergraduates[106] think about organic evolutionary change and adaptation. The spectrum of undergraduate students' understanding falls across the following causal-explanatory frameworks

6.1 Benevolent God—Balanced nature—Natural adaptation—Skin deep Darwinism!

S#58 has theistic tendencies. For he seems to believe that there must be someone or "some driving force", "balancing" and "maintaining" everything on this earth, and if any creature "tries to dominate" this well balanced, well maintained system, such moves will be efficiently countered by the driving force: "[I]n every aspect of life, I have seen that all things been balanced, means everything has a reason there… has a reason for it, for presence of it. So… from childhood, I am thinking that there is God… or any driving force who maintain all this. So like question… is, either the God [is] present or, [is] this all due to physical reason… Everything is just so balanced, means if anyone try to dominate over this system, then something miracul[ous] happen like, like in the case of Dinosaurs, they were [going on and on], just evolving, evolving, but in one stage, who knows that [why/how] they just completely get elapsed" (IR to K2). Similarly, in the case of L plants, when either insects become too many or the plants become too rare, thus threatening the survival and existence of the plants, then "for their survival, they start developing hair… to protect themselves against the insects" (ibid.; IR to P). Indeed, for him, the adaptive change is necessary for survival and seems to be

[106] See the Section 3.1.

necessitated by the survival-need; in the whole scheme of balanced affairs, it is pretty *natural*; he calls it "natural adaptation"[107].

Though he has considerable theistic inclinations in understanding the world, he is aware of Darwin and Lamarck, of people holding Darwin and his theory with great respect though it's controversial. But, he is explicit in claiming that he "always believed that Lamarck is right", even if he is well aware of the examples that disfavour it[108]. In thinking about Lamarck's theory, he says that he is thinking about the "basic core… [or] principle [of] use and disuse of any organ". According to him: "Lamarck had told that if we use an organ then gradually we develop [it] … So you might think [as an example], why we are more intelligent than ape? … [G]radually when those ape start leaving… those trees, in search of food, in terrestrial environment, they gradually less[en] the use [of] their… jaws for deriving food… and their hands for climbing the trees… [and] here the application of Lamarck comes, means they use their brain for these things, for making some plan, for catching animals… for making tools… and gradual less[en the] use of their jaws and use more of their brain, [this] will make them more developed or more intelligent as compared to [other] apes [which did not have this terrestrial life]… [Thus the change in some of the apes is] for the adaptation" (IR to L3).

Contrast this with how he views Darwin and his theory. Darwin's theory concerns only "morphological and physiological" aspects of life; after all, he thinks that Darwin developed his theory just by *observing* and putting together these aspects. In fact, in the contemporary sense Darwin's theory is "just

[107] Like almost all other students in my sample, he too seems to use 'natural' in the sense of 'obvious, automatic *and* unmediated by human agent'. Here it might help to quote his L4 response: "Natural change is truly through nature without any human interruption… [It] takes long time. E.g. formation of Himalayas" (WR).

[108] He talks about the following example that "disfavours" Lamarck's theory: if "my hand is cut due to some reason, according to Lamarck my [coming] generations [will] also get that cut hand, but this is not true" (IR)

telling about mutations" – there is little to Darwin beyond the later discoveries of genetical mutations! "Darwin… will tell you every aspect since from the beginning to the end of any organism… their growth, their competition, then survival of fittest and everything … He showed how they developed, gradually developed, by seeing just morphological behaviour. In other sense, he was just telling about mutations … [In his] voyage… [he] see[s] different islands, the people, the creature which are present there, like [on] Galapagos island. Just seeing all this, he noted down, [and] when he just made them into compact way and presented new theory…" (IR)[109] The causality in (what he thinks to be) Lamarck's theory is perhaps perceived to be deeper than Darwin's shallow observations of "competition" and "survival of the fittest"; further, his Lamarckian world view of development and balance seems to fit well within his general conception of "balanced nature", not the perceived Darwinian worldview of competition and struggle.

6.2 Evolution of different animals/plants—different kind of "primary" cause (or force)—similar underlying (genetic) cause

S#60 clearly narrates his understanding of both the theory of Lamarck and the theory of Darwin. He is aware of the limitations of Lamarckian view, but he still understands a number of evolutionary phenomena in terms of "Lamarckian" ideas. In fact, he claims that different types of organisms evolve by different mechanisms. In his words, *primary force* governing evolution is different in different cases: in the giraffe's case it is the "natural selection of… traits which are advantageous in adverse conditions", but in the insect's case it is obtaining the food full of essential ingredients, whereas in the case of snakes it is disuse of the disadvantageous trait. Though the primary force is thus different in these cases, the ultimate "genetic mechanism behind evolution" he offers, is thought to be the same in all the cases.

[109] This was in response to the question that S#58 writes in his J2 written answer. The question was: "is really, what Darwin has said is true in every extent?"

Now coming to the details of S#60's conception, for him the evolutionary change is always progressive and developmental. For example, he writes that the sentences in J1 "aim to highlight the adaptation which organisms have evolved successfully in their own habitat" (WR to J1). Moreover, he adds, the birds have "obviously come from the reptile stock" and "archaeopteryx" is the "evidence" of this "development". Now, the question is *how* this adaptive development takes place? In the case of birds, the adaptive developmental change is due to the adverse environmental conditions in the "terrestrial" life. "Due to less availability of food" and "due to predators" these land-dwelling reptiles "have developed this ability of flying" and these "adaptations have come to being, this light air-filled bones" etc. Thus, according to him, changing environment is essential for the process of adaptive change; in fact it is one of the main causes, a triggering "impulse": "Primary thing, the main requirement for adaptation, is a change in environment, that is a thing… The normal environment in which the organism is living, that is changing. This [i.e. the environment] will probably give some stimulus… I am not talking of… nervous system stimulus. Not this thing. It is giving some sort of impulse that, that now the conditions are changing" (IR).

For, S#60, then, is the environmental change enough to necessitate the evolutionary adaptive development in the organism? *No*. Though the changing environment is an essential causal factor in the adaptive development, it does not cause the developmental change by directly transforming all the individuals under its influence. There is more to this student's causal-explanatory-story of adaptive developmental change than changing external conditions. Adaptive change is not possible, S#60 thinks, unless the organism has "ability to adapt". What is this "ability to adapt"? "It is not the special capability of organism", but it comes with the fortune of already having an as yet *unexpressed* character, which now – in the changed adverse conditions – has become extremely useful. The environmental change causes adaptive transformation by "stimulating" the "expression" of an existing "inbuilt'

adaptive trait. Having this adaptive trait is having the ability to adapt: "The organisms who have in them this inbuilt characteristic, certain inbuilt traits, which can be used under those adverse conditions, they can adapt… The trait must have been within the organism from before, but the organism didn't get the chance to use it; now under the adverse condition it is getting the chance to use the thing, its the hidden weapon it is having, now you can use it to conquer the adverse condition … But for the expression [of] that trait, now you need that environmental change" (WR to J2).

So there are two causal-explanatory elements in S#60's understanding: an individual's "ability to adapt" and the "adverse conditions". Examples of adverse conditions that he offers are "food stress", sudden increase in the temperature, etc. Moreover, we come to learn that the "ability to adapt" is understood to be synonymous to what he calls as the "genetic mechanism behind evolution". It is indicative of genetic adaptive potential of the organism; in other words, it connotes existence of dormant gene/s whose expression would result in development of the adaptive trait. During the interview, he tells that his school textbooks did not talk about what he now thinks to be the "genetic mechanism behind evolution". It is only recently (in his under graduation days) that he is "getting deeper inside these sort of things, like gene expression and all" (IR).

What S#60 terms as the "genetic mechanism behind evolution" (or the "ability to adapt"), is also a dominant causal element in the explanatory narratives of other students. Let us call such causal-explanatory frameworks, in which the adaptive change is traced to some form of realization of genic-potential, as *adaptive transformation by activation of gene expression*. But, as we will see when I discuss the understanding of a few more students, this causal-explanatory framework takes various forms in different students. For example, in the case of S#59 it support a detailed Darwinian understanding, whereas in the present case (of S#60), it supports a "Lamarckian" understanding.

According to S#60, "Lamarck proposed that the development or the evolution of some new… organ, or [its] modification, depends on the use and disuse of that particular organ". He gives the example of "[evolution] from reptiles to snakes". "Lamarck proposed that", he says, "since snakes are living in the crevasses of rocks or some trees or in the soil making their holes, so [their] small legs were hindrance for moving easily in those crevasses. So gradually they didn't require to use them, that is why, it is gone, it has disappeared slowly… while [in] their closer kin… reptiles, lizards and all, they still have this things because they are ploughing on the wall, on the tree barks, [and] because their lifestyle is suited to use these legs, but snakes can do away with this things" (IR)[110]. As I discuss below, he is also well aware of his understanding of Darwin's theory and of the limitations of Lamarck's theory vis-à-vis Darwin's. Yet, *in the case of snakes* he finds Lamarck to be "quite legible" because having legs is "very problem[atic], it's a disadvantage for" moving deep into "crevasses and rocks" and also for "curling" their bodies as they do, and that's why "Lamarck's this observation might be correct" (IR). His earlier explanation – the one where "ability to adapt" along with the external conditions cause evolution over numerous generations – is not opposed to his "Lamarckian" explanation. In the former case, a useful but as yet unexpressed character is expressed while in the latter case a non-useful (and hence presently unused) character is suppressed. In either of the cases he could say that the organism has the "ability to adapt", in the former case by expressing the adaptive trait while in the latter case by suppressing the non-adaptive trait – for him the "ability to adapt" (to the changed conditions) is thus a "primary force" (IR).

The "ability to adapt" is, however, not a *primary* force in *all* the cases, according to S#60. For example, in the giraffe's case, he "[does] not think its ability to adapt which is a primary force". He explains the evolution of short

[110] While discussing the bird-statement in J, this student had begun talking about Darwin and Lamarck.

necked giraffes into long necked ones using Darwin's theory – "[in giraffes] the main thing is… the special advantage this long neck [has] … that is the primary force in their evolution" (IR)[111]. This is how he details the Darwin's theory with the giraffe's case in point: "Darwin said that… evolution happens due to the natural selection of certain beneficial traits… in certain organisms[112]. He said that previously there was a stock of… sort of deer [like] animals, some had longer necks and some had shorter necks and some were intermediate necks. Now due to the climatic change… the lower trees were totally wiped out. So the smaller organisms, they were taken up by the predators and otherwise [also] they can't get the leaves on the top, top part of the plants, that is why they died. But… those deer like animal which, which had this longer neck, they could take the leaves and that is why they could survive. So they were fit to survive that condition, that adverse condition, that is why the *nature* selected this additional quality, additional modification in them… nature has selected them [the longer necked ones], for further evolution, and those… with the shorter necks… have been wiped out. So nature is selecting beneficial traits under adverse conditions" (my emphasis) (IR). You may note the agent-like description of 'nature' in his narration where the 'nature' is portrayed as the 'selector'. Nevertheless, setting this aside for the moment, many of us may like to believe that this student has a standard enough understanding of natural selection. To a significant extent this claim may not be bogus because of the student's emphasis on the pre-existing individual *variation* and on the *advantage* of having longer necks (which is taken to be a "primary force" in the evolution of giraffes). But, the *un*-Darwinianness of his apparently Darwinian understanding comes into focus once we detail out the causal structure of his explanations.

[111] During the interview, when he completes explaining his "ability to adapt" based understanding of the bird-statement in J, he was asked: "Can you think of this ability to adapt in the case of giraffes?"

[112] Note, "in certain" *not* in *all* organisms!

Though the survival of long necked giraffes is understood to be due to the advantage they have, the idea that this survival of organisms with the beneficial trait *is* their "natural selection", is not evident in any of his responses; rather he thinks that beneficial traits are selected by "nature". An evolutionary biologist or a historian and philosopher of organic evolution may not mind equating the conception of this student claiming "*nature is selecting* beneficial traits under adverse conditions", with the conception claiming "under adverse conditions beneficial traits are *naturally* selected", as expressions of equivalent and equally correct conceptions. But evolution educationists and biology teachers cannot just afford to take this equivalence for granted. Before accepting the conceptual equivalence between these two statements the researcher/teacher has to look for other complementary evidences confirming the student's Darwinian understanding; she has to make sure that to turn the artificial into the natural, the student is *not* simply replacing a conscious agency in artificial selection with some vague "natural" agency, without any appreciation of *how* the Darwin's idea of *natural* selection works, and without the appreciation of *how* "accumulative selection" (Darwin 1859 p. 30, 43,133) *causes* the adaptive evolution. The present student's understanding of natural selection seems to be *lacking* in these complementary evidences, it seems to be lacking in the Darwin's concept of accumulative selection. For this student differential survival of the variant giraffe is caused by the advantageous variation it has, but this differential survival is not seen as a *cause* of accumulative evolutionary adaptive change. Thus, the evolutionary adaptation is not understood to be the result of *accumulative-natural* selection of slight beneficial variations. Instead, the adaptation (long neck) is thought (by S#60) to first "develop" and then "selected", because the individual possessing it "is fit" and hence "obviously has the right to survive and evolve" and so "nature" selects them "for further evolution" (IR). S#60 canonises 'nature' as natural 'selector', a natural agency that does the job of selector – it is natur*e's* selection, not natur*al* selection. We, of course, have to grant that this student, at least partially, understands a few

(or at least one) phenomena in terms of the theory of natural selection, but to broaden and generalise his understanding of the theory, he has to move from understanding natural selection as selection-*of*-beneficial-traits to understanding it as a selection-*caused*-by-the-(benefit of)-beneficial-traits. This move in understanding, when made, will help the student develop a *non*-agency-centred notion of natural selection, and will (hopefully) naturalize his explanations in such a manner that they are more in tune with Darwin's theory of natur*al* selection.

6.3 Teleological Genic Transformation through Mutations Necessitated by Multiple Factors

S#57 thinks that adaptive transformation of the individual is caused by mutations[113]. These adaptive-transformative-mutations are deemed as a survival necessity. They are understood to be caused by the changing environmental conditions *and* the necessities created by these conditions. Hence her understanding of the cause of mutation is teleological; but at the same time, she is aware that the mutation could also be caused by the "mismatch in the DNA repairing".

In general, though she clearly states that the individual similarities and differences are caused by the individual "genetic constitution" (IR & WR to C4 & C5), she also invokes a multitude of other causal factors to explain individual variation: "[individual] similarities and differences may [also] be due to habit, habitat, environmental conditions… metabolic activities" (WR to C4).

Like a number of other students (being reported here), for S#57 too, the conception of change by transformation complements a skeletal, incomplete

[113] Mutations centred conceptions of evolutionary change are also reported in the literature. See, for exmaple, Demastes et. al. 1996 (e.g., Student M in this study says: evolution "occurs *through mutation* of a species" p.415, my emphasis).

conception of natural selection, where individuals are adaptively transformed by the appropriate genetic mutations. And these mutants which have acquired useful traits will survive better than others and thus, she thinks, are "naturally selected". Here are her responses to the giraffe-situation: "Giraffes'… necks may be shorter or longer. They eat leaves of trees. In the severe droughts only large and tall trees survive. Because of which the giraffes having the smaller neck length do not survive as they cannot get the food i.e. leaves from larger trees…" This much may sound roughly consistent with the Darwinian thought. But, for her the just sketched situation does *not* necessitate selection, instead it demands individual transformation through adaptive mutation: "…So, there is a change of smaller length neck to larger one. This adaptation made the species of giraffes to survive... Adaptation is due to mutation… To survive in these environmental conditions, the change i.e. mutation happens" (WR to C). This is how, in one stroke, the teleological transformation complements a skeletal idea of selection. Long necked giraffes survive and they get these long necks through the transformative-mutation. Moreover, remember that they get these long necks so that they could survive.

The survival-need and the consequent mutation, not selection, is the predominant theme of her explanations. Evolutionary change is not caused by accumulative selection of particular individual variants. For her, the evolutionary change issues from the adaptive mutations caused by the needs imposed by the changing conditions: DNA mutates "as per the body requirements", for example (IR to K). In fact, the necessity of slight individual variation is not at all mentioned in the context of natural selection. For instance, insects will not vary or change or mutate as long as the need for mutations does not arise – as long as their colour matches with the

surrounding: "These insects if are protected or defended naturally[114], then, they will not change" (WR to K3).

I will now give another evidence of how, in S#57's understanding, the elements of selectional-explanation exist but are dominated by the teleological-transformationist-explanation: "Change in the biological world is due to different things as environmental conditions, mutations, natural selection, adaptive radiation, defence etc. In the regions of industries, one moth is observed as *Biston betularia* which is grey in colour. But that moth was unable to survive on the plants or trees as it get identified very easily by prey. This easy identification of grey coloured moths was because the tree barks had become black due to the smoke and on these black tree barks grey moths could easily be identified. So the survival had become very difficult for them. Hence, for survival, after a few years, a sudden change, mutations, occurred within them, natural selection happened and they were converted into black coloured moths i.e. *Biston carbonaria*… The adaptation was for survival"[115].

6.4 Genic-naturalistic-teleological adaptive change: Genome is conceptualised as nature that naturally acts in accordance with the necessities

S#13 seems to equate "nature" with the organism's "genetic composition". The "nature" is supposed to "brings out" the (adaptive-transformative) change in the organism so that the organism could successfully face problematic situations. In fact, it is thought to be "the rule of nature that one should have the ability… to overcome the obstacles which one [is] facing". Her understanding of adaptive evolutionary change is teleological, and yet

[114] Here naturally seems to mean "on their own", without someone else protecting them from without.

[115] This is a mix of her written and interview responses. Her written response was written in clear English, her interview response was a mix of English and Hindi, wherever she had used Hindi words, I have translated them

naturalistic. It is teleological because the adaptive transformation is brought out specifically to "overcome a problem" in the organism's life. It is naturalistic because, one, the "genetic composition" (dubbed as the "nature") brings out the adaptation, and two, this "bringing out" of the adaptive transformation is *never* thought to be dependent on efforts and habitual actions of the organism (like neck-stretching). Like in the case of number of other students beings discussed here, S#13's teleological—transformationist[116] understanding of adaptive change is supported and *naturalised* by her gene-activity centred understanding of the adaptive change. Whenever necessary, genetic composition brings out the adaptive change simply by activating genes that are already present in at least some of the individuals. For example, in the case of giraffes, she thinks that a genetic change is "responsible… for increasing the length of the neck". This change, however, is *not* "because of stretching", but because of "necessity for the survival": it "is *necessary* for them to eat the leaves [of tall trees] for their survival … In the changed environment, they *have* to survive, that's why the genetic change occurs" (IR). The necessary change is effected via adaptive gene activity, *not* by any conscious efforts on the part of the organism to meet the needs. Here, it should be noted that, though S#13's understanding uses the "adaptive transformation by activation of gene expression" framework, unlike S#60 for example, for S#13 this framework does not complement the "Lamarckian" (change by use/disuse) understanding of evolutionary change.

For S#13, necessity is not always the sole cause of the adaptive activation of gene expression. Sometimes specific gene expression is caused by the external conditions, like continuous exposure to smoke in the case of moths. But, the conditions cannot cause immediate gene expression, a number of generations (or at least one) have to experience the conditions before the adaptive genes could be active: in the moth's "own lifetime it [the change of colour due to

[116] The opposite of *teleological—transformationist* would be *non-teleological—selectionist*.

exposure to smoke] may not happen … [but] its next generation may become [dark in colour] … One should be able to survive in the condition which [one] is facing, that's why the next generation may *express* the black colour" (my emphasis) (IR). It should be noted that, he is aware of the fact that "due to smoke accumulation on barks, the dark coloured moths are not identified [by the moth eating birds]" and hence "dark coloured moths are more in industrial areas" (WR). But, evidently, this remains an isolated fact in her genic-naturalistic-teleological understanding of the cuse of evolutionary change.

6.5 Non-teleological gene expression produces two kinds of variants— non-accumulative selection

S#12's view[117] combines a conception of dominance and recessiveness of genes with a broad-skeletal conception of selection. Her understanding of evolutionary change does not attribute any causal role to the slight individual variation. The dominant/recessive gene expression pattern produces two *kinds* of variation – long necks and short necks, for example. One of the variants, in this case long necked giraffes, survives and proliferates and that explains the evolutionary change. The student could be said to have some idea of Darwin's theory, but she certainly does not have an understanding of *accumulative* selection.

According to S#12's conception, ancient giraffes were short-necked because they had a dominant gene responsible for the short-neck phenotype. But, at least some of the ancient giraffes also had a recessive, mutant form of the dominant gene. The mutant form of the neck-controlling-gene, if expressed, would produce long-necked giraffes. But, during those days, as the gene responsible for long necks was recessive, long necked giraffes were rarely produced; and even if they were, this long neck did not "give them any edge"

[117] Unlike all other students in this study, no written responses of this student could be collected. The analysis of her understanding is based on the interview transcript.

over others (IR to C1). Does this mean that the favourable mutation in the neck-controlling gene is caused by the external conditions? No, she says: "Drought or some physical factor won't as such create mutations, mutations have their other reasons; other mutagenic causes are there". In S#12's understanding, genetic factors are enough to explain evolutionary change from short to long necks, but (*un*like S#13, e.g.) the genetic transformation is *not* understood to be teleological.

6.6 Evolution is unfolding of hidden genetic traits: Adaptive activation of gene expression, governed by survival necessities, changing conditions and the organism's efforts—Transformation complements non-accumulative selection

S#15 has an idea of the Darwinian scheme of explanation: Today's giraffes "have evolved from shorter ones… most of them had shorter necks… [However] some had, in comparison with others, longer necks… When this severe crisis came about, this drought, they have to get their leaves from tall trees, and those ones who had advantage of long necks than others, they survived and they reproduced more, and eventually giraffes with longer necks perpetuated" (IR to C1). *But*, this explanation is evidently overshadowed by his understanding of evolution as the genetic unfolding of hitherto "hidden" traits. He says: "actually, this elongation of neck is actually hidden in their genetic trait; it was hidden [in] some of them… In the absence of that crisis [of prolonged droughts] it was not expressed, but when there [was] a need from nature, then it was expressed generation by generation" (IR)[118]. Typically, he thinks evolutionary change to be an adaptive activation of gene expression, governed by the survival necessities in the changing conditions and the organism's efforts to beat them. His causal understanding is gene-centred:

[118] In response to his C1 (written) answer, it was asked to him that if a short neck giraffe uses its neck to eat the leaves of tall trees, can the giraffe's neck become longer because of its continuous use and stretching.

"Whatever we are [is] actually expressed by [our] genes, [this is the case in] any organism. So there is difference, in the same species also there is difference. And this difference is [because], in some cases, what these genes are supposed to express [is] not expressed… up to that extent, as in some other cases. So [because] of this, as I mentioned, some of them had comparatively long neck, they have that gene, which expresses that quality [of] longer neck. [It] was more expressed in them…, [whereas it was] less expressed in the shorter ones. And so as the condition demanded, so this longer [necked] ones… had more ability to survive, and by this… [the] trait, which is already there in their gene, was more expressed, means more developed, by generation by generation." (IR). Note that, for S#15, if a giraffe has the gene for long necks, then the extent of its expression depends on the demands of the conditions. But, do these environmental conditions influence many genes or just those controlling the neck-length? He thinks that only the neck-length controlling genes get induced by the droughts because they are the ones whose activity is needed at that time: "actually its the need, need will change, target that gene only; means as this condition creates this drought, so there is need of only elongation of neck, so need will create the change" (IR). Contrast the specific adaptive gene activation in giraffes with the case of moths. He thinks that, in moths, the conditions like pollution – only if very high – can cause genetic changes like mutations. And, the pollution induced change can be in any of the genes, not necessarily in the genes controlling the colour. Why this difference?[119] The difference is because, in addition to the living conditions and consequent needs of the organism, the organism's efforts towards the suitable adaptive transformation are equally important. Giraffes "stretch [their necks] to eat", but moths "don't do anything, they are just eaten up" (IR). Hence, in the giraffes specific genes are activated, but not in the case of moths.

[119] The questions that I have written while narrating the understanding of S#15 are actually the questions asked to S#15 during his interview.

Recall that his explanation of "why we now see giraffes with much longer necks" had Darwinian elements. Similarly, his response to "why the number of dark coloured moths is increasing" resembles standard Darwinian understanding, except a stark reference to the moth's *becoming* dark: "[F]irst, before the industrialization… maximum [number of moths] were light coloured, [and] some were dark coloured; means out of… thousand, one or two were dark colour. As… there is advent of industrialization … *due to pollution, some become black*. Ok… [the] birds feed on these insects and it's obvious, it's clear, those who are not black, they will be preyed down easily, and those who are black, they will have their survival benefit over the others, and so that *benefit made them proliferate* in a greater pace than the other ones; so as this continues their number increases and after some time almost all of them become black" (my emphasis) (IR to B1).

In S#15's explanation above, two very distinct *kinds* of conceptions of evolutionary change – namely, transformationist and *non*-accumulative (hence skeletal) selectionist – are evidently encapsulated in the two response fragments: "due to pollution, some *become* black" and "*benefit* made them proliferate". Similarly, his explanation of the giraffe case also had a transformationist and a selectionist component: first one explaining the gene-mediated, necessity-governed, effort-directed, unfolding of adaptive traits (that suitably transforms the individual), and the second one narrating how those who had comparatively longer necks had the advantage and hence out-survive others. Is S#15's understanding compatible with the Darwin's understanding? *No*, because unlike Darwin for him adaptive genetic change is caused by the 'need' that is created by the 'demand' of the prevailing conditions. The evolutionary change is achieved through the unfolding of the transformative action of the genes, not through accumulative selection. He does refer to the "advantage of long necks" and links it to the survival of the giraffes, but this survival is not causally-linked to the *accumulative* evolutionary change. For, those who survive get a chance to unfold the adaptive genetic trait; and, in the

final analysis, evolutionary change is caused by the increased gene-expression: "to outstand that crisis [of drought]…you should have that quality [of slightly long neck]; … they should survive first… then only they will be able to express that [gene/s] or proliferate; those who can't, they will perish" (IR)

6.7 Teleology—Genic Transformation—Nature's Selection: Confusions of confounding teleological, gene-centred and transformationist conceptions

S#55 thinks that organisms, including plants, try to adapt to the environmental conditions in which they live – they are even conscious of the efforts they have to take to survive in the existing conditions (for example, they may be aware that "they are devoid of certain nutrients" (IR to P)). Now, to adapt they have to change themselves: "Adaptation is trying to fit into an environment" (IR to L). For S#55, the organic change, including adaptive evolutionary change, is possible only through mutations: "Evolution is all about the changes in the genetic makeup of the organism… so evolution is basically because of mutations" (IR to P). Hence, she is led to think that, the *trying* of organisms to change themselves to adapt as well as the *environment* to which they are adapting, have to have some role in "bringing" the *mutations*: "adaptational change" has to have "something to do with the environment" and also with the "trying to adapt" (IR to J & K).) *But*, she does not know *how* the environment and the organisms' strivings are related to the mutations.

Added to all this is her interpretation of the terms "spontaneous" and "natural". However, it is this interpretation that helps her in partially resolving her own question of how the necessary compatibility between mutations and environmental changes is achieved or maintained. She relates the 'spontaneous' with the 'natural', where 'natur*al*' is no different from 'natur*e's*'; and hence for her spontaneous mutations mean mutations occurring because of 'nature'. Now, as environment is a part of the nature, she thinks that the mutations caused by environmental conditions are the same as what

are commonly known as “spontaneous mutations”. For her then, the mutations “may be [because] environment is imposing stresses on the organism” (IR to J). And this way, the question of the relationship between evolutionary change by mutations and the environmental conditions in which these mutations are taking place (which, to her, is the central question; see the previous paragraph), is at least partially taken care of, she believes. I write “partially taken care of”, not fully, because during the course of interview she admits of her great confusion in understanding how exactly the environment and the organisms’ efforts are related to the mutations (recall that for her mutation is the sole means of evolutionary change). Thus, her confusion could be the effect of her twofold conviction, which she herself admits to be contradictory: one, that every change in the individual, including the evolutionary change and adaptation, is a consequence of gene mutations; and two, the adaptational needs of organisms and their efforts to meet these needs, as well as the environmental conditions in which the organisms are living and to which they are to adapt, have some significant role to play in causing the adaptive change. Thus the confusion stems from her not having a convincing answer to the question of how the need and efforts to adapt could affect the *genetic* process of adaptive change.

In her own words, for her “the ultimate goal [of any organism] is to fit into the environment, ultimate aim is to fit into the environment to survive. So I think mutations helps in that, it brings about evolution and then it helps”. But, at the same time she knows that “mutations basically… [a]rise… in nature… due to certain defects in replication and all the processes that take place… due to some errors in the transcription and translation, all that processes” and so she does not know how, to what extent, or “whether they, [the genes], are affected by the environment”. She knows the molecular basis of mutations; she knows that “we cannot bring about mutation by like trying to change… or it’s not necessary then every mutation that is taking place it will give like desired result. So [for her] the whole thing is contradicting now”. To add to this, she is

aware of "natural selection": "natural selection is a property by which they… not property exactly… like…. They – [the green insects] – are protected from the preys… like… when they are feeding on the green leaves… there predators cannot recognize them. So like this is a way of natural selection, so like, they survive in there" (IR to K). But, while talking about an evolutionary change from non-red to red insect-colour (a situation discussed during the interview), in an insect population feeding on red leaves, she says that she is "not able to think" how this change takes place. But after giving a long thought to it she comes up with a clearly non-Darwinian explanation: "They acquire the colour of the stuff they are feeding on so that they will be safe from their predators and they will be safe in their environment" (IR). Apart from the preceding explanations, she talks about the evolutionary change mediated by the environment controlled recessiveness and dominance of the neck length determining genes: Giraffes "develop some long necks to reach the leaves up of the tall trees … Now the conditions in [which] they are living in, they have to have a long neck to reach the leaves of tall trees, if they have to survive … [So] the short necked character has become recessive … [and the long necked character has] become dominant… because of change in the environmental conditions" (IR to C1, C3-4 and C7).

When told to summarise her contradiction, she said: "I am all confused about change, trying to change, whether they are successful or not, then whether mutation is responsible for their change and whether environment is playing some role in the changes or whether mutation and environment are related" (IR). Why this confusion in explaining and understanding evolutionary change? One of the major reasons is that, a number of different ideas could possibly constitute the causal explanations of evolutionary change. Often, these ideas are not conceptually contradictory. Indeed they might as well seem to complement each other in forming a coherent whole explaining the evolutionary change. For example adaptive change appears to be a change directed to achieve certain functional outcome that makes the individual

survive in the given conditions. These conditions also seem to matter then. Also the students are generally aware that offspring inherit the traits from their parents and they often have some idea of its genetic basis. Thus, to the student, the genes, the living conditions, the survival needs, all of these seem to be equally – and necessarily – valid contributors to the causal-explanation of the adaptive evolutionary change.

6.8 Selection complemented by Transformation-II

S#59 has quite detailed, and evidently standard, conception of natural selection. He interprets the statements given in J and K as instances of his "concept of evolution", of "adaptive change", of "adaptations that make a particular organism survive better in its specific chosen habitat" (and hence accepts it) (WR to J1). He explains the change of the smooth L plant fruits to the hairy L plant fruits using the concepts of "survival advantage" and "selection pressure" and assuming the variation in the fruit skin hairiness since the beginning: "Among the ancient smooth fruit producing L plants, some hairy fruits would have been produced and they would over generations increase in proportion due to natural selection as they would not be eaten by the beetles. Since these hairy fruits are not eaten, they have an advantage… Over generations due to this survival advantage and selection pressure working in this direction, the L plants producing hairy fruits would predominate in the population" (WR to P2). Similarly, preexisting variation in neck lengths, survival advantage of being long necked and the changing average neck length in the evolving population mark his Darwinian understanding of the adaptive change described in C.

From many of his responses, it is seemingly clear that he understands evolutionary change in a Darwinian way, and distinguishes short term individual adaptive change from long term populational adaptive change. To him, the former is caused by an individual's need to change in the face of short

term changes in the environmental conditions, whereas the latter is caused by the process of natural selection. His understanding of long term evolutionary change is also grounded in the concepts of advantageous variants and consequent populational changes. The written response to K4 is another example of his standard 'selectional' understanding, as it emphasises the colour-variation, presence of green variants, the advantage that individuals with particular colour-variation have, how particular variation will be advantageous only in a particular set of conditions (like presence of predators and leaf colour) and the changing structure of the evolving population. Moreover, in K3 he writes that the leaf eating insects were not always green, rather "they evolved into these colours over years / generations" and these "leaf eating insects will be of same green colour unless the colour of the leaf itself changes to some other colour. Otherwise by natural selection, the green coloured insects feeding on green coloured leaves will continue to remain green or in fact in future, over generations they will evolve to resemble the leaf colour… more & more".

Nevertheless, hereditary evolutionary change by *selection* is not the only alternative which engages him. For, he thinks that environmental conditions could cause hereditary adaptive *transformation*, of individuals having appropriate genes, by manipulating their gene expression pattern. What will happen if a population of insects living on green coloured leaves start living on red coloured leaves? It was this question that received a transformational account of evolutionary change from him. According to this account, environmental conditions could adaptively transform the individual by manipulating the extent of expression of the gene/s (in his words by manipulating its "penetrance"): "Like [if] I [and] you have the same gene but you may express it to a different extent, I may express it to a different extent, based on the environment I am exposed to… So even a twin when he is born, he is having the same genetic constitution as his twin, but based on environmental influence his variability, penetrance of the genes is getting

different … [In insects living on green leaves, red colour producing] gene will not be expressed because over generations they have been feeding on the green leaves. Because of the environment the penetrance of that [red colour producing] gene would be less in those organisms. But when I shifted [them] to the red leaves, over generations, the penetrance of the gene will increase. So more organisms will become red, those who are having that [gene], they will become red, they will survive better than the others and they will replace [green coloured insects]" (IR).

Note how seamlessly he has combined the developmental transformative action of environmental conditions with the idea of natural selection. His account of change by adaptive-transformative gene expression complements – rather feeds into – the student's detailed understanding of change by natural selection. The environment-induced change does not contradict the selection-mediated change because the effect of the former (transformative change) could easily be taken as one of the causal factors in the explanatory narrative of the latter (selection process). The resulting (combined) narrative is a hybrid of Darwin's *selectional* understanding of evolutionary change and (what I have been calling as) the *transformational* understanding of evolutionary change. What is lost in this hybrid narrative is Darwin's emphasis on *slight* individual variation as well as his *de*-emphasis on the conditions, in which a variation would be advantageous, as a cause of the variation[120]. In this student's explanation, the "red-environment" causes the transformation of insects through the expression of red-colour-giving genes. The advantageous colour-variation is caused by the transformative action of the environment in

[120] For example, Darwin writes: "Seedlings from the same fruit, and the young of the same litter, sometimes differ considerably from each other, though both the young and the parents… have apparently been exposed to exactly the same conditions of life ; and this shows how unimportant the direct effects of the conditions of life are in comparison with the laws of reproduction, and of growth, and of inheritance ; for had the action of the conditions been direct, if any of the young had varied, all would probably have varied in the same manner" (Darwin 1859, p. 10).

which having red colour would be an advantage. S#59's hybrid explanatory narrative that combines the selectional and transformational understanding of evolutionary change is, however, *not* to be confused with the narratives of those students who understand evolution to be purely a transformational process. In the latter case (unlike the understanding of S#59), environmental conditions would cause the transformation of the *entire* population; the environment is not posited as causing the adaptive change in only those individuals who have the necessary genetic potential (like having a gene or genes for red colour). There will be no distinction between adaptive individual transformation and natural selection of the adaptive variants. In contrast, S#59 seems to maintain this distinction – for example, he distinguishes between a scenario in which a whole "population itself adapts... [that is] all the animals start developing hollow bones" and a scenario in which "nature or survival selects those animals" who have more hollow bones than others. In the latter case the "normal curve [of bone density in a population] will shift" as "the mean bone density of the population… decrease[s]" because the animals with less bone density "are able to survive and reproduce better" (IR).

6.9 Evolutionary change by natural accumulative selection

Now, I will characterise the causal understanding of the students whose explanations have little non-Darwinian elements (*un*like the ones discussed in the previous sub-sections). The student, whose understanding is similar to the one offered by Darwin's theory of natural selection: one, almost invariably distinguishes between the cause of variation and the cause of natural selection, and between individual (ontogenetic) change and evolutionary (phylogenetic) change; two, has a clear understating of the causal contribution of an advantageous variation in the variant's survival (and hence the variant's natural selection); three, interprets 'chance' (as in, e.g. 'chance variation') and

'natural' (as in, e.g. 'natural change') as they standardly are, in the context of the theory of natural selection. I will now illustrate this.

S#53 understands the cause of variation (in his words "mutations") by contrasting "chance" with "purpose". The causal event producing variation does not have any goal or purpose. In fact he thinks that it will be "absurd" to talk of "purpose" here: "[Occurrence of mutations is always by chance] because actually you can not have a distinct bias. Like… if you have a bias that this mutation is bound to happen, it sort of talks of purpose… Like… if there is a bias for a gene mutation which will lead to this formation of these waxy cuticle. So that means this species has a purpose, which is like very absurd. How can a species have a purpose of developing something? It's always chance". Just as the cause of variation is not directed by any conscious or super-conscious purpose, it is also not directed by the environmental conditions: "the change in environment is not the cause for mutation" (IR to J).

This student not only dissociates the *cause* of variation from a directing conscious agency or the environmental conditions, but at the same time thinks of the *effect* of the variation/mutation: mutation occurs "always [by] change" and "the chance can be negative or positive". For example, he says that a chance mutation/variation could be of help to the variant to "perform… [a] function in a better way, which gives it more advantage than others". Further, he thinks that "If the mutation which happens doesn't have any positive effect, any positive advantage in that changed environment, natural selection will not happen. But if in that changed environment a chance mutation happens, which is more favoured, then… [its] frequency will keep on increasing" (IR). He thus (correctly) locates the cause of natural selection in the positive advantageous *effect* of the mutations. When he talks about the central idea in the Darwin's theory, he talks about how the variation enhances adaptability and contributes to the better survival: "the light, air filled bones and the waxy layer both

enhances the adaptability to the respective conditions and hence the chances of survival" (WR to J1). He emphasises the "survival advantage" even in his L3 response. There he relates biological changes to changes in the physical world, but immediately writes that "such [biological] changes must have a survival advantage" (WR).

We saw how his (S#53's) interpretation of 'chance' is suitable in understanding natural selection. Similarly, his interpretation of 'natural' must be helping him in understanding the *natural* in 'natural selection'. Unlike S#13 or S#55, he does not relate 'natural' with the 'nature'. Natural is understood as necessary or automatic -- a natural change is "unaided change", a change that is "bound to happen". In contrast artificial change is aided change; it is generally "due to interference from humans" (WR to L4-5). Here is his example of natural change: "The rising of the Himalayas… was bound to happen. Bound to happen in a sense that… suppose [if] human kind 200 years back [had] tried to nullify such a change, it wouldn't have been possible … [T]he plate tectonics, which were already formed, they were formed in such a way so as Himalayas will automatically be formed… [I]f the plate tectonics didn't form that way, so may be Himalayas wouldn't have been there. But that [the formation of plate tectonics] again is due to some other thing which preceded it, and in all there [is a] sequence of things, human interference doesn't play any part, it's all very natural … We can initiate or we can catalyze that change, may be. We can…we can. For example…we talk about, like desert formation due to drying up of a river. It's a natural change, naturally it would have taken may be 1000 years, due to our misleading activities we can reduce it down to 100 years" (IR).

Also, it is evident that S#53 understands individual variation as a "continuous" and "natural" variation: "continuous variations… [are] bound to happen in any population". Further, he relates the natural continuous variation to the adaptation and evolution: "if such a continuous variation leads to a more

favourable adaptation, then it can lead to evolution ... Suppose a situation comes after certain time, which favours still taller neck lengths, so then this continuous variation [in neck length] which was already there is giving rise to natural selection" (IR to C3).

Like S#53, S#54 too understands adaptive variation as originating by 'chance' and *not* by any kind of 'necessity' – survival or the one "imposed" by the external conditions. And, for this reason, rejects the statements in J. Further, he understands the selection of these "adaptations" (or adaptive variation) to be a consequence of their *self-advantage*: the "adaptations arose by chance and were selected because they were advantageous to the organism in the particular niche. Whereas the statements [in J] apparently say that the adaptations arose because of the niche" (WR to J). Thus, he does not confound the cause of a variant character with its beneficial-consequence: external conditions, in which the trait is beneficial, do not cause the trait's genesis through the transformation of a non-adaptive trait into an adaptive trait. But, the conditions could be such that, under these conditions, some of the existing (variant) traits are favourable to the individuals who have happened to have them.

Moreover, for this student, evolutionary change is related with the *establishment* of an existing (adaptive) variation, not to its *origin*. Contrast the understanding of S#54 with the student, in whose understanding there is little distinction between individual-transformative-change and evolutionary-selectional-change and hence to her evolutionary change is explained if the origin of individual adaptive change (i.e. adaptive variation) is explained. The focus of such a student would be on the 'origin' or 'cause' of the variation, not on the 'establishment' of the variation in the population, nor would it be on the 'advantage' of the variation. I now quote an instance illustrating S#54's focus on and understanding of the 'advantage' and 'establishment' of a variation in the population of insects: The colour "confers evolutionary advantage to [the

green insects living on green leaves] … [But] if a mutation in insects making them green arises on bark populations, the survival chances [of these mutants] will be low, they would be spotted by the predators for instance and the change will not be *established*" (WR to K4; my emphasis).

Like S#53 and S#54, S#56 too understands natural selection in terms of "advantage" or "disadvantage". He too has a distinct idea of *how* (in each of the cases) advantageous variation causes the survival of the variants, in the prevailing conditions. I will now instantiate how the distinction between individual (ontogenic) adaptive change and evolutionary (phylogenic) adaptive change is understood by this student in terms of "short-term adaptation" and "long-term adaptation".

For S#56, the "statements [given in J, (and also K)] are examples of long term adaptation, which are culmination of millions of years of evolution guided by selection pressures as well as random events like genetic drift" (WR to J1). He contrasts the long term adaptations with "short term adaptations… like people going out in sun will get darker skin … Long term adaptive changes are at the level of population and they are able to be transmitted from one generation to the other. And short term adaptive changes are mainly somatic in nature. They actually do not affect the germplasm as such; like a person who is exercising too much, he will get muscle, but his germplasm, his sperms are not gaining that weight" (IR to K1).

S#56 not only understands the "individual/evolutionary" distinction, but also recognises and writes about the apparent *teleology* in the statements given in J as well as K. For him the statements give in J and K, signify reversed cause-effect relationship. In other words, to him these statements sound teleological: "The *cause* and *effect* relationship (use of the word 'why') is not quite definitive. The sentence could have been put in a reverse order as well" (WR to J1). In (he elaborates in the interview) "teleological explanations… we are

taking the effect first… and then we are projecting the cause back". But, "after we have known mechanism of evolution… [these] type of statements acquire new meaning" (IR to J1). However, significantly, he appreciates that our intuitive conceptions are invariably teleological; to begin with they were teleological – "you cannot exclude teleology from the conceptual development of science because whenever you see something for the first time, your mind always work in a teleological way… Like whenever you see that, ok certain plants are having so many thorns, so suddenly, suddenly in your mind an idea will emerge that ok these thorns are because they [the plants] would have to be protect against the [enemies]" (IR to J).

6.10 Summary and Conclusions

The undergraduate student considers various causal possibilities and reflects on them together. She is seen explicitly referring to God, Lamarck and Darwin in a single explanatory narrative and thinks theistic and Lamarckian conceptions to be causally "deeper"[121] than those of the Darwin. Darwin's theory, the student thinks, mainly concerns the morphological and is merely a bundle of observations that tells nothing beyond what we now know as mutations. While the student's Darwin talks about the struggle, her theistic conception explains "balance" in this world. This balance, and downsizing of the organisms who try to breach this balance, is something that could hardly be explained by purely physical causes, the student thinks. In the student's theistic understanding of the balanced and well-maintained world, she situates the adaptive change and finds it but "natural" that for survival (and for overcoming the dominance of competing individuals) the individual adapts to the prevailing conditions.

The undergraduate understands evolutionary change using multiple causal accounts that often vary from case to case. The student may think that the

[121] Going "deep" up to the level of genes!

primary causal force governing evolution is different in different cases. But many of these causal accounts are very often grounded in genes and their activities. The gene-centred causal accounts dominate the undergraduate's understanding of organic change. These accounts take various causal-forms in the student's explanations and mostly support the transformationist understanding of the change.

We saw how the school student explains the individual adaptive transformation in terms of adaptive ability, where the adaptive ability, in itself, is thought to be the cause of adaptive change. In undergraduates, the causal-explanatory notion of adaptive ability often gets explicitly rooted in the gene-centred explanatory narrative of evolutionary change. In this narrative, genic activity becomes the locus of causality, and adaptive ability is understood as adaptive *genic* ability: that is, having the adaptive ability is simply having the genetic potential that could be realised in the adverse conditions.

Unlike the school student, the undergraduate's conception of adaptive ability is not only rooted in the gene-activity but it also gets entangled with what the student thinks to be Lamarckian and Darwinian ideas of organic change. So, in the student's understanding, the genetic adaptive potential is put to use by the expression of an advantageous but dormant character, whereas the expression of disadvantageous and unused character is suppressed. The student also thinks that the expressed adaptive character is *selected by nature*; and in thinking this she *agenciates* nature by casting the nature in the role of a selector. This is nature's, not natural selection, where the student's causal-explanation has no evidence of *accumulative* selection[122]. The student's selectional understanding is not only limited to a case (or at most a couple of cases), but in thinking of selection, she is often thinking of selection-*of*-beneficial-traits, not selection-*caused*-by-the-(benefit of)-beneficial-traits.

[122] See the main text of this chapter and the Section 1.5.1

Apart from the adaptive gene activation, adaptive gene mutation caused *for* the survival in changing conditions, complements the student's skeletal selectionist ideas. The student's teleological notion of the adaptive change, which we discussed so often in the earlier chapters, is apparent again, now well rooted in her understanding of genetic mutations. Note that, what is playing out here is not necessarily the misunderstanding of mutations (the student is well aware of the mechanisms that cause mutations), but it is the dominance of teleological ideas, now sanified and perceived by the student to be deeply rooted in the physical notion of gene mutation. Indeed, the student's teleological ideas could become so entrenched with her idea of the genetic adaptive ability that the student becomes a *natural* teleologist. She begins thinking that it is the *nature* of the living entity, embodied in its genome, to adapt. In other words, the student thinks that it is natural that the genome brings out the adaptive individual change, simply by "activating" an adaptive gene. The adaptive trait is thus already in existence, but "hidden"; during evolution the hidden adaptive traits get expressed in accordance with the survival necessitates and (the related) individual efforts. It is, of course, not necessary that the student who understands the change in terms of adaptive gene activation should always be teleological in her thought. Without being teleological, she may be think that the gene activation pattern could produce only two *kinds* of variants, out of which one is selected. Thus her understanding here is non-teleological and selectionist, but it has little room to accommodate the causal conception of *accumulative* selection.

We see that various students evidently accommodate their teleological thought with their understanding of the genetic bases of change and inheritance. We even come across a student in whose understanding the causal explanation centered on individual adaptive *transformation* by adaptive gene activation, co-exists complementing a detailed – *not* skeletal – selectionist understanding. But such complementarity is not present in all the cases. We do find a student who could neither deny the teleology in the adaptive change, because it is so

apparent and clear to her perception; nor could accommodate the theology with the her gene centred causal understanding.

In the student's understanding, individual adaptive transformation though is commonly, but *not* necessarily, linked with the Darwinian selectionist understanding. We find students whose explanations are entirely selectionist. Such students: one, almost invariably distinguishe between the cause of variation and the cause of natural selection, and between individual (ontogenetic) change and evolutionary (phylogenetic) change; two, has a clear understating of the causal contribution of an advantageous variation in the variant's survival (and hence the variant's natural selection); three, interprets 'chance' (as in, e.g. 'chance variation') and 'natural'.

7 Conclusions and implications: Towards the problematic of understanding Darwin's theory of natural selection

7.1

Before we begin to conclude this work, in the light of the preceding chapters, I will critically look at some of the literature in science education research that theorises about the difficulties in understanding organic evolution (by natural selection).

As we have been discussing and will discuss in the following sections (also refer to the Section 1.6), the student's understanding of the *natural* in "natural selection" is central to the issues of learning Darwin's theory, and hence the analogy between the natural and the artificial is of significant pedagogical concerns. Moore et. al. (2002) bring this up in claiming that the most significant difficulty in the pedagogy of natural selection is the difficulty created by use of "figurative shorthands" (p. 66) in written narratives of expert biologists and textbook writers. This use of figurative language, they argue, would often have "anthropomorphic and teleological" effects (p. 66) on students' understanding. Using words like "competition", "survival of fittest", or even "*action* of natural selection" can easily convey a sense of an *active agency* where organisms seem to be acting purposively to achieve beneficial fit with the changing environment. The usage of these words can also be taken to represent the process of natural selection in "agentative terms" (p. 66). For experts, terms like "competition" may just be metaphorical shorthand but, Moore et. al.'s work demonstrates that novices often fail to understand it as figurative shorthand in the representation of the process of natural selection (also see Wood-Robinson, 1994).

While Moore et. al. locate the difficulty in understanding natural selection in the metaphorical representations of the theory, Rudolph and Stewart (1998)

use their historical analysis to interpret the problematic of understanding Darwin's theory. Their argument is: there existed a historical discord between the model of science Darwin's theory of natural selection presupposes (or introduces) and the model of science then accepted by the scientific community of the time; there are educationally interesting parallels between the then accepted model of science and the model of science currently presupposed (by teachers/researchers) in science classrooms – both derive their conception of science from Newtonian physics; there are interesting parallels between accounts of 19th century reception of Darwin's theory and the current accounts of student learning; and students' difficulties in understating the theory "are less perplexing when considered in light of resistance Darwin encountered from the scientific community of his own time" (p. 1070).

Darwin's theory, Rudolph and Stewart write, was perceived by Darwin's contemporaries as strongly materialistic, naturalistic, and not meeting the prescribed standards of having deductive predictions proved by direct observations. The theory met with the deep-rooted belief in the divine agency and metaphysical commitments to teleology and essentialism. The authors claim that students' difficulties in understating the theory "are less perplexing when considered in light of [this] resistance that Darwin encountered from the scientific community of his own time" (p. 1070). But throughout this well written paper we keep wondering how the 19th century reception of Darwin's theory explains the difficulties of students in the present day evolution classroom. One possible answer that this paper might offer is that the Darwin's contemporaries and today's students share the same metaphysical (teleology, essentialism) and methodological (physics centered, highly empirical and normative conception of scientific method) commitments, and hence they have difficulty in understanding and accepting the theory. Even if this is the correct diagnosis of the contemporary difficulties in understanding Darwin, the following questions remain: *how* does the essentialist and

teleological thinking hampers students' understanding of natural selection? And, *how* the more inclusive, heterogeneous conception of science would help students to develop naturalistic thought that looks at nature naturalistically, leaving behind their teleological and essentialist thinking? The history of biology can contribute in our understanding of "the past intellectual conditions that impeded the scientific *acceptance* of Darwinism", but the claim that these same conditions "have persisted over time and may influence student conceptions in ways that make *understanding* evolutionary theory difficult today" (p.1075; my emphasis) definitely needs further elaboration and defence. The authors seem to merge the important distinction between *acceptance* and *understanding* of a scientific theory; and they seem to suppose that understanding and acceptance of a theory are intrinsically related with one's conception of science, and a more naturalistic conception of science that includes "methodological, metaphysical, and social components as fundamental constituents of practice" (p. 1085) would help students *understand* Darwin's theory. It is easier for me to see the claim that, if the students accept a theory because they deem to be scientific (as seemingly is the case in India), then the *acceptance* of Darwin's theory will depend upon students conceptions of science. But it is quite difficult to see how *understanding* the theory is affected by one's conceptions of nature of science, even if it is more naturalistic and inclusive. Even if we grant that the understanding and the acceptance compliment each other, one may not necessarily guarantee the other[123]. Agreed that if the metaphysics one subscribes to is in conflict with the metaphysics inherent in Darwin's theory, like Darwin's contemporaries, our students will have great difficulty in accepting the theory. And to remedy this, students must be provided with "a more accurate view of the functional role metaphysical assumptions play in the advancement of science" (p.1082). But recognizing the difference between one's own metaphysical commitments and those implicit in the theory, though

[123] See Southerland and Sinatra, 2005.

essential, is not enough to define and solve the conceptual difficulties today's students face in understanding Darwin's theory of natural selection. They would also have to learn how the Darwin's explanation is naturalistic, and how the causality in his theory does not operate to accomplish the goals of any agency. "A unit on evolution taught in a traditional science classroom may seem to students something of an entirely different kind, consisting of material describing a theory not subject to the usual rigorous tests of scientific accountability", but the point that this is "*obviously* a potential obstacle to student learning" (p. 1078; my emphasis) is not that obvious. I entirely agree that Darwin's theory is of its own kind, and the realization of profound metaphysical and methodological implications of Darwin's theory and their legitimization as proper science by our students should be one of the main goals in evolution education. But, to *learn* how the theory is different from others and to strengthen the realization of these differences, our students have to engage with the causal structure of the theory. Without this engagement, the "naturalistic model of scientific practice" (p. 1082) would be of little help in learning the naturalism of Darwin.

Ferrari and Chi (1998) place the onus of the students' misunderstanding of natural selection on their "deeper" mistake of *mis*categorising the concept of natural selection to an "ontologically distinct" category, a category to which it does not belong (like categorising a "living" dog as a "stuffed" one; if this is done then the misclassified "dog" will be inferred of being "finally crafted" or say "ill looking" etc) (pp. 1234-1235). In contrast, I put the onus of the students' misunderstanding on the causal-epistemological uniqueness of the idea of natural selection (See the Chapter one). Ferrari and Chi (1998) suggest that "students will greatly benefit from science instruction that emphasized the underlying ontology of modern evolutionary theory" (p. 1231). Apart from my differences with their interpretation of the "ontological category" of the process of natural selection, I suggest that the instruction in natural selection will greatly benefit (benefit whom?) from the emphasis on the

epistemological-causal-explanatory structure of the idea of natural selection, that is on *how* the idea of *selection* explains evolutionary change. Of course the two claims (mine and Ferrari and Chi's) need not be diagonal to each other, but they do differ significantly in their focus.

To a certain extent, it *may* turn out that students do indeed miscategorise some of the ontological features of the "selection"; but, in the main, my work proposes that the root of their misunderstanding lies in their misconstruing of the causal explanatory structure of the process. Their misconception may not be because (as Ferrari and Chi argue) the students apply the "event ontology" to evolutionary processes, but because of their failure to construe how *natural* selection is possible and how the selection *causes* evolutionary adaptive change – the idea of *natural* selection is not generally present in the student's possible world.

In the preceding paragraphs I have highlighted the differences between my theorising of the students difficulties in understanding natural selection, and that of Ferrari and Chi's. My position is explained at many points in this work. When it comes to Ferrari and Chi's position, I have specific dissenting comments on their construal of the process of natural selection as an instance of an "equilibration sort of concept" (p. 1237). Ferrari and Chi distinguish between "event attributes" and "equilibrium attributes" of ontological processes. They claim that students understand evolutionary process as events (for example, events in which individuals are struggling to achieve certain goals), attributing to it an event like properties. But natural selection does not fit in this "event ontology", instead it fits in, they argue, the "equilibration ontology". It would, however, be a mistake (misrepresentation?) on the part of Ferrari and Chi to categorise natural selection as an instance of "equilibration process" alone, and interpreting natural selection so that it has all the properties of "equilibration" and none of the properties of "events". If one examines the attributes of these distinct ontological categories ("event

attributes" and "equilibration attributes"), it is evident that natural selection will have a few attributes of *both* the "event-like processes" and the "equilibration-like processes". Hence it would be un-illuminating to trace the students' misunderstanding to the so called *miscategorisation*; the distinction between "event ontology" and "equilibration ontology" could perhaps be fruitfully applied to the learning of certain concepts like the concept of 'diffusion', but in the case of 'natural selection' it seems to be an artefact of an unsuccessful application of a preconceived distinction to the study of the problematic of evolution education. If one carefully and even faithfully follows this "ontological" distinction outlined by Ferrari and Chi, it turns out that natural selection has *some* of the properties from *both* the contrasting categories – it has some of the "event attributes" *and* some of the "equilibration attributes", while not having some from each of the categories.

For example, natural selection could be categorised as an instance of equilibration process because it is simultaneous and continuous (all the variants in a population are simultaneously subject to the process of natural selection, and as long as individual variation is there – which usually is the case – natural selection continues to operate), it could as well be categorised as consisting of distinct causal events (survival of dark coloured moths are distinct selectional events, caused by the advantage dark colour has in the polluted environment). Now, if the natural selection is a consequence of distinct survival events caused by the individual advantageous variation, it cannot be said to obey a property of "uniform action" that a typical equilibration process is claimed to have. It makes no sense, in fact it is ironic, to say that just as "all molecules participate in the same sort random motion", all individuals in a population participate in the same sort of random selection! Selection is "selection" because it is not random. Unlike the process of diffusion (diffusion is Ferrari and Chi's classic example of equilibration process), natural selection is neither uniform nor random (and that is the reason it is called "selection"), but consists of deterministic causal events (e.g.,

Hodge, 1987; Sober 1984, especially pp. 86-102) – the origin of variation is random not its natural selection. Just to take an example from Ferrari and Chi's analysis: They classify the following response as showing an equilibration attribute of *not* alluding to the "causal subevents". The response is – "if one of the trees that was planted in a more parasitic environment had genes that protected it better, it would survive and reproduce while the other trees died". This response is clearly causal: the "better protection" provided by the genes *causally* contributes to the survival of the trees.

Hence I conclude, contra Ferrari and Chi (1998), that the "ontological" distinction between "events" and "equilibration" processes is not useful to assess and explain the difficulties students have in understanding natural selection. Even if in one's reading of natural selection seems closer to the *equilibration* processes, on another equally valid reading it clearly and essentially seems to have causal *events*.

Before moving on to my concluding statement of the problematic of understanding natural selection, I will critically review two recent proposals in evolution education – Catley (2006), and Geraedts and Boersma (2006).

Catley (2006) proposes to have move emphasis on the species concept, and hence on what is termed as "macro-evolution", in evolution education. But its relevance for evolution education is not immediately clear from Catley's arguments. Evolution educators, I suppose, would like to distinguish the reconstruction of the evolutionary life history from the *understanding* of the processes that cause and explain this evolution. For "the paradigm of outgroup comparison" may allow "inferences to be made about events that happened in the past" (p. 773), but how does it help in understanding the explanations that will justify these inferences. Inferring evolutionary patterns may be "the *primary* activity of evolutionary biologists" (p. 779, my emphasis), but not necessarily of evolution educators. The primary concern of evolution

educators, I believe, is to communicate the ideas that explain the life history and evolutionary patterns to the students. The author assumes that the "specific tools" used by scientists should be equally useful for the students (p.770). He seems to have mixed the significance cladograms carry for phylogeneticists with the potential significance it might have for the evolution education. For example, the author claims that cladograms provide "a conceptual framework to explore and test many evolutionary concepts" (p. 781), but for whom? For a working evolutionary biologist committed to the philosophy of Hennig or for a teacher interested in making sense of the evolutionary process? Also, the author seems to have merged the process/product distinction. The claim that the cladogram is a "visualization of *processes"* (ibid., my emphasis) can be contested. Whether cladograms represent the products of evolution or the process of evolution is a matter of debate. Cladograms may bring out the evolutionarily significant characters, but learning the causal significance of these character, learning the process of evolution, is clearly a distinct issue. Are these causal processes that explain the grandeur of life represented in cladograms? As far as *understanding* natural selection is concerned, I question the utility of the distinction between micro-evolutionary and macro-evolutionary perspectives. Natural selection is *a* process[124] having both micro and macro level consequences. The student first needs to understand this process, and then the conditions under which it leads to the divergence of characters. To infer the process by looking at the evolutionary relationships depicted in the cladogram presupposes the understanding the process itself.

In a significant work, Geraedts and Boersma (2006) propose a learning—teaching strategy, focusing on "reinvention" through short texts and a series of questions – one leading to the other, following, according to the authors, the logic of theory of natural selection. The sequence of questions that is meant to

[124] A process wherein advantageous variation accumulates across generations.

"reinvent" the neo-Darwinian theory is reflected in the following order: phenotypic variation; variation in adaptedness; differences in the chances of survival and of reproductive success, and its effect on the composition of the population after; introduction of the concept of natural selection, introduction of the concept of mutation. Thus, as we can see the sequence clearly, and successfully, follows the logic of Darwinian theory. In fact, in my view, it is done so logically that it misses to concretely *establish* the causal link that consequently leads to natural selection, the link between the self-advantage and the self-survival of a slightly adapted variant. After developing the concept of adaptive variation in the first cycle, the focus of the teaching learning sequence shifts on the concept of population, keeping implicit an individual advantageous variation's crucial causal contribution in the survival and reproduction of the variant. In fact, as no causally complete story of natural selection can afford to miss it, this important point of how advantageous individual changes or variations are necessary for the process of natural selection is talked about at the end of the sequence. The result is that student's learn all the events occurring in the long process of natural selection – adaptive individual variation, differential survival and reproduction, changing composition of the population and random variation. But, in this whole learning sequence, I doubt if they get a chance to learn the causality that links these events into the natural process of selection. I will now illustrate my position with some evidences from the paper.

As I noted earlier, after introducing the concept of variation, the sequence switches to the concept of population, and, apparently, it is within the context of population, the concepts of differential survival and reproduction are introduced. The authors do mention that they "build on" the individual differences in adaptedness to bring in the concept of differential survival and reproduction, but, they never tell *how* do they do it. This *how* is significant because the concept of natural selection is ingrained here; students will find it extremely difficult to understand natural selection, if they fail to grasp the

causal contribution of the variation's self-advantage in the process of its selection. Instead of "building" the idea of selection, the sequence seems to move on swiftly to the changing composition of the population and introduces the concept of natural selection "by *referring* to this change" (p.851; my emphasis). The authors write: "Given the assumption that differences between individual organisms are at least partially hereditary, students must be able to predict a change in the composition of the population after several generations" (ibid.). The emphasis on population in the sequence is not misplaced, but, in my view, it comes at the cost of *emphasis* on the explanation of the selection of *individual* variation. The authors state: "The notion that evolutionary change takes place at the population level and not at the level of the organisms is in fact central to our learning and teaching strategy" (p. 849). But, the important question, which we have to answer, is in what sense does the change *take place* at the level of populations? In overplaying the change at the level of population one should not forget, *how* this change comes about. It is the selection and inheritance of *individual* changes that eventually effects into evolutionary change that might get manifested at the population level. We have to keep in mind that, it is the *character* of evolutionary change, not merely its level, that makes the decisive difference between Lamarckian and Darwinian theories of evolution[125] .

Having critically looked at the literature in science education research that directly deals with problematic of the student's understanding of organic evolutionary change, we will now move on to the concluding statement of this work.

[125] The focus of discussion shifts slightly if one talks about group selection, but the essential point remains, and I suppose that here we would not like to take the discussion to the group selection debates.

7.2

No two individuals in a population are identical to each other and we always find that a characteristic varies across the (intra-populational) individuals – the individual variation is ubiquitous. The student in this study (and the student studied in various other studies[126]), clearly recognises the individual variation. But, when focusing on the variation the student's thought is primarily focused on its *cause*. That is, while thinking about variation in a character among the (intra-specific) individuals, the student usually thinks about the individual changes, and their cause, that produce the individual variation in question[127]. The student distinguishes, neither between the cause and the consequence of the individual variation, nor between the individual and the evolutionary change.

To understand Darwin's theory, the student should distinguish between the cause (origin) and the consequence (effect) of the individual variation. The student's causal explanation often fails to honour this distinction. The theory of natural selection is the 'theory of effects' – what matters is the effect of continual variation and inheritance, not its cause (as long as the variation is stable and hereditary). The student's focus is on the cause, and since she rarely differentiates between the individual change and the evolutionary change, for her the cause of individual change (i.e. individual variation) is the same as the cause of evolutionary change – origin of variation among individuals directly accounts for the origin of variation among species.

[126] For exmaple: Jensen and Finley1996, p.898; Clough and Wood-Robinson 1985b, p.307; Wood-Robinson 1994

[127] Bishop and Anderson (1990) are also pointing to this in noting that: evolutionary change is not viewed by the student as a changing "*proportion of individuals*" possessing a particular trait. Instead, evolutionary change is seen by her as "*gradual change in the traits themselves*" (p.423; emphasis in original).

To enhance the *causal* significance of the *consequence/effect* of the variation in the student's thought, the teacher/researcher could focus on the variation's *advantage* – the student may think about the possible advantages of some of the variation for the variant individuals. But, recognising the individual variation and realising its advantageousness for the variant is often not enough to understand natural selection. The student may recognise that a particular characteristic varies from individual to individual and that a particular variation is advantageous for the variant. But, this advantage is often perceived as a goal towards which the casual-system (whatever that may be) works. Note that again the student is thinking of the cause, this time the cause of an *advantageous* variation. For example, if neck length varies among the individual giraffes, and if longer necks are advantageous, then the student thinks that the biology or behaviour of the giraffe will somehow act to cause the longer necks. The advantage of the variation is thus understood as an effect, but rarely as a cause. In natural selection self-advantageous variation is the cause (see chapter one). Hence, to understand natural selection the student has to think not only of the advantageous effect of the variation, but also of the effect of this advantageous effect[128] (which is natural selection of the variants having advantageous variation).

Another distinction central to understanding natural selection is the distinction between the function's contribution in causing the *genesis* of a structure, and the function's contribution in causing the *existence* of the structure – to repeat, the theory of natural selection is a theory of effects and existence, not the theory of causes and origins.

In the preceding paragraphs we discussed how understanding individual variation is a pre-requisite for understanding natural selection. Whereas the

[128] The *effect* of individual variation in the giraffe neck length is advantageous to the giraffes who have necks longer than the others, and the *effect* of this advantageous variation in the neck length (having longer necks) is natural selection of the long neck giraffes.

student usually is thinking about the *cause* of the variation and about how the advantageous variation could be caused, to understand natural selection, the student is to think about the *effect* of the individual variation and what this effect of the individual variation finally *effects* into. It must however be noted that in the student's scheme of understanding either of these could be absent. For example, the student may understand the individual change as deviations from the normal and natural; she understands the variation as consequence of defective reproduction, development, nutrition etc. For this student, the variation will be necessarily *non*-advantageous. The student here is locating the cause of variation within the individual, and the variation may also be random for her – the two conditions that are essential if one is to understand natural selection. To understand natural selection, it is important that the student dissociates the cause of variation from the *external* conditions and thinks about its random occurrences. The student seems to do that. But, for understanding natural selection, the student's causal-explanatory framework must permit the possibility of *self-advantageous* variation. The student, who thinks the variation to be aberration from the normal and natural, lacks in exactly this – in her understanding it would be almost impossible to conceive of an *advantageous* (and hence adaptive) variation.

7.3

Given that the student's thought is focused on the cause of individual change, that is on the cause of the individual variation – *not* on the variation's causal-consequence or causal-effect; and given that for the student there is little separation between the individual change and the evolutionary (or populational) change, it should not surprise us that the student understands the evolutionary change in terms of individual transformations. In fact, it is paradigmatic to the student to understand evolutionary change in terms of *transformation* of individuals, rather than in terms of *selection* of individuals. The student explains the organic adaptive change by transformative action and

not by accumulative selection. In the preceding chapters, I have discussed a large variety of the transformationist causal conceptions – theistic, teleological, essentialist, naturalistic-physicalist, gene-centred etc., and their multiple combinations. I do not intend to summarise all that discussion here, as one could find a broadly sketched summaries at the end of each of the chapters. But we will revisit some of the essentials below, while further detailing out the problematic at hand.

Along with the cause/consequence distinctions discussed in the preceding section, the nature of causes could also explain their prevalence in the student's thought. The causality in transformationist explanation is concentrated and deep – it is located in some unitary agency. For example, it involves physical causal action or the efforts on the part of the individual[129]. There is no such single concrete causal-agency operative in the selectionist explanation.

The cause in the school student's transformationist explanation is further "deepened" and naturalised in the undergraduate's thought by rooting it in the gene-centred explanations. We frequently spot the undergraduate student using her understanding of genetic basis of variation to naturalise her ideas of adaptive individual transformation. In such causal-explanatory frameworks, the adaptive change is traced to some form of realization of genic-potential: adaptive activation of gene expression or adaptive gene mutation is thought to be caused by survival necessity, environmental stress, changing conditions, or a combination of these (S#13, S#57, S#60). Moreover, the adaptive gene expression or mutation is very often caused for fulfilling the needs of the time, it is often a teleological gene activation/expression. But not always. The gene activation could be understood, at the same time to be naturalistic (i.e. purely physicalistic, without any reference to any conscious efforts) as well as

[129] The reader is referred to the discussions in the preceding chapters.

teleological. Or it could also be understood to be non-teleological and naturalistic.

In the preceding chapters we also discussed various forms of creationism operating along with various transformationist conceptions. It is significant to note that gene-centred understanding could also support the student's creationist conceptions. The student may think, for example, that the characters and the character determining genes must have always been in existence (perhaps since their creation by the God), but they may possibly be dormant. The individual (developmental) change is caused by the changes in the activity of the genes, when the dormant genes become active developing the adaptive character (some genes may be active at some time whereas other ones some other time).

The student may think evolutionary change to be impossible in the absence of a plausible transformationist explanation that could account for the large scale evolutionary changes. The student thinks of a number of possible causes and rejects them as *un*explanatory. For example, in the giraffe neck case, she thinks of continual stretching of the neck or droughts as the examples of the causes that do not have enough explanatory potential to explain the said large scale change in the neck length. In fact these are the vary causes with which the other students understand the neck length change. Yet they may fail to be of any causal value in some of the students' understanding. It seems that when the student does not understand organic (evolutionary) change as individual transformation, the usual alternative does *not* consist in understanding the change by accumulative selection. In the absence of transformationist framework, the student is seen either denying the possibility of change or subscribing to the creationist explanation.

Finally, before we close this discussion of the transformationist cause in the student's explanation, it has to be noted that, for the transformationist student,

adaptation is *becoming* – becoming better in survival and reproduction. In contrast, in the selectionist caual explanation, adaptation is *being* – being better in survival and reproduction.

7.4

Transformationist cause predominates the student's understanding. But, this does not exclude them from the selectionist thinking. Indeed, in the undergraduate's understanding we often see the (skeletal or fragmented) selectionist explanations accommodated to some form of the transformationist explanations. In the (undergraduate) student's thought, either the "selected" individuals are adaptively transformed, or the adaptively transformed individuals are "selected", and thus the complementarity of selectionist and (teleological) transformationist explanations is quite common: for the student, the latter may be a general fact applicable to most of the living beings whereas the former may be a specific fact applicable only to specific populations in some specific conditions. For the student, the latter explains the organic adaptive transformation and hence also the organic evolution, whereas the former explains the population level changes with no perceived relation with the organic evolution.

Even the notions of "competition" and "struggle" are used by the student to aid her transformationist understanding of the evolutionary change. For her competition may *not* be a contributor to the process of selection. On the contrary, competition heightens the need of the animals to have, or to develop, the adaptive trait that will help them survive through the current competition.

Selectional and transformationist explanations may be *scientifically* incompatible, but they are not *conceptually* incompatible. It seems that this conceptual complementarity (of different *kinds* of scientifically incompatible explanations) allows the student to assimilate the learned elements of selection theory to her intuitive-transformationist understanding, and thus some (often

skeletal) idea of selection gets wedded to an idea of adaptive transformation. When it comes to explaining organic evolution, these two ideas – namely, *transformation* and *selection* – are together pressed into action. In some students, the multiple causal factors complement each other in explaining the evolutionary change and end up having a non-contradictory (or coherent) understanding of evolutionary change that incorporates genic-transformationist as well as selectional explanations with equal ease. Whereas another student finds so many causal-factors confusing and could not decide on the details of causal-relationships among various elements of the causal-picture explaining the evolutionary change.

The theory of natural selection presupposes *slight* individual variation and explains adaptive evolution by accumulative selection, not by adaptive (genetic) transformation. It is not aimed at explaining the *origin* of adaptive individual variation, but its *accumulative evolution*. But, the student's conception, where adaptive characters are acquired via the genetic change explains well *both* the origin as well as evolution of the individual variation. Even if the student adds her idea of natural selection to the notion of acquired adaptive characters, to complement and complete her explanation of adaptive evolutionary change, in effect most of the explanation is done by the acquired adaptive transformation and little by her notion of natural selection.

The student's thought not only complements her selectionist understanding with her transformationist understanding of the organic change, but – perhaps in search of a concrete causal agency – often *agenciates* the "natural" in "natural selection".

The "natural" is generally understood in the light of the "artificial", but it is understood variously. In chapter one, we saw how the natural gets defined in the theory of natural selection. There the natural is understood in a complete *contrast* to the artificial, where natural is something that could happen without

the human agency. The student also understands the natural in the light of the artificial. But, she understands the natural in *analogy* with the artificial, where the natural is caused by the 'nature' just as the artificial is caused by the 'human being'[130].

For the student, n*ature* selects the adaptively able, that is nature selects those who have the *ability* to adapt to and sustain certain conditions; and once selected by nature, their ability is actualised when the selected individuals are adaptively transformed. This is what Darwin's theory is all about, the student thinks. She thinks: if the Darwin's theory is all about the survival of the fittest, then the *fit* is selected according to the Darwin; and if the *fit* is the one who has adaptive abilities, then it is pretty obvious that the adaptively able is selected.

Thus, Darwin's theory is often dubbed by the student as "*nature's* selection of the fit; or the fittest one are said to be selected by *nature* – i.e. survival of the fittest"; it is not seen as the *natural* preservation or survival of the better and better variants in the successive generation and thus as an *accumulative natural* selection. Students fail to "sum up in their minds slight differences accumulated during many successive generations" (cf. Darwin 1859, p. 29). Hence, the teacher/researcher has to ensure that to turn the artificial into the natural, the student is *not* simply replacing a conscious agency in artificial selection with some vague "natural" agency, without any appreciation of *how* the Darwin's idea of *natural* selection works, and without the appreciation of *how* "accumulative selection" (Darwin 1859 p. 30, 43,133) *causes* the adaptive evolution.

[130] I say *analogy* because, instead of understanding natural as something that happens without human agency, the student visualises some agency in nature that acts almost like a human being (though it is not a human being in essence, it is one in action).

To take her skeletal and fragmented understanding of natural selection that is often limited to explain just a few instances of evolutionary change, the student has to move from understanding natural selection as selection-*of*-beneficial-traits to understanding it as a selection-*caused*-by-the-(benefit of)-beneficial-traits. This move in understanding, when made, will help the student develop a *non*-agency-centred notion of natural selection, and will (hopefully) naturalize his explanations in such a manner that they are more in tune with Darwin's theory of natur*al* selection.

We could also hope that the non-agency-centred notion of organic change will also help the students in understanding the fundamental distinction between change caused by transformative action and change caused by accumulative selection. Natural selection causes evolutionary change by accumulative selection. But, accumulative selection, if at all, occupies secondary position in the student's understanding. The student naturalises the idea of adaptive transformation, by placing it in the gene-activity centred paradigm of understanding organic change. In contrast, Darwin naturalised the idea of adaptive accumulative selection.

I will conclude this discussion by listing out the various distinctions the student has to learn to understand Darwin's theory of natural selection: cause vs. consequence of the variation; individual change vs. evolutionary change; heritable vs. non-heritable individual change; cause of individual change vs. cause of evolutionary change; change by transformative action vs. change by accumulative selection; nature's selection vs. natural selection; genesis of a functional structure vs. existence of a functional structure; the causal value of usefulness of a structure for its *existence* vs. the causal value of usefulness of a structure for its *origin*.

The preceding pages sketch the problematic of understanding the causal structure of natural selection. In these pages we come across a spectrum of the

student's causal understanding of evolutionary phenomena, and how this spectrum contrasts with the causal structure of Darwin's theory of evolution. This contrast helps us frame the pedagogical issues related with the learning of the natural selection theory. I have discussed some of these. But a more detailed discussion of these, specifically in the context of the textbooks from which the teacher and the learner generally draw their understanding, demands another occasion.

References

Allen, C., Bekoff, M., & Lauder, L. (Eds.). (1998). *Nature's purposes: Analysis of function and design in biology*. Cambridge, MA: MIT press.

Bardapurkar, A. S. (2008) "Do Students See the "Selection" in Organic Evolution? A Critical Review of the Causal Structure of Student Explanations". *Evolution: Education and Outreach 1(3),* 299-305.

Banet, E., & Ayuso, G. E. (2003). Teaching of biological inheritance and evolution of living beings in secondary school. *International Journal of Science Education 25*(3), 373-407.

Bishop, B. A., & Anderson, C. W. (1990). Student conception of natural selection and its role in evolution. *Journal of Research in Science Teaching, 27*(5), 415-427.

Bizzo N. M. V. (1994). From down house landlord to Brazilian high school students: What has happened to evolutionary knowledge on the way? *Journal of Research in Science Teaching, 31*(5), 537-556.

Brandon, R. N. (Ed.). (1996). *Concepts and methods in evolutionary biology.* Cambridge: Cambridge University Press.

Brumby, M. (1979). Problems in learning the concept of natural selection. *Journal of Biological Education, 13*(2), 119-122.

Catley, K. M. (2006). Darwin's missing link – A novel paradigm for evolution education. *Science Education, 90*(5), 767-783.

Clough, E. E. & Wood-Robinson, C. (1985a). How secondary students interpret instances of biological adaptation. *Journal of Biological Education, 19*(2), 125-130.

Clough, E. E. & Wood-Robinson, C. (1985b). Children's Understanding of Inheritance. *Journal of Biological Education, 19*(4), 304-310.

Cobern, W. W. (1994). Point: Belief, understanding, and the teaching of evolution. *Journal of Research in Science Teaching, 31*(5), 583-590.

Darwin, C. (1964). *On the origin of species: A facsimile of the first edition*. Cambridge, MA: Harvard University Press. (Original work published 1859)

Darwin, C. (1872). *On the origin of species* (6th ed.). Retrieved December 31, 2007, from http://darwin-online.org.uk

Dawkins, R. (1986/1988). *The blind watchmaker.* London: Penguin.

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*(1), 7-15.

Demastes, S. S., Good, R. G., & Peebles, P. (1996). Patterns of conceptual change in evolution. *Journal of Research in Science Teaching, 33*(4): 407-431.

Ferrari, M., & Chi, M. T. H. (1998). The nature of naïve explanations of natural selection. *International Journal of Science Education, 20*(10), 1232-1256.

Fodor, J. (2007, October18). Why pigs don't have wings. *London Review of Books, 29*(20), 19-22.

Geraedts, C. L. and Boersma, Kerst Th. (2006). Reinventing natural selection. *International Journal of Science Education, 28*(8), 843-870.

Greene, J. C. (1959). *The Death of Adam: Evolution and its Impact on Western Thought,* Iowa: Iowa State University Press.

Gruber, H. E. (1981). *Darwin on man: A psychological study of scientific creativity* (2nd Edition). Chicago: University of Chicago Press.

Gutheil, G., Vera, A., & Keil, F. C. (1998). Do houseflies think? Patterns of induction and biological beliefs in development. *Cognition, 66,* 3-49.

Hodge, M. J. S. (1987). Natural Selection as a Causal, Empirical, and Probabilistic Theory. In L. Kruger, G. Gigerenzer, and M. Morgan (Eds.), *The Probabilistic Revolution,* (Vol. 2, pp.233-270). Cambridge, MA: MIT Press.

Hodge, M. J. S., & Kohn, D. (1985). The Immediate Origins of Natural Selection. In D. Kohn (Ed.), *The Darwinian Heritage* (pp. 185-206). Princeton, NJ: Princeton University Press.

Jordanova, L. (1989). Nature's powers: A reading of Lamarck's distinction between creation and production. In J. R. Moore (ed.), *History, Humanity and Evolution: Essays for John C. Greene* (71-98). Cambridge, UK: Cambridge University Press.

Jensen, M. S., & Finley, F. N. (1995). Teaching evolution using historical arguments in a conceptual change strategy. *Science Education*, *79*(2), 147-166.

Jensen, M. S., & Finley, F. N. (1996). Changes in Students' Understanding of Evolution Resulting from Different Curricular and Instructional Strategies. *Journal of research in Science Teaching, 33*(8), 879-900.

Kargbo D. B., Hobbs E. D., & Erickson G. L. (1980). Children's beliefs about inherited characteristics. *Journal of Biological Education, 14*(2), 137-146.

Kitcher, P. (Ed.). (2003). Darwin's Achievement. In *In Mendel's Mirror* (45-93). NY: Oxford University Press.

Lawson, E., & Thompson, L. D. (1988). Formal reasoning ability and misconceptions concerning genetics and natural selection. *Journal of Research in Science Teaching, 25*(9), 733-746.

Lewontin, R. C. (1968). The Concept of Evolution. In D. L. Sills (Ed.). *International Encyclopaedia of Social Sciences* (Vol. 26, pp. 202- 210). The Macmillan and Free Press.

Lewontin, Richard C. (1978). Adaptation. *Scientific American, 239*(3), 157-169.

Lewontin, R. C. (1984). The structure of evolutionary genetics. In E. Sober (Ed.), *Conceptual Issues in Evolutionary Biology* (3-13), Cambridge, MA: Bradford/MIT Press.

Lewontin, R. C. (2000). Darwin's Revolution. In *It ain't necessarily so* (pp. 43-73). London: Granta Books (First published in *The New York Review of Books* of June 16, 1983).

Mayr, E. (1988). *Towards a New Philosophy of Biology*. Cambridge, MA: Harvard University Press.

Moore R., Mitchell G., Bally R., Inglis M., Day J., & Jacobs D. (2002). Undergraduates' understanding of evolution: ascription of agency as a problem for student learning. *Journal of Biological Education*, *36*(2) 65-71.

Psillos, S. (2007). *Philosophy of science A-Z*. Edinburgh: Edinburgh University Press.

Richards, R. J. (1992). Evolution. In E. F. Keller & E. A. Lloyd (Eds.), *Keywords in Evolutionary Biology*, Cambridge, MA: Harvard University Press.

Rudolph, J. L., & Stewart, J. (1998). Evolution and Nature of Science: On the Historical Discord and Its Implications for Education. *Journal of Research in Science Teaching, 35*(10), 1069-1089.

Settlage, J., Jr. (1994). Conceptions of natural selection: A snapshot of the sense-making process. *Journal of Research in Science Teaching, 31*(5), 449-457.

Sober, E. (1984/1993). *The Nature of Selection: Evolutionary theory in Philosophical Focus.* Chicago: University of Chicago Press.

Southerland, S. A., & Sinatra, G. M. (2005). The shifting roles of acceptance and dispositions in understanding biological evolution. In S. Alsop (Ed.), *Beyond Cartesian dualism: Encountering affect in the teaching and learning of science*. Dordrecht: Springer.

Tamir, P. and Zohar, A. (1991). Anthropomorphism and Teleology in Reasoning about Biological Phenomena. *Science Education, 75*(1), 57-67.

Wilson, R. A., & Keil, F. C. (2000). The shadows and shallows of explanation. In F. C. Keil, & R. A. Wilson (Eds.), *Explanation and cognition* (87-114). Cambridge, MA: MIT Press.

Wood-Robinson, C. (1994). Young people's ideas about inheritance and evolution. *Studies in Science Education, 24*, pp. 29-47.

Appendix

The questionnaire used in the study

A

There are many varieties of mosquitoes.

An insecticide, known as DDT, is used to kill them. A small quantity of DDT kills some of the mosquitoes; some others die only when a large quantity of DDT is used. Some do not die at all. Those who die due to DDT are called DDT sensitive mosquitoes, and those who do not die are called DDT resistant mosquitoes.

Scientists studying mosquitoes have discovered that due to the continuous use of DDT, the number of DDT resistant mosquitoes is increasing.

A1. Read the above description carefully and write in your own words what it says. If you know something more about the given situation, write it down.

A2. While reading and rewriting, some questions about the given situation might have come to your mind. Please write them down.

A3. When you study a few mosquitoes, you will find similarities and differences among them. Write down the similarities and differences that come to your mind.

A4. What could be the reasons for the above similarities and differences?

A5. Let us suppose that the same parents have given birth to all the mosquitoes in your house. Among these mosquitoes, could some be sensitive to DDT and some resistant to DDT? Please give reasons for your answer.

A6. Do you think that DDT resistant mosquitoes were there hundreds of years ago? Please give reasons for your answer.

A7. Would there be DDT resistant mosquitoes after hundreds of years from now? Please give reasons for your answer.

A8. Imagine that for a few days, some humans are to become mosquitoes. Would you suggest them to be DDT resistant mosquitoes or not? Give reasons for your answer.

B

There are many varieties of moths.

Some are dark-coloured and some are light-coloured. They rest on tree barks, with wings spread. Birds catch the resting moths and eat them.

In some cities more and more industries are set up and the amount of smoke in the air is increasing. Due to high smoke levels, large number of smoke particles settle on tree barks. As a result, tree barks in these cities become darker.

Scientists studying moths have discovered that in some of the industrialized cities with high smoke content in the air, the number of dark-coloured moths is increasing.

B1. Read the above description carefully and write in your own words what it says. If you know something more about the given situation, write it down.

B2. While reading and rewriting, some questions about the given situation might have come to your mind. Please write them down.

B3. When you study a few moths, you will find similarities and differences among them. Write down the similarities and differences that come to your mind.

B4. What could be the reasons for the above similarities and differences?

B5. Let us suppose that the same parents have given birth to all the moths living on a tree. Among these moths, could some be dark in colour and some light in colour? Please give reasons for your answer.

B6. Do you think that dark coloured moths were there hundreds of years ago? Please give reasons for your answer.

B7. Would there be dark-coloured moths after hundreds of years from now? Please give reasons for your answer.

B8. Imagine that for a few days, some humans are to become moths. Would you suggest them to be dark coloured moths or not? Give reasons for your answer.

C

All giraffes do not have exactly the same length of neck.

Some giraffes have longer necks than others. Giraffes eat the leaves of trees. During severe droughts only large and tall trees survive.

It is believed that thousands of years ago, giraffes had much shorter necks. It is after severe droughts for many years that we now see giraffes having much longer necks.

C1. Read the above description carefully and write in your own words what it says. If you know something more about the given situation, write it down.

C2. While reading and rewriting, some questions about the given situation might have come to your mind. Please write them down.

C3. When you study a few giraffes, you will find similarities and differences among them. Write down the similarities and differences that come to your mind.

C4. What could be the reasons for the above similarities and differences?

C5. Let us suppose that the same parents have given birth to all the giraffes, living in a part of a jungle. Among these giraffes, could some be long-necked and some short-necked? Please give reasons for your answer.

C6. Since when do you think giraffes with long necks have existed on the earth? Please give reasons for your answer.

C7. Would there be long necked giraffes after thousands of years from now? Please give reasons for your answer.

C8. Let us suppose that for a few years, some humans are to become giraffes. Would you suggest them to have long necks or not? Give reasons for your answer.

D

All human beings are not identical.

A deadly virus (micro-organism), known as X-virus, can enter the body of human beings. After entry, if these viruses reproduce and grow in number, that person suffers from the X-viral disease and dies. But some, in whose bodies X-virus enters, do not die. Those who die due to X-viral disease are called X-disease sensitive and those who do not die are called X-disease resistant people.

Doctors studying human diseases have discovered that in places, where there are frequent attacks of X-virus, the number of X-disease resistant people is increasing.

D1. Read the above description carefully and write in your own words what it says. If you know something more about the given situation, write it down.

D2. While reading and rewriting, some questions about the given situation might have come to your mind. Please write them down.

D3. When you study a few people, you will find similarities and differences between them. Write down the similarities and differences that come to your mind.

D4. What could be the reasons for the above similarities and differences?

D5. Let us consider a couple living in a village with many children. Among these children, could some be X-disease resistant and some X-disease sensitive? Please give reasons for your answer.

D6. Do you think that X-disease resistant people were there thousands of years ago? Please give reasons for your answer.

D7. Would there be X-disease resistant people after thousands of years from now? Please give reasons for your answer.

D8. Imagine that for a few years, some animals are to become human beings. Would you suggest them to be X-disease resistant or not? Give reasons for your answer.

J

 # Birds live in the air ---- that's why they have light, air-filled bones
 # Many aquatic plants have a waxy coating on their leaves ---- because they live in water

J1. Explain, in detail, what is said in these statements. Do you accept these statements? Give reasons.
J2. What questions come to your mind when you read these statements?
J3. Add more examples to the above list?

K

Many of the leaf-eating insects are green, but those that feed on bark are mottled-grey

K1**.** Write, in detail, what is said in the above statement.
K2. What questions come to your mind when you read the above statement?
K3. Were the leaf-eating insects always green and the bark eating ones always mottled-grey? Will these insects be of the same colour for years to come?
K4. Why is it that many of the leaf-eating insects are green, but those that feed on bark are mottled-grey?

L

L1: What do you understand by the “physical or non-living world” and by the “biological or living world”?

L2: What do you understand by the change in the physical world?
Give as many examples as possible.
Try to think and write about the cause of change in each of the examples that you have written.

L3: What do you understand by the change in the biological world?
Give as many examples as possible.
Try to think and write about the cause of change in each of the examples that you have written.

L4: What do you understand by “Natural Change”?

L5: What do you understand by “Artificial Change”?

L6: What do you understand by “Natural Cause”?

L7: What do you understand by “Artificial Cause”?

M

M1: Choose an animal or plant that in some ways can be useful for the human beings. Now suppose you want to change that animal or plant so that it becomes even more useful and valuable for us. Write down the steps that you would follow to change that animal or plant so that it becomes very useful and valuable for us.

M2: A breeder has some fruit trees in his garden. He tries to improve the taste of the fruits of these trees but he is not successful in doing so. What may be the possible reasons for his failure? What would be your suggestions to help him in his efforts?

M3: Once a poor sheep breeder promised to his king that, one day, he will gift him with the best quality wool. But the king told him, "As you have a small lot of sheep, you can never produce the best quality wool". Will the poor sheep breeder be able to keep his promise? Why?

P

All the fruits of a plant are not identical.

Insects, like beetles, feed on the smooth-skinned fruits.

In the Sahyadri ranges, we find a plant called "L" plant. The fruits of this "L" plant have hairy-skin.

We know that in ancient times, the skin of "L" plant fruit was not hairy. But now all the "L" plants have hairy fruits.

Why is it that today fruits of all the "L" plants are hairy?

Try to explain how this change from the ancient smooth fruit producing "L" plants to today's hairy fruit producing "L" plants has taken place.