SYNOPSIS

Of

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

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BY

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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

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

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 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 as an empirical element of the science education research and the latter as a normative element.

The structure of the thesis mirrors the structure of the synopsis. An analysis of Darwin's theory, primarily based on his *Origin of Species* (Darwin, 1859/1964; hereafter the *Origin*), 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.

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

The present work draws primarily and extensively from the *Origin*. I find that the structure of the *Origin* and its representation of the theory of natural selection are, by far, immensely fruitful 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 the theory of natural selection aims to explain? How the theory describes the process (or the structure) it aims to explain, and how it achieves to explain it? 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?

Darwin's theory aims to describe and explain 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 – the

[2] This is an extended summary of a chapter in the thesis bearing the same title.

focus is on its *consequence*; it explains the *accumulation* of individual differences. The aim is to explain how adaptations are perfected, *not* how they originate.

A population of individuals could be changed in two fundamentally distinct ways[3]: 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*[4]. 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. 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 (like environmental conditions, for example), it would be a change by "natural *transformation / production*", not "natural *selection*".

Darwin studied domestic breeding. He was not the first one to look at domestic breeding practices, but he saw *selection* there that others could not. The reason[5] is that, others did not "sum up in their minds slight differences accumulated during many successive generations" (Darwin 1859/1964, p. 29). To understand *selection* as a cause of evolutionary change, first one has to

[3] 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.

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

[5] This reason is pedagogically important to us, educators, too.

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

Darwin discovered how selection causes evolutionary change both artificially as well as naturally. 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 human mediation is necessary to run the selection. This transition from selector's selection to natural selection

had to wait for Darwin[6]. 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 well 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.

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[7]. 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

[6] 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.

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

useful to the human beings the selector ensures its preservation, if the change is useful to the individual itself, this *particular* advantageousness or usefulness-to-the-self *causes* its preservation. And in both cases the inheritance of the change ensures its accumulation across generations.

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.).

Naturally selected individual variation is already useful to the individuals – in this sense then, it is already an *adaptive individual* variation. 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[8].

[8] 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.

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).

To sum up, 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[9]. To understand *natural* selection we ask: how the existing individual changes are

[9] Here we should not forget that the selector is an immediate cause of selection, but ultimately and generally the selector is selecting a variation be*cause* of its use to the selector.

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

Causal Structure of the Student's Explanatory Narrative of Evolutionary Change

A Critical Review of the Causal Structure of Student's Explanation

How the student, studied in the evolution education literature, understands evolutionary change?[10] The conception of *need* have been shown to play central role in the student's understanding of evolutionary phenomena. Indeed, Demastes et al. (1996) have called it "controlling conception", that "plays an important role in the learner's conceptual ecology for evolution" (p.416). The student thinks that the "adaptive" response or the "adaptive development" is a survival necessity in the current conditions. These responses are typically teleological as the adaptive change is thought to be taking place to achieve certain useful goals. Indeed, in Clough and Wood-Robinson's (1985a) study, the student thinks the adaptive change to be a *conscious* response of the organisms. Jensen and Finley (1995) have called the student's teleological responses as instances of "evolution on demand". Students are often satisfied with a kind of *functional* explanation, where explaining the function of an organ is thought to be sufficient to explain its evolution (Bishop and

[10] See Bardapurkar (in press).

Anderson, 1990). But, students are not always unaware of the anthropomorphic-teleological explanations. Many students in Tamir and Zohar's (1991) study could easily recognise anthropomorphic formulations (especially in the case of plants), but very few students could offer (non-teleological) mechanistic explanations.

For the student, the teleological explanatory conception of *need* is often *in*sufficient to explain the adaptive change. Along with some need-based conception, the student often refers to use/disuse of body parts (e.g., Bishop and Anderson; Bizzo, 1994; Settlage, 1994), or to "internal force" (Deadman and Kelly, 1978) to explain the adaptive change. Even mutations are considered to be a survival-response of the organisms (Banet and Ayuso, 2003). However the student conceives of evolutionary change, she rarely sees *selection* as a cause of evolutionary change. For the student evolutionary change is almost always an *individual-transformation*. And often the adaptively transformed character is transferred to the following generations. To illustrate this, I now quote a transcript of a typical response from Geraedts and Boersma (2006): "[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" (p. 861; my emphasis). But, we see a simple manifestation of "inheritance of acquired characters" only in younger children (10 years and below in Karbo et. al., 1980). Older children also grant the inheritance of acquired characters, but their notion is much more subtle as the inheritance is supposed to be dependent on a number of other factors 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. (e.g., Clough and Wood-Robinson, 1985b; Lawson and Thompson, 1988).

The aim of this review was to recapitulate various ways in which the student, studied by the (science education) researchers, understands the evolutionary change. But, the studies reviewed here 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 student's explanatory-understanding. However, to diagnose, define and detail out the problematic of understanding natural selection, we have to have a subtle picture of the student's causal-explanations that focuses on the *variety* of causal-possibilities the student thinks about. With this aim, we now turn to the discussion of causal structures of the student's explanations in the present study. Before we do that, let me provide methodological details of the study.

Methodology

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 are interviewed in this study come from a government aided (the school depends on the government funds in a major way) school 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 work at various positions in a research and development institute. The undergraduates who were part of this study come form a wide variety of backgrounds that vary on academic, socioeconomic and geographical counts – at the time of the interaction they were studying different subjects (physics, biotechnology, etc.) to earn different degrees (in sciences, medicine, engineering). This variety in this last sample was made possible by a talent nurture programme conducted by my institute, in which these students were participants. Following is the number of students, in the brackets is given the questions to which they responded both in writing and during the interview (in

all, each students had to respond to either 16 or 24 open ended descriptive-explanatory questions): 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). Total number is 83.

The four situations (that is a description of an evolutionary phenomena) – A, B C, D – and the questions following them, were constructed to explore how the students view individual variation and how do they explain its existence. In the situation described to them, 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 an environmental condition relevant to the varying trait—increase in the number of individuals having a particular variation in the trait. The questions were constructed to confirm with this structure, not necessarily to get the scientific-historical details right. The students were told that the situations described to them may not always reflect what has *actually* happened. The guiding question was, assuming that these have been these cases of evolutionary change, how would they make sense of it. Each situation was followed by a number of open ended questions asking for descriptive-explanatory responses.

The remaining questions preserve the important purpose *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 student's view the adaptations, and how teleology plays out, if it does, in their causal-explanations of these adaptations. Unlike the previous questions that are based on 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 question *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 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.

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 her causal understanding of the given descriptions; that is, to reconstruct how the student describes and explains 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 this analysis. Here I list the various causal-explanatory frameworks using which the individual students understand the instances described to them. 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. The details of each of the causal-explanatory framework enlisted below are described in the thesis.

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

The spectrum[11] of Class VII student understanding falls across the following causal-explanatory frameworks.

- *Impossibility of the evolutionary change-I*
- *Impossibility of the evolutionary change-II: Essentialist understanding*
- *Evolution… a natural change*
- *Congenital defects explain the differences*
- *Internal working of the body explains the differences (transformation is not necessarily adaptive)*
- Non-*hereditary adaptive development via conscious efforts—and a story of "power" germs*
- *Nature Divinised-I: Theistic—essentialist—teleological—developmental—nature's change*
- *Nature Divinised-II: Living conditions—and god—determine the individual characteristics*

[11] Thanks to the suggestion of B. M. Udgaokar because of which I learnt to use of the word "spectrum" in the present context.

- *Creationism-I: Creative god and clever scientists—increasing population explains increasing number of variants*
- *Creationism-II: Creationist-essentialist understanding*
- *Creationism-III: Theisitc, physicalist, progressivist conception of change*
- *Creationism-IV: Theistic conception, where individual transformation is caused by the efforts and practice, or by the food*
- *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*
- *Time, teleological responsiveness of living things, their effortful use of a structure, and factors like food and climatic change, explain* adaptive *transformation*
- *Transformation of the "old" into the "new": The (quality of) available food* and *the* a*mount of genetic factor determine the individual differences*
- *Simple evolutionary world view-I: Change is because of evolution*
- *Focus on the behavioural-I (with little reference to the physical)*

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

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

- *Impossibility of the evolutionary change-III*: Insensibility of the *how* of large scale evolutionary changes
- *Creationism V: Evolution? Nonsense!*

- *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 a proximate cause*

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

- *Creationism-VIII: Theistic-essentialist teleological transformative action*

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

- *Natur*e's *(not natur*al*) selection-I: Nature, conceived as god, selects the capable*

- *Natur*e's *(not natur*al*) selection-II: Nature selects the capable*

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

- *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*

- *Teleological adaptive transformation*

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

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

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

- *Multiplicity of causes explain the (individual) change-II*
- *Multiplicity of causes explain the change-II: Teleological inheritance*
- *Multiplicity of causes explain the change-III: The change is understood as natural,* non-*teleological, individual transformation*
- *Selection without evolution: Causally empty selection*
- *Fragments of selectionist explanation, with (enough) scope for suitable adjustments with the surrounding and teleological transformation*
- *Selection—complemented (and dominated) by—Transformation-I: The environment selects as well as contributes to the fitness for survival*
- *Survival of the fittest: The survival of the capable, of adaptive adjustments, of struggle, or of genic activation and development*

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

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

- *Benevolent God—Balanced nature—Natural adaptation—Skin deep Darwinism!*
- *Evolution of different animals/plants—different kind of "primary" cause (or force)—similar underlying (genetic) cause*
- *Teleological Genic Transformation through Mutations Necessitated by Multiple Factors*
- *Genic-naturalistic-teleological adaptive change: Genome is conceptualised as nature that naturally acts in accordance with the necessities*

- *Non-teleological gene expression produces two kinds of variants— non-accumulative selection*
- *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*
- *Teleology—Genic Transformation—Nature's Selection: Confusions of confounding teleological, gene-centred and transformationist conceptions*
- *Selection—complemented by—Transformation*
- *Evolutionary change by natural accumulative selection*

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

- Even when the student is aware of both Darwinian and Lamarckian explanations, as well as the limitations of the latter, she explicitly opts for the latter, may be because causality in the Lamarckian account is concrete and deep: it involves physical action and the efforts on the part of the individual, for example. There is no such single concrete causal-agency operative in the Darwin's theory.
- While making sense of natural selection, the student *agenciates* nature. 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.

- To understand Darwin's theory, the student should distinguish between the cause (origin) and the consequence (effect) of a 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). When the student thinks about variation, she thinks of its cause, not consequence.
- The student rarely differentiates between *individual* change and *evolutionary* change; and therefore, for the student, 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.
- 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. Natural selection causes evolutionary change by accumulative selection.
- In the student's understanding adaptation is *becoming* – becoming better to survive and reproduce. In contrast, in Darwin's theory adaptation is *being* – being better in survival and reproduction.
- 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. For example, a student views the multiple causal factors complement each other in explaining the evolutionary change and ends up having a non-contradictory (or coherent) understanding of evolutionary change that incorporates genic-transformationist as well as selectional explanations with equal ease. Another student, on the other hand, 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 what could labelled as a notion of natural selection.
- We frequently spot the 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. In these frameworks, 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. 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. For example, the student sometimes thinks of non-teleological adaptive gene expression.

- 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.

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