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Evolutionary Pedagogy

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I. Introduction

The transformation of organisms along a time axis can be considered to be phylogeny (a process of divergence and emergence of species) along a long-term time axis or ontogeny (a process of birth from conception through the embryo and fetus stages) along a short-term time axis. Both phylogeny and ontogeny involve a process of transformation from a simple form to a complex one. Regardless of the length of the time axis, an organism is composed of atoms and molecules and therefore bound by the basic law of physics related to "matter and information." For instance, onshore vertebrates constantly transform, receiving the binding effects of not only inertia but also gravity. With regard to eukaryotic organisms, each cell (an element) stores information concerning the entire system of the individual body as genetic information, which accumulates as adaptation to the environment progresses. With regard to vertebrates, their central nervous system, which consists of a spinal cord and the brain, takes control of processing information including that for the environmental adaptation of the individual. In an individual body, genetic information is expressed in the linkage with environmental changes and the passage of time. The period during which the individual body continues to change is the developmental period, which covers a long time frame from the fetal period, infancy and puberty to adolescence. To establish the optimal learning and educational curriculum for each period, both the perspective of each individual's developmental mechanism and that of phylogenetic evolution are important.

II. Homology between phylogeny and ontogeny: its wide range influences on various fields

Various discussions have taken place over the homology between phylogeny and ontogeny since ancient times, of which the most influential may be the theory of recapitulation by Ernst H.P.A. Haeckel (1834–1919), who stated that phylogenetic and ontogenetic developments have a strong homology, in which the "basic principle of evolution and development" exists. Etymologically as well, "evolution" and "development" share the same original meaning and concept of the "unrolling of a scroll." Accused of data fabrication and slandered and defamed by many, Haeckel's theory of recapitulation was discredited and terminated in the field of biology despite the spectacular start of his career as a successor advocate of the theory of evolution by Charles R. Darwin (1809–1882). Actually, Haeckel's hypothesis was examined and its application and development were explored in various fields by many scientists who noticed

that his concept is related to the root of life. However, because this theory was almost completely discredited in the field of biology, the major field in which the theory falls, Haeckel's theory of recapitulation disappeared from the primary research and only results obtained in a wide range of other fields with the help of his concept remain. Scientists who actually examined Haeckel's theory of recapitulation include Sigmund Freud (1856–1939), Carl G. Jung (1875–1961), Jean Piaget (1896–1980), Henri J.F. Rousseau (1844–1910), Friedrich Engels (1820–1895) and Herbert Spencer (1820–1903). Many examples of the application of the theory are indicated in publications by Stephen J. Gould (1941–2002).

III. Suspicion of data fabrication by Haeckel

As if strengthening the old suspicion that Haeckel's illustration was a fabrication, a relatively recent science periodical carried research supporting that Haeckel's fabrication was a fact (Pennisi, E., "Haeckel's Embryos: Fraud Rediscovered," *Science,* 1997). Based on the source of this research, I felt the existence of a serious problem in this controversy. Haeckel's illustration omitted the placenta and the vitellus, for example, although a photo of an actual embryo naturally shows the placenta and the remaining ovum part, which makes quite an impression on the viewer. In addition, the phases of the embryo were not necessarily precise when compared to species of which the embryo/fetus periods are largely different. As pictures and photos have been recognized as art, the illustration that was alleged as data fabrication does leave room for the producer's intention and bias. Haeckel publicly countered the allegation, saying, "In the course of scientific exploration of the unknown, approximately 6 to 8% of imagination always exists in science," which was interpreted as him admitting a fabrication (*Münchener Allgemeine Zeitung* ["Munich general newspaper"], 1909).

However, a reliable paper appeared that criticized the aforementioned *Science* article and its original source from a similar viewpoint as I mentioned above (Richards, R.J., "Haeckel's Embryos: Fraud Not Proven," *Biology and Philosophy,* 2009).

Haeckel's first depiction of the tree of life, *The Evolution of Man,* is full of vitality and vibrancy and makes a strong impression on viewers, which, however, is the essence of artistic design rather than science. As an exact science, such poses an additional arbitrary element. Especially in the case of Haeckel's theory, controversies with various theories of creation have continued to date.

IV. Knowledge in recent molecular biology

Despite all these concerns, I have a feeling that recent molecular biology is discovering phenomena that support Haeckel's intuition. Down-to-earth research in comparative embryology has recently revealed that in the development of vertebrates, gene expressions that occur during the period of embryonic pharyngeal arches (the period when a trace of fish's gill arches or something similar is transiently present on the embryo: 32–40 days after conception in the case of humans) show the highest similarities among species throughout the embryo and fetus periods (Irie, N., & Kuratani, S., "Comparative Transcriptome Analysis Reveals

Vertebrate Phylotypic Period during Organogenesis," *Nature Communications,* 2011). In other words, we may be able to regard embryonic pharyngeal arches almost as the "archetype" that Johann W. von Goethe (1749–1832) coined in the morphology that Goethe himself initiated. Furthermore, among many species, from flies to humans, a large similarity exists in their homeobox gene families that direct the formation of body structures. Especially among vertebrates, different species' homeobox gene families are substantially alike, which could be called a subroutine working for both phylogeny and ontogeny. In addition, it has been revealed that in the change of neurotransmission substances from excitatory to inhibitory (e.g., GABA), ontogeny undergoes a similar process of phylogenetic evolution.

V. Extensibility from the fetal period to adolescence or thereafter

Various concepts of spiral education are based on the underlying idea of learning and education, just like climbing a spiral staircase built on the developmental history of civilization. This means that a long-term time axis can be effectively traced in a short-term time axis, largely linked to the theory of recapitulation. The development of cerebral neural circuits is roughly classified into two aspects. One is a new neural circuit being formed and new functions being created by learning. Other than the new linkage of newly formed neural circuits, the neural information transmission becomes faster via myelination, which is determined in the process of evolution. Recent neuroscience has gradually been revealing a mechanism of synapses (connections between nerve cells) in the brain being built on spines. At the same time, other research is revealing that myelination accelerates neural transmission, which accelerates information processing, enabling complex thinking and recognition. Here is a possibility that the history of human evolution is recapitulated. Myelination, which continues until adolescence, is especially important because it could be an influential factor throughout the period of school education.

VI. Conclusion

Individual bodies continue transformation from the fetal period through early adolescence. The perspective of the evolution of organisms enables learning and education in accordance with the development of neural systems. Although the attempt was made to apply learning and education in accordance with the development of neural systems in the field of child care for the early development period, the possibility of applying this perspective for the middle and later periods of development is becoming apparent. In learning and education, it has become possible to build an educational system in line with the development of neural systems on the basis of the history of organisms' evolution, which is the step that follows "Brain-Science-Based Education." I would like to call this new area "Evolutionary Pedagogy." Although many scientists inspired by Haeckel stopped thinking, as if time had stopped with the suspicion of data fabrication, now is a good time to start the clock ticking again.

For me to come to the above conclusion, I owe much to Dr. Courtney Ross, Founder and Chair of the Ross School in the United States. I would like to express my sincere gratitude to

her. Last summer, she welcomed me at her beloved boat in Papeete after finishing sailing from the Galapagos Islands. The location happened to be the place where the HMS Beagle cast anchor to welcome the queen of Tahiti (*Darwin's Diary*: November 25, 1835).