European Journal of Health and Biology Education
Volume 9, Issue 2, 29 - 36.
ISSN: 2165-8722
https://www.ejhbe.com/

Use of the Evolution of Nervous System as a tool for Teaching of Evolution through Natural Selection

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Received: June 14, 2020 ▪ Revised: September 7, 2020 ▪ Accepted: December 15, 2020

Abstract: The paper presents the design, implementation and evaluation of a teaching intervention for the teaching of Evolution. This is carried out through an evolution-based investigation activity of the nervous system from Protozoan to Humans. Specifically, students were able to follow two main evolutionary pathways related to the Nervous system. In the first place, they were familiarized with a march of the Nervous System (NS) from Protozoans to Vertebrates and from Fishes to Humans. In a second stage they studied and compared the difference between the development of Spatial Memory and Hippocampus between polygamous mice and taxi drivers of London and NY city. I.e. they were faced with a case of adaptation in a Darwinian evolution way in contrast to a Lamarckian case of an acquired trait. The results of two studies concerning the increased size of the Hippocampus as a result of the impact of the environment and as an adaptive characteristic of reproductive and survival strategies were given to students who were invited to investigate whether this characteristic is inherited or not in the two cases. In addition to the main question, individual concepts of Evolution through Natural Selection and Neurobiology are explored. The teaching intervention applied is a proposal for the teaching of basic concepts of Evolution through the promotion of the idea of using the Evolution by Natural Selection as the Unifying Theory of Biology. The results show a statistically significant percentage of reconstruction of students' misunderstandings about the inheritance of acquired characteristics and the mode of action of Natural Selection.

Keywords: *Evolution, teaching, neurobiology, spatial memory, hippocampus.*

To cite this article: Athanasiou, K., & Petromelidis, V. (2020). Use of the evolution of nervous system as a tool for teaching of evolution through natural selection. *European Journal of Health and Biology Education*, *9*(2), 29-36. https://doi.org/10.12973/ejhbe.9.2.29

Introduction

The Theory of Evolution through Natural Selection (TENS) is the scientific theory which has, probably, influenced human thought more than any other (Dobzhansky, 1973). It is related to all cognitive regions of Biology. It highlights the relationships between different aspects, structures and branches of Biology, which, without it, they would be independent and unconnected sections. In this way it brings together the science of Biology and is its Unifying Theory, because it can explain both the diversity and the similarities that life shows (Athanasiou, 2013; Cummins et al., 1994; National Association of Biology Teachers, 1995). Without Evolution, the distinct objects of Biology are unconnected to each other, and for a student, it is a memorization of independent knowledge, so that he loses interest in his involvement with it. On the contrary, the teaching of Evolution connects these independent pieces of knowledge in a single context, providing the student with an important tool for understanding the natural world (Mayr, 2001; National Academy of Sciences, 1998). The fact that the theoretical framework of Evolution lends itself to the combination of the many different branches of Biology in a coherent science seems to be ignored by both the Greek educational system and the International one, as well, with the result that Evolution remains a marginalized unity at the end of the textbooks of the 3rd Gymnasium and the 3rd Lyceum classes, occupying the least possible area of the curriculum (Prinou et al., 2009).

Theoretical Framework: About Inquiry

Inquiry is the way scientists work on the discovery of new knowledge in the world. According to the National Research Council - NRC (2006) of the United States and the so-called *Rocard report* (Rocard et al., 2007), Inquiry learning aims to

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the active participation of students in the processes of discovery of the natural world. It includes many different activities, such as case studies, observation, data collection, experiment, etc. It can be applied at all levels of education, but because it is time consuming, it is preferred mainly in the lower grades The reasoning of activities in the Teaching of Nature Sciences as an Inquiry is to "show" rather than to "say", to expose the process of science in practice and not to talk about science. There may be a gap in the activity, a lack to be reached by the student, a conclusion to be drawn on the basis of the data given to him, or to make a case based on the data given to him (Athanasiou, 2009; Minstrel & Zee, 2000).

Modern Teaching, particularly Teaching of Science, considers as very necessary the recording the ideas or perceptions of students. Students have already formed some early perceptions of the world around them, even before they are taught about it at school. These are the "reception structures" with which the new knowledge to be taught at school will interact, i.e. the tools with which they will try to understand school knowledge. The new knowledge they acquire is the result of this interaction between their practical-experimental perceptions with school knowledge (Hatzinikita & Christidou, 2001).

Previous Research Used

The teaching intervention was carried out through an activity based on Neurobiology and Evolutionary Biology. The activity selected concerns two studies from the scientific literature, namely, the study of spatial memory in polygamous mammals, on the one hand, and the study of hippocampus in taxi drivers of London, on the other. More specifically, in these two studies, it was considered the spatial memory as adaptability and as an acquired character, respectively. The activity involved studying data from two scientific studies. The first of these concerned the evolution of spatial memory, as reflected in the size of the Hippocampus (the area of the brain responsible for converting short-term memory into long-term memory), in various reproductive strategies related species, monogamous and polygamous respectively, while the second referred to the study of structural changes in the Hippocampus of taxi drivers related to their ability to navigate.

The first study, conducted by Jacobs et al. (1990) is entitled "Evolution of spatial cognition: Sex-specific patterns of spatial behavior predict hippocampal size" refers to differences in hippocampus size between different sexes from related rodent species with different reproductive strategies of their males, which are polygamous and monogamous respectively. Thus, in this study, the size of the hippocampus could be predicted based on gender-determined spatial reassignment patterns. More specifically, male polygamous control a much larger area and exhibit a larger hippocampus size than their females but also in relation to their related monogamous rodents, male and female. Similar findings exist for the hippocampus of storage and non-storage birds respectively. These data, as given to the students, are shown in Figure 1.

The second study, entitled, "Navigation-related structural change in the hippocampi of taxi drivers" has been conducted by Maguire et al. (2000) and refers to structural changes in the hippocampus area related to navigational abilities. Structural changes in the brains of people with extensive navigational experience, such as licensed London taxi drivers, were analyzed and compared with those of control group individuals, who are not taxi drivers. The rear hippocampus area of taxi drivers was significantly larger than those of the control group. The size of the Hippocampus is correlated with the amount of time they spend as taxi drivers (positive for the rear and negative for the anterior area). This data is in line with the idea that the rear hippocampus stores a spatial representation in people highly dependent on their navigational abilities. There appears to be capacity for local plastic changes in the brain structure of healthy adults in response to environmental requirements.

The main question that students were asked, based on the above data, whether the increased size of hippocampus was due to the environmental or random changes, and whether this is inherited in the two distinct cases. The aim was to highlight possible misunderstandings about the inheritance of acquired characteristics, having in mind to trying to re-construct them (Bishop & Anderson, 1990). In order to understand the distinct role of the Hippocampus in the memory process, and thus to associate its size with increased memory requirements, students should be aware that different areas of the brain have distinct roles.

Methodology

The activity was carried out using two identical copies of a questionnaire, and they were applied step by step, asking two questions at the time, before and after the part of the teaching intervention that was related to these questions. The intervention took place in 4 classes of the 1st Lyceum of the city of Naousa, in Northern Greece. The classes had an average number of 25 students, summing a total of 100 distributed questionnaires. However, since this took place at distinct times during the week at the corresponding time of the course and not in a continuous three hours, the number of answers per question ranged from 94 to 99, due to the absence of a number of students at a time.

Research tools

The questionnaire was compiled in collaboration by two teachers who carried out the teaching intervention. It arose as a result of the choices about the teaching sequence that was designed to answer the issues that emerged from it. The questionnaire was then answered independently by each of the two students and then the minimum acceptable answers were agreed in cooperation in order to be categorized as right / acceptable or wrong / unacceptable. Where researchers disagreed, there was discussion until they agreed.

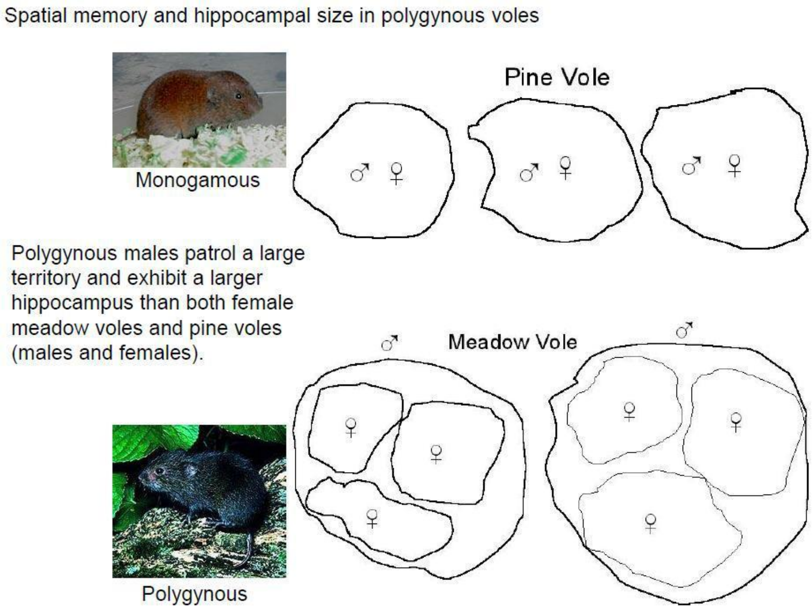

Figure 1. Hippocampus size in polygamous male rodents compared to their females and compared to relative monogamous species (From Jacobs et al., 1990).

The Questionnaire

The questionnaire-worksheet consisted of twelve, both, open and closed-ended questions. Most of the questions were open-ended, according to the subject in examination, i.e., Evolution, Natural Selection, etc. Since one of the main teaching objectives was to highlight the students' previous ideas and their transformation according to progress in scientific knowledge, their performance was followed to a greater extent by open-ended questions.

The Question #1 asked students about their familiarity with terms like Protozoans, Metazoans, Radial/Bilateral Symmetry, Cephalization, Vertebrates. The second question was referring to the subcategories of Vertebrates and their differences as for the gray matter of their brain, while the 3rdand 4th questions were referring to the areas of *Wernicke* and *Broca* as they first appeared in Chimpanzees and how these areas were interconnected latter in *Homo sapiens* through the *Arcuate Fasciculus*. There were some other questions about the fossils, the dinosaurs and geological time, the survival of first mammals and the appearance of larger hippocampi in food storing birds and polygamous male rodents. The last two questions were referring to studies that found the larger hippocampi in taxi drivers of London and the difference in their enlargement process compared to the enlargement in some animal species due to the action of Natural Selection.

Teaching intervention

The teaching intervention took place, also, in the 1st Lyceum of the city of Naousa, in Northern Greece. The choice of class was also determined by the fact that the activity concerned Neurobiology and the teaching of the Nervous System, took place just after the end of the teaching of the chapter of the Nervous System, as it is included in the curriculum of the Greek Education System. Thus, the students had already been taught some elements of Neurobiology and this provided them, on the one hand, with the prerequisite knowledge for the teaching intervention, and on the other hand, it held-up the students' interest for further investigation of some issues of the Nervous System. The students were divided into groups of two people. All individual worksheet-questionnaires were in duplicate. Students were asked to answer two open or closed questions, at a time, before the teaching intervention. In this way, students' pre-existing knowledge and ideas were recorded for individual subjects related to Neurobiology and Evolution. Slides or videos containing information about these questions were then viewed. For example, a video of the Nobel prize-winning in Medicine 2000, Eric Kandel (2008), on the mapping of brain regions performing specific functions, subtitled in Greek, was viewed. Based on the information collected, students were invited to investigate in groups the same questions. Immediately after the teaching intervention they responded individually to the second copy of the worksheet (named

After). The process was repeated step by step for the subsequent questions. The teaching intervention lasted 3 distinct teaching periods.

Processing of results

The processing of questions and answers was based on the examples of questions and correction instructions of the PISA competition (Organization for Economic Co-operation and Development [OECD], 2009). Thus, the questions were separated into sub-questions and then the answers were ranked into three categories: acceptable (correct/sufficient), unacceptable (wrong or insufficient), and those that were not answered at all (I do not know/do not answer). As mentioned before, most of the questions were decided to be open-ended, and this resulted in the receipt of answers that had to be classified in the above categories. The answers that were considered as correct for each sub-question, or possibly wrong or insufficient according to our expectation, were all recorded. Thus, the judgment of an open-ended question results in the separation of the answers into correct-sufficient, on the one hand, and to wrong-insufficient, on the other. Thus, there were two columns created for each sub-question, one named "Before" and one "After", and the answers of the 1st and 2nd copy of the questionnaire were all marked, respectively. Responses were then compared, and statistical data were obtained.

Due to the application of, mainly, open-ended questions in order to highlight the students' misunderstandings or improvements over evolutionary issues, the categorization of the answers with the mechanism mentioned as acceptable and unacceptable was crucial. Thus, the statistical processing was possible only for the estimation of the percentages of correct answers taken before and after the didactic intervention, and then the percentage of the transformation of the answers due to it. As we discuss later in the section of the "Limitations of the study", this is probably, one of the constraints of our method, where, due to time limits, constraints of the curriculum and weakness for other kinds of design, it was not possible to do anything different. I.e. to have control classes for comparison of average, application of T-Test, etc. Nonetheless, the latter, by no means reduces the value of the intervention, that, as it is mentioned in the section of results, was impressive for some of the individual concepts.

Results

The first 4 questions concerned exploring some concepts of Neurobiology. In the first two that refer to the evolution of the animal nervous system, (more specifically vertebrates), the rates of reconstruction of pupils' previous perceptions after the intervention are from small to satisfactory (between 9.1% and 42.4%). In the next two questions about the location and function of different areas of the human brain and the differences with those of humanoid monkeys, the rates of reconstruction of students' previous perceptions after intervention are from satisfactory for the position (32%-47%) to very satisfactory for the operation and differences of these areas (58.0%-68.7%).

As for the questions about the geological time and the time of appearance of the different categories of animals and for their chronological coexistence, the rates of reconstruction of the students' previous perceptions after the intervention were found from very small to satisfactory (1-30%), while the correct answers afterwards reached up to 70% of the total, when they were asked about the possibility of coexistence of humans and dinosaurs. *"I believe that this is not the case now because (the dinosaurs) have disappeared. But if there existed (the dinosaurs) there would be no humans because they would have eaten them" was one of the student's answers".*

In the question that requires an understanding of the mechanism of Natural Selection and concerns the reason for the survival of small mammals during the Jurassic Period when the dinosaurs dominated, not allowing the appearance of other Phyla, the percentage of conceptual change was significant (46.5%) and the percentage of correct responses after the intervention reached a 52.5%. *«They survived because they had characteristics that helped them adapt better»*, answered one of the students.

In the question about the reason why we are examining the Hippocampus of mammals, the percentage of conceptual change after the intervention was significant (50%) with the percentage of correct answers being 53.2%. «*Because the hippocampus is the area of the brain associated with memory*» was one of the answers. As for the evolutionary process of how made their appearances the larger brains in polygamous rodents, the rate of reconstruction of students' perceptions was low (16%) and the rate of reconstruction of students' perceptions was low (16%), as well, since the correct answers did not exceed a 18.1% (Figure 2). «*It is a random feature*», «*I didn't understand it*» was some of the answers.

As for the question on how they inherited larger hippocampi the offspring of polygamous rodents and those of storage birds, the rate of conceptual change was moderately satisfactory (25.5%), while the percentage of correct responses following the teaching intervention was satisfactory (45.8%). «*It has a genetic basis and thus will be inherited to their descendants*» was an answer of a student.

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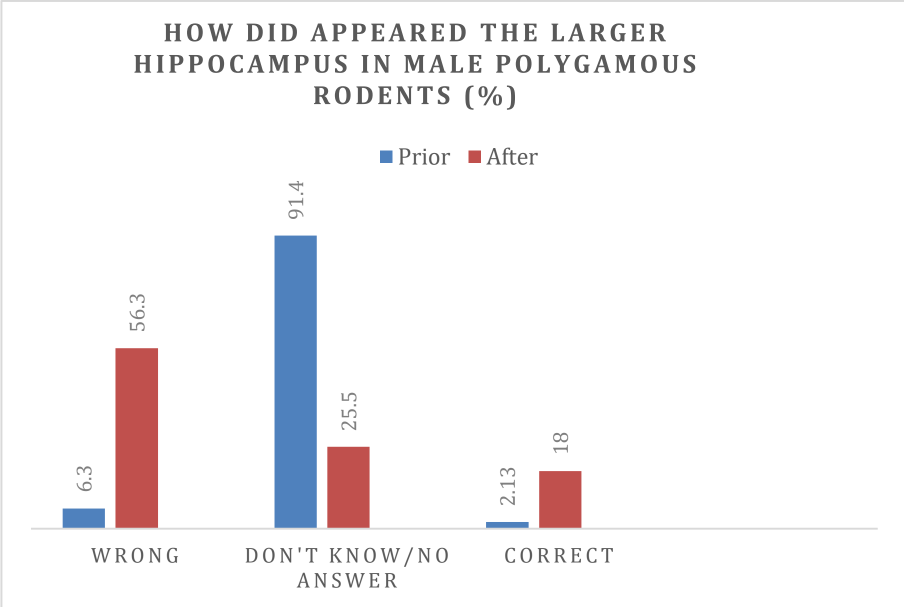

Figure 2. Students' answers about the mechanism of appearance of larger hippocampal size in polygamous male rodents before and after the teaching intervention (n=94).

In the question that deals with the causes of the increase in the size of the hippocampus in taxi drivers during their lifetime, depending on the time they spend on the wheel, the rate of conceptual change was significant, reaching a 37.2%, while the overall percentage of correct answers reached a percentage of 69.1%. : «*This is due to the environment. Because of their work, they must remember all the streets*», was one of the answers.

In the second part of the question concerning the inheritance of the characteristic to the children of taxi drivers, the percentage of conceptual change is high (51.1%), while particularly high, as well, is the percentage of correct responses after the intervention (70.2%). Here it is obvious that the conceptual change in students' perceptions of the legacy of acquired characteristics is clear; 70% of students considered the increase in the size of the Hippocampus due to the nature of their work and as such it is an acquired one, since they answer that the character is not inherited. «*This trait is an acquired one and will not appear in the children of taxi drivers as a change in their genetic material*» was one of the answers.

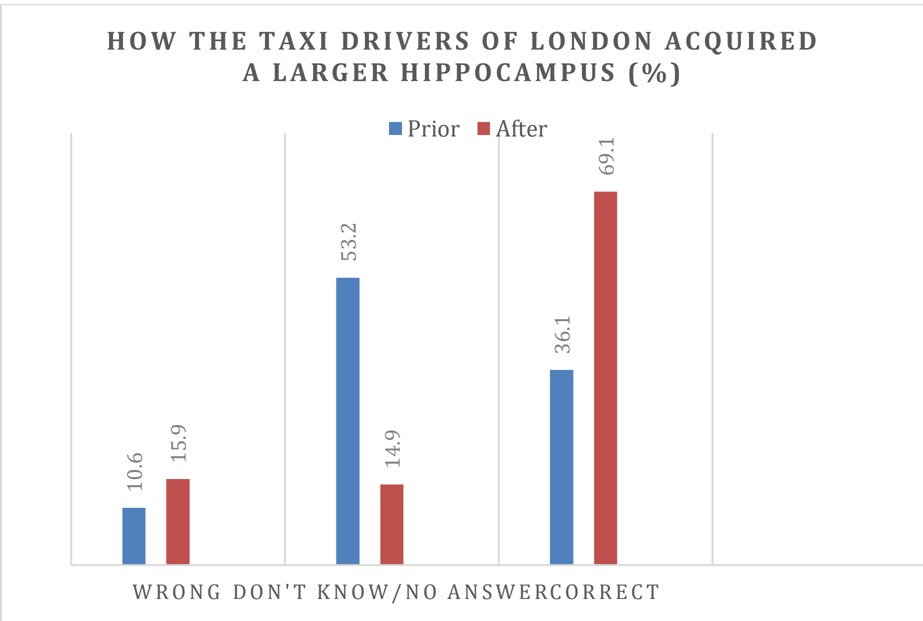

Figure 3. Students' answers, as it was counted before and after the teaching intervention, about the mechanism of appearance of larger hippocampi in taxi drivers of London and NY, that had many hours driving experience (n=94).

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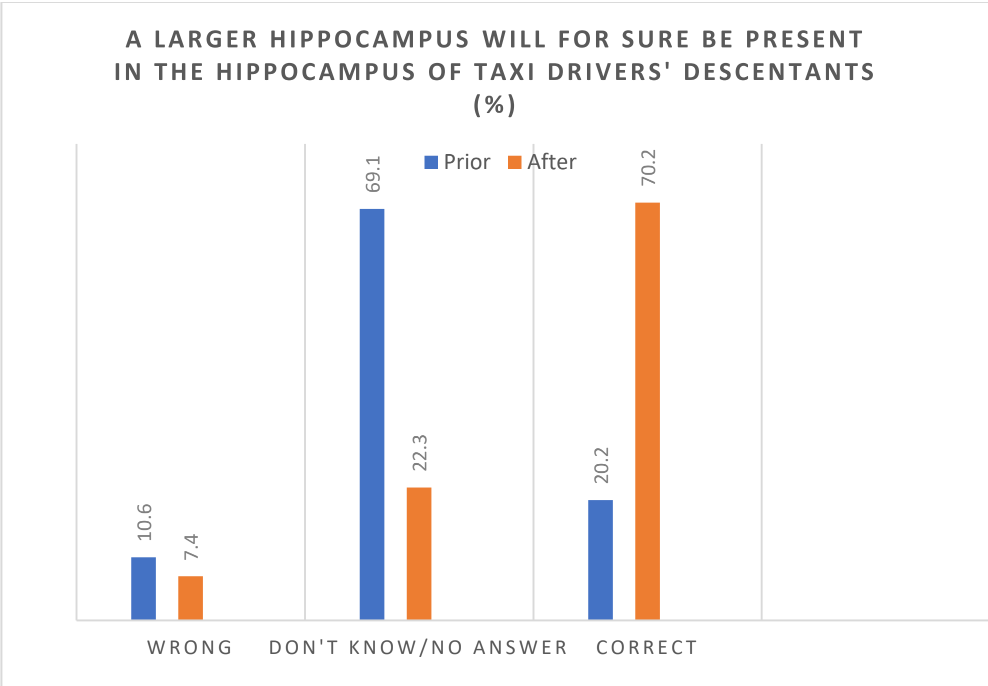

Figure 4. Students' answers taken before and after the teaching intervention about the possibility of appearance of larger hippocampi in the descendants of taxi drivers that had been found with enlarged hippocampi (n=94).

Discussion

The present study is part of a project aiming, on the one hand to study the process of better understanding, and on the other, the development of effective teaching ways in order to attain acceptance and understanding of the TENS by various students' and teachers' groups.

The teaching intervention we have described is a proposition for teaching basic concepts of the TENS in a class that has not been taught the TENS, before. The main question that the students were asked to answer concerned the emergence of better spatial memory in polygamous rodents and the possibility of inheriting or not the largest hippocampus, i.e. the area of some vertebrate brain associated with the increased demands on it (Jacobs et al., 1990). Here it is clear that the conceptual change in students' perceptions of the legacy of acquired characteristics is clear. A 70% of students, after the teaching intervention, consider that the increase in the size of the hippocampus in taxi drivers is an acquired character due to the nature of their work and reply that it is not an inherited character. As for the how it was made their appearance the inheriting character of the largest hippocampi in the offspring of polygamous rodents and storage birds, the rate of conceptual change while it was a bit less, it reached a considerable percentage of correct responses which was close to a 50%. It appears to be less noticeable by the students that the emergence of larger hippocampi is due to random changes in the genetic material of these rodents and that the action of Natural Selection favored the survival of individuals who carried mutations for a larger hippocampus in species and sexes that had higher demands for spatial memory. A fact indicating that the full understanding of the action of Natural Selection as a "population thinking" process is not so simple and needs multiple interventions (Mayr, 2001).

One other issue which is very common as a problem faced in the route of understanding the TENS, is the difficulty of its acceptance by many students and teachers (Rutledge & Sadler, 2007; Athanasiou et al., 2013). The latter, very often, contributes, in a negative way, to the rejection of the TENS and, by extension, to their understanding. The fact, that students were very much able, after the present intervention, to have a better understanding and were keen to accept some substantial concepts related to the TENS, is of great importance. As such, we could mention the notion of Geological Time and the fact that life is very old. Also, the idea of the non-concomitant appearance of the millions of species which is going in hand-to-hand with the idea of the loss of many other species during the Life-History (i.e.

disappearance of Dinosaurs), and the sudden appearance of the many species of mammals after the end of Jurassic period, during which were thriven only very small mammals. Some of these ideas constitute the so-called "the geological argument", which, as we have suggested previously, is a very proper teaching instrument for preparing students for the acceptance, and, accordingly, the full understanding of TENS (Katakos et al., 2018).

Conclusions

Al-together, this teaching intervention, as it is described in the present work, supports the idea that, teaching activities of this type might be very useful in the teaching of specific or individual concepts of the procedure of the TENS. For example, students were easily familiarized with the concept of Geological Time in the example of Jurassic period and the impossibility of Human existence during it. Likewise, they understood that fishes appeared much earlier than reptiles, while the latter made their appearance before the early mammals that, in turn, predated the apes and hominids. And, that the connection between the Broca and Wernicke areas in the brains of humans happened in an ultimal stage of the course of evolutionary history. Similarly, students became more familiar with the concept of adaptation arising in a population as part of the process of the TENS, in distinction to morphological changes taking place in the lifespan of individuals, as it is the case of the enlargement of hippocampi of taxi-drivers in London and NY. And this is a case, which in turn suggests, that the teaching scheme that we applied helped students to get rid to some extend of their Lamarckian views. And it is known, of course, that Lamarckian views are some of the most common alternative concepts occurring among students and teachers in every level of education and every part of the world (Kampourakis & Zogza, 2007). All these improvements are, of course, very useful as auxiliary events and concepts in the route of understanding the main process that interests us, and which is, by no means other than the full understanding of what is the TENS and how Evolution occurs. The latter demands not merely the understanding of many auxiliary concepts, but needs more integrated teaching interventions, which require time, alternative methods of teaching, and enhanced teachers' training, as well.

Limitations and Recommendations

As for the method used for the assessment of the outcome of the framework of the present way of teaching, the study would be much more comprehensive if, in addition to its application in classes where the present teaching intervention were taking place, there were run classes where the way of teaching might be the conventional way, for the purpose of the assessment of the real outcome of the approach of the present scheme. So, we suggest to future researchers to schedule similar research where there will be a control group, consisting of students that have taught the chapter of Evolution by conventional teaching procedure. This will give the opportunity to assess the real outcome of the intervention that we have elaborated and presented here.

As far as the way of teaching itself is concerned, we should not miss the central objective of the teaching intervention which is none other than a holistic understanding of the Central Theory of Biology, i.e. TENS (Cummins, et al., 1994). We might say that the full understanding of TENS has two completely interrelated constituents: A. The understanding of its individual aspects and features that constitute it, on the one hand, and the understanding of the TENS, itself, on the other. Interventions like the present one seems to be quite useful for understanding individual aspects of the TENS, a teaching target that by itself is very important. Nonetheless, we as educators need to remember that the TENS refers to a wholistic procedure that needs time, skillfulness by the teacher and proper teaching methodology in order to become explicit. The present teaching intervention, after all, lasted only three teaching hours and concerned an audience that had never heard of TENS before. However, the students, it looked like they got in a new world of ideas as they approached difficult to understand concepts related to adaptation, acquired vs inherited characters or the History of Life, as it is depicted in the fossils. An instrument that, as we have previously reported, is very important for the accepting and the full understanding of the TENS. The later, however, seems to need additional teaching methods, like Inquiry and Constructive Teaching Procedures, that all demand time, effort and skillfulness. And, above all, teachers that accept and fully understand Evolution.

Reference

Athanasiou, K., Katakos, E., & Papadopoulou, P. (2012). Conceptual ecology of evolution acceptance among Greek education students: the contribution of knowledge increase. *Journal of Biological Education*, *46*(4), 234–241. https://doi.org/10.1080/00219266.2012.716780

Athanasiou, K. (2013). Teaching evolution as the Unifying Theory of Biology: analysis and conclusions of research focusing on the specific teaching experience: In E. Mavrikaki, P. Stasinakis & C. Zahopoulos (Eds.), *Proceedings of the 2nd Pan-Hellenic Conference, "Biology in Education"* (pp. 105-112). Pan-Hellenic Union of Biologists. https://doi.org/10.13140/RG.2.1.3850.6960

Bishop, B. A., & Anderson, C. W. (1990). Student conceptions of natural selection and its role in evolution. *Journal of Research in Science Teaching*, *27*(5), 415–427. https://doi.org/10.1002/tea.3660270503

Chatzinikita, V., & Christidou, V. (2001). Students' practical-experiential learning: General characteristics. In K. Dimopoulos & V. Chatzinikita (Eds.), *Didactics of Science* (pp. 153-188). Hellenic Open University. (In Greek).

Cummins, C. L., Demastes, S. S., & Hafner, M. S. (1994). Evolution: Biological Education's Under-Researched Unifying Theme, *Journal of Research in Science Teaching*, *31*(5), 445 – 448.

Dobzhansky, T. (1973). Nothing in Biology makes sense except in the light of evolution. *The American Biology Teacher*, *35*(3), 125-129.

Jacobs, L.F., Gaulin, S.J., & Hoffman, G.E. (1990). Evolution of spatial cognition: Sex-specific patterns of spatial behavior predict hippocampal size. *Proceedings of the National Academy of Sciences, 87*(16), 6349–6352. https://doi.org/10.1073/pnas.87.16.6349

Kampourakis, K., & Zogza, V. (2007). Students' preconceptions about evolution: How accurate is the characterization as "Lamarckian" when considering the history of evolutionary thought? *Science and Education, 16*, 393–422.

Kandel, E. R. (2008). *Making your mind: Molecules, motion, and memory. Lecture 1- mapping memory in the brain*. http://www.hhmi.org/biointeractive/making-your-mind-molecules-motion-and-memory,

Katakos, S., & Athanasiou, K. (2020). The 'Geological Argument' as an Instrument for the Acceptance of the Theory of Evolution among Greek Science Teachers. *Journal of Genetics and Cell Biology, 3*(3), 183-186.

Maguire, E., Gadian, D., Johnsrude, I. Good, C., Ashburner, J., Frackowiak, R., & Frith, C. D. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proceedings of the National Academy of Sciences, 97*(8), 4398–4403.

Mayr, E. (2001). *What evolution i*s? Basic Books.

Minstrel, J., & Zee, E. H. V. (Eds.). (2000). *Inquiring into Inquiry Learning and Teaching in Science.* American Association for the Advancement of Science.

National Academy of Sciences. (1998). *Teaching about Evolution and the Nature of Science*. National Academy Press.

National Association of Biology Teachers. (1995). *Position Statement on Teaching Evolution.* https://nabt.org/Position-Statements-NABT-Position-Statement-on-Teaching-Evolution

National Research Council. (2006). *National Science Education Standards*. National Academy Press.

Organization for Economic Co-operation and Development. (2009). Take the Test: Sample Questions from OECD's PISA Assessments. OECD.

Prinou, L., Halkia, L., & Skordoulis, C. (2011). The Inability of Primary School to Introduce Children to the Theory of Biological Evolution. *Evolution: Education and Outreach*, *4*(2), 275–285. doi:10.1007/s12052-011-0323-8

Rutledge, M. L., & Sadler, K. C. (2007). Reliability of the Measure of Acceptance of the Theory of Evolution (MATE) Instrument with University Students. *The American Biology Teacher, 69*(6), 332-335.

Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walberg-Henriksson, H., & Hemmo, V. (2007). *Science Education Now: A Renewed Pedagogy for the Future of Europe*. European Commission. http://ec.europa.eu/research/science-society/document_library/pdf_06/report-rocard-on-science education_en.pdf