Interdisciplinary Journal of Environmental and Science Education
2022, 18(4), e2275
ISSN 2633-6537 (Online)
https://www.ijese.com

Review Article

Teaching Evolution as the Unifying Theory of Biology via a University Course: Re-Count of a Praxis

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Citation: Athanasiou, K. (2022). Teaching Evolution as the Unifying Theory of Biology via a University Course: Re-Count of a Praxis. *Interdisciplinary Journal of Environmental and Science Education, 18*(4), e2275. https://doi.org/10.21601/ijese/11976

ARTICLE INFO

Received: 14 Dec. 2021

Accepted: 23 Mar. 2022

ABSTRACT

The aim of the presentation is to discuss the findings of a series of research projects that we have been carried out with various groups of students in the University of Athens and concern the teaching of biology by means of evolution through natural selection (THES). In the article it is discussed the conclusions after teaching a biology course based on evolution as the unifying theory, while at the same time more general issues are raised: Is it, for example, a realistic goal to teach biology by means of this kind of teaching? Secondly, what is the usefulness of such a perspective. Which was studied by quantitative and qualitative studies on the conceptual ecology (CE) of the evolution of Greek students. The latter showed the value of this kind of approach in the acceptance and understanding of the THES, as part of students' CI. Thirdly, ccomparative studies with beginners and advanced students in terms of evolution education showed, that, merely teaching evolution within a course, even if the latter is based on the THES, it is not enough to make someone in-depth connoisseur. It seems that to be acquainted with it to more depth the learners need to go through two stages: in the first, they may move from the stage of owing Aristotelian views of the issue, i.e., from typology, to the early "Darwinian" ones. And they need to go through a second one, where via, in-depth educational training, they might move to the next, namely, the population view of thinking.

Keywords: evolution, teaching, unifying theory, conceptual ecology, typology, population view

INTRODUCTION

Clarification of Concepts and Terms

The theory of evolution through natural selection as the unifying theory of biology

The theory of evolution through natural selection (THES) (Darwin, 1859) is relevant to every aspect of the science of biology. It demonstrates the relationships that exist between different functions, structures, and branches of biology, which would otherwise show no correlation between them. Thus, it unifies the science of biology and is defined as her *central unifying theory* because it can explain both the diversity and unity of life (Demastes et al., 1995; National Association of Biology Teachers, 1995; National Research Council, 1996).

Conceptual ecology of evolution

Conceptual ecology (CE) refers to fundamental organizing conceptions that serve as the changing conceptual environment in which conceptual change occurs. Thus, CE controls and modifies this process (Strike & Posner, 1992). CE of evolution, as described by Demastes et al. (1995) in addition to acceptance, also includes the following elements:

1. pre-existing perceptions related to evolution–understanding of evolutionary theory,
2. scientific orientation (the extent to which the apprentice organizes his/her life around scientific activities),
3. the view of the nature of science,
4. the view of the biological world in terms of competition and causal relationships and not in aesthetic terms, and
5. the religious orientation.

Furthermore, Deniz et al. (2008) included for countries such as Turkey, the educational level of parents among these factors, as an important factor influencing acceptance.

Aristotelian concepts (typology) and neo-Darwinian perceptions (population view) on the emergence and differentiation of species–consequences for teaching

One of the most important contributions of constructivism to the teaching of science and biology is the fact that it treats learning and teaching as a process of conceptual change. One well known conceptual change model in science education is

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based on students' epistemologies which is derived and refined by Posner et al. (1982) and applied to classroom instruction. They suggest that conceptual change is like Kuhn's (1996) notion of a paradigm shift and Piaget's (1957) notion of assimilation, accommodation, and disequilibrium. This means that when teaching a scientific concept or theory, we might start from students' previous concepts, and with the help of various teaching methods and strategies like *inquiry*, we should try to help students reach the scientific truth (Dorion, 2010).

Certainly, the range of teaching methods in science teaching is quite large, but we will mention here the history of science. Although, some eminent philosophers of science, like Thomas Kuhn, they did not see this tool with a good eye (Kindi, 2005). Personally, I agree with this view in reference to the teaching of physics. How can we talk about evolution of scientific concepts and ideas in physics, when there are so many scientific revolutions and changes of paradigms (Kuhn, 1996)? For example, the concept of power or the low of motion in Aristotle is totally "incommensurable" to that of Newtons' or Galileos' paradigms. On the contrary, in biology, because the only paradigm shift, we can think of, is the one from Aristotelism to Darwinism, as it was completed by the movement of neo-Darwinism, it is totally legitimate to talk about evolution of ideas or concepts. Especially when someone approaches the evolution of the THES as a process of conceptual evolution, it is useful to remember that in the beginning there made their emergence the ideas of Aristotle, about the synchronous appearance of all species of living organisms, and that they remained stable and unchanged throughout the history of life, keeping their characters (*typos*) stable and unchanged (*typology*) (Ayala, 2004). Then, made their appearance the Darwinism in its premature form, as it was introduced by Darwin himself, who since he did not know anything about genetics and mutations, as Mendels' principles became known some fifty years later, he maintained some Lamarckian ideas, about the inheritance of acquired characters (Ayala, 2004). And, finally, we end-up with neo-Darwnism and the *population thinking*, introduced by some eminent persons like Dobzhansky (1937, 1973) and Mayr (1959, 1982). As far as the second and third historical phases are concerned, namely, the transition from the era of the early evolutionists to the prevalence of the neo-Darwinists in its present form, the path was not so smooth and lasted almost a whole century. According to Ayala (2004), Darwinism in the last part of the nineteenth century, came to face-to face to an alternative evolutionary theory, known as *neo-Lamarckism*. This was followed by the *Mendelians vs Biometricians* controversy (Provine, 1971).

This historical route, we as teachers of biology of any level, ought to have in mind for an additional reason: according to constructivism, students, in their route to the conquer of scientific truth repeat often the historical course of events in their minds (Driver, 1985). Thus, it is feasible to remember when teaching evolution to beginners, that our students, as it is the case with scientists of previous generations, will not come to the state of understanding the idea of "population thinking" in the THES immediately, but the mere conquest of an early Darwinian view may be a form of great conquest.

Research Questions

Based on all these, a different way of teaching an introductory course in biology for non-biology-major students was organized and applied, in which the teaching of THES occupied a central role. The course has been taught for ten consecutive academic semesters during which quantitative and qualitative research procedures were applied, aiming to three main groups of goals and questions:

The main issue that is examined in this communication, is the feasibility of teaching biology in an alternative way: Is it possible, useful, and applicable to teach biology, in such a way as to put in the center of biology's introductory courses the evolution as her unifying theory? What is the reception of such a practice by the students? Did they understood basic concepts of biology as the result of evolution and not as procedures leading to it? Can we change the structure of the curriculum and of biology textbooks to fulfill such a rationale?

In addition to this main group of questions, we are trying to answer some other secondary ones that are very much related to the first ones: In what way was influenced the "*conceptual ecology of the evolution*" of first year-students by this kind of teaching, if there was any? Are there any peculiarities in Greek society that are worthy to be considered when teaching biology in this way? Is there new evidence coming-out as for the acceptance of the THES after teaching in this framework? Are there conclusions that can be drawn from comparing beginners taught in this way and advanced students of THES, in terms of the road that leads to the mastering these concepts?

METHODOLOGY: THE IDENTITY OF THE RESEARCH PROCESS

The research process concerned three different research subsections:

1. Evaluation of the course,
2. Studies on the conceptual ecology of evolution before and after the course, and
3. Comparative studies between beginners (such as the specific target population) and advanced students of biology in Greece.

The Course and Its Evaluation

First-year students of education were taught an introductory course that uses evolution as its central unifying framework. For that reason, the course begins with a general chapter on evolution, which includes an introduction to the nature of science (NOS) and the concept of *theory*. Thus, students started to realize, that the TEN "it is not, simply, a theory". The students have, occasionally, to do bibliographic research and write paper/s related to the NOS and the role of fossils in understanding aspects of evolution and the history of life. The chapters on genetics, DNA, classification, etc., were taught as processes related or driven by THES. For example, the chapter on genetics was introduced as a teaching module that is trying to explain the phenomenon of the appearance of carriers of *b-Thalassemia* in countries, like Greece around the

Table 1. Students' evaluation of biology course, which was using THES as its unifying theory (%), N=75. Academic year 2019/20

Question/answer	Not at all or zero	A little or non-satisfactory	Moderate	Much or satisfactory	Very much
Q1. It helped me to conquer basic concepts which it dealt with.	1.37	4.11	6.85	46.58	41.10
Q2. Degree of new knowledge added.	0.00	5.48	6.85	41.10	46.58
Q3. The course offers necessary scientific tools for approaching & understanding the subject of your studies in general.	1.37	4.11	21.92	42.47	30.14
Q4. Good organization & presentation of the syllabus in course.	0.00	1.37	10.96	36.99	49.32
Q8. The course met your expectations.	1.37	2.74	8.22	49.32	38.36
Q9. Evaluate the quality of the course as whole.	1.37	1.37	5.48	52.05	39.73

Mediterranean basin. Which, as it is known, is a phenomenon based on the action of natural selection (Flint et al., 1986). The course was given in the form of a lecture, but it was also available in a virtual classroom, where, among other resources, they could find the lectures in PowerPoint format, through an *e-class* site.

Studies on Students' Conceptual Ecology of Evolution

A total of two classes of first year students of education in the University of Athens participated in the survey. All of them had chosen to attend an introductory semester–course in biology and all those who agreed to participate (anonymously) were included in the sample of the research.

Data collection

It was done by means of a questionnaire.

Measurement of knowledge

A modified version of the multiple-choice questions developed by Rutledge and Warden (1999) was used.

Acceptance of evolution

To evaluate the acceptance of evolutionary theory, we used the MATE scale developed by Rutledge and Warden (2000).

Understanding the NOS

The scale of the questionnaire of Johnson (1985) containing 17 questions was used.

Degree of progressive thinking

Measured on the AOT scale (actively open-minded thinking scale) as described earlier (Athanasiou & Papadopoulou, 2011; Athanasiou et al., 2012).

Religious orientation

It was measured by five questions that measured the degree of religiosity and the general attitude towards religion. The data was entered, encoded, and analyzed with the help of the SPSS statistical package.

Comparative Studies Between Beginners and Advanced Students in Greece

As a research tool we selected a well-known and tested questionnaire, such as the conceptual inventory of natural selection (CINS) test (Anderson et al., 2002), which we translated and which we "applied" to various subgroups of students at the National and Kapodestrian University of Athens. For the needs of the present study, we choose the specific class and the students of the Biological Department of the University of Athens, using CINS.

The CINS consists of 20 questions covering some of Mayr's (1959, 1982) basic ideas:

1. Organisms give more offspring than can sustain the available resources (living and transfer *capacity).*
2. All the members of a species compete to each other for available resources.
3. Resources are limited, therefore, there exists *competition with the result that* some of the organisms do not survive (*limited survival).*
4. Organisms within a species differ from each other in hereditary traits and this is called genetic *diversity.*
5. Variations arise through mutations and genetic recombination *(origin of diversity)*.
6. A large proportion of diversity is *inherited,* and, in this way, parents pass on their traits to their offspring.
7. Among these offspring, there is differential *survival, viability,* and *reproductive success*.

Through differentiated reproductive success, it occurs (*population change*), which under certain conditions of isolation can lead to new species (origin *of species).* Some more detailed description of the process may be found elsewhere, as described earlier (Athanasiou & Mavrikaki, 2013).

RESULTS

The evaluation of the course was done by the students themselves through the special place of evaluation of the courses created by the National and Kapodestrian University of Athens (UoA, 2013). The answers of the vast majority of the students were very positive and showed that there can be a biology course that uses the THES as a unifying and organizational element, without the need to teach previous concepts, as some people suggest. Results are shown on **Table 1**.

As for the question *how necessary do you judge the prerequisites of the course?* Only 6.67% of the answers judged it as "much" and a 20% as "very much". Regarding the question "*how difficult do you judge the level of the course for the level of studies that was taught?*" the answers "very" and "very much" were 23.33% and 6.67%, respectively, i.e., only a total of a 30%, which is less than a third of the class.

In this we tried to study the consequences of this framework of teaching a biology course on the conceptual ecology of evolution (CEE) of students. The main results of the surveys of the two classes of students in two different semesters are presented in **Table 2**.

Table 2. First year students of education answers regarding the THES before and after the course

2009/10	**Mean**	**SD**	**Maximum**	**Minimum**
Pre-course survey (N=112)				
Acceptance of THES (MATE)	70.95	7.49	90	41
Understanding of THES	5.04	1.56	9	1
Religiosity	6.25	2.78	12	0
Post-course survey (N=120)				
Acceptance of THES (MATE)	74.72	9.75	100	45
Understanding of THES	9.10	2.17	13	4
Religiosity	6.82	3.43	15	0
Thinking dispositions (AOT)	144.23	13.68	174	110
2019/20	**Mean**	**SD**	**Maximum**	**Minimum**
Pre-course survey (N=120)				
Acceptance of THES (MATE)	74.45	8.8	53	96
Understanding of THES	7.63	2.61	2	15
Understanding of the NOS	60.83	4.94	49	71
Religiosity	14.1	3.77	5	24
Thinking dispositions (AOT)	144.44	10.78	114	175
Post-course survey (N=120)				
Acceptance of THES (MATE)	80.56	8.72	61	98
Understanding of THES	10.51	3.19	4	18
Understanding of the NOS	61.41	4.92	48	76
Religiosity	13.64	4.12	5	23

Table 3. Percentage of correct answers to CINS for various student groups

Group of students	**Percentage of correct answers (%)**
Students of education–biology course not attended	15
Students of education–biology course attended	50
Students-biology majors of 1st, 2nd, & 3rd year	60
Students-biology majors of 4th year	75

Among other things, it seems that an important, but weak, correlation between the understanding of evolution and its' acceptance was there before this kind of didactic intervention ($r=0.212$, $p<0.01$), while in the study after the didactic intervention a significant and relatively strong correlation was shown ($r= 0.543$, $p<0.01$). We also found a significant, medium-strength negative correlation between religiosity and THES acceptance, in both (before- and after-didactic intervention) surveys (before: $r=-0.373$, $p<0.01$, after: $r=-0.384$, $p<0.01$).

The didactic intervention led to significant improvements in both acceptance ($t=-8.29$, $p<0.01$, Cohen's $d=0.6955$), and understanding of THES ($t=-83.67$, $p<0.01$, Cohen's $d=0.988$). It is interesting to say that understanding the THES along with religiosity accounted for 39.70% of the variation ($F=18.26$, $p<0.01$) in the post-intervention test, and that they were much higher than in the pre-didactic trial. These findings support the evidence that this type of teaching a biology course, improves the acceptance and understanding of evolution within the framework of CEE.

Education students' understanding of natural selection after the biology course using the THES as its central unifying theme can be explained, as follows: Students' performance in the CINS test is presented in **Table 3**.

By looking on that one can suggest that the higher the training on evolution, the higher the CINS score achieved. Indeed, students' degree of evolution teaching is positively and statistically significantly correlated to their understanding of natural selection score in the CINS test. Thus, 4th year biology majors achieved the best score, followed in rank by biology students in their first, second and third years of studies. The same implies for biology non-majors: those who had attended a biology course scored higher than those that had not attended a biology course while both scored lower than biology majors' students (Lazaridis et al., 2011).

The examination of how to answer whether in each individual concept of CINS the beginners in terms of the CINS and the advanced students (proximal, teleological, or evolutionary answers) are shown in **Table 4** (Athanasiou & Mavrikaki, 2013; Lazaridis et al., 2011).

1. *Heritable diversity* is the scientific concept contained in questions 7 and 17 of the CINS and seemed to be accompanied by the most teleological answers given by beginners compared to the advanced students (42.6%).
2. *Population stability* is included in questions 3 and 12. This concept is the one in which the two groups gave the most extreme response rates, i.e., the lowest and highest percentages of evolutionary responses (34.4% and 92.6%, respectively).
3. The concept of *differential survival* presented the most extreme values in "close type" answers in terms of THES, between the two groups of students (41.8% and 0.0%, respectively).

DISCUSSION AND CONCLUSION

The first question that this paper is trying to answer is whether there can be a university or other general biology course that may go beyond the usual structure of such courses and be designed by using the THES as its' central unifying

Table 4. Percentage of correct responses (%)[1] for each of the 10 scientific concepts that are included in the CINS for each one of the two groups of Greek students

Scientific concept	Biology majors of 4th year	Non majors–biology course attended
Biotic potential	49.6	35.6
Population stability	77.4	60.6
Resources limited	67.4	50.0
Limited survival	85.9	53.9
Variation within a population	77.4	69.2
Variation inheritable	72.2	47.1
Differential survival	79.9	43.3
Change in a population	74.2	32.7
Origin of variation	86.7	43.3
Origin of species	83.5	42.4

Note. [1]Estimated as the mean of the percentage of correct responses for each one of the two items for each scientific concept

theory. More specifically, to what extent such a general course can begin with a general introduction to THES, in one hand, and, to what degree can be followed all the other modules or chapters, that usually are considered as prerequisite chapters and concepts before the students are familiarized with the THES. As it is illustrated in **Table 1** the answer to this question of the responding students at the end of various semesters were very positive, supporting the idea very much. The students of the present study assessed very positively the course itself, its' structure, its' way of presentation, its' level of difficulty, etc. Another interesting aspect that most of them brought about was the fact that they did not find as necessity the introduction of prerequisite concepts that many teachers and textbooks of biology usually consider as necessary, before introducing the module of THES.

As for the consequence that this type of teaching a general biology course has to the CEE of students, it seems, that it can help to increase the acceptance and knowledge of THES as part of their CEE. This is indicated in the results of the surveys of the two classes of students in two different semesters that are presented in **Table 2**.

Another interesting point that was revealed in our study is the fact that in both measurements, conducted in a time gap of some ten years between different students of the same course, it did not seem to be affected another typical component of students' CEE, namely, their religiosity. The later, besides the fact of being considered as an important component of the CEE of evolution, is a factor that significantly influences the acceptance of THES (Demastes-Southerland et al., 1995, Mantelas & Mavrikaki, 2020). The fact that students' religiosity did not show any significant difference before and after the teaching of the specific course suggests that this way of teaching biology, with the THES as her unifying theory, can be applied without offending students' religious beliefs. However, we must note here, that Greek students present a high level of thinking disposition (TD), which is another component of CEE, that seems to escort their mode of religiosity, i.e., the Greek-Orthodox one, that most of them belong to. We must note, also, that for populations with a "Greek Orthodox" tradition, as it is the case with the ones of this study, it seems that as there is existing an equal element of religious reference with the Bible, namely the Holy Tradition, there is no absolute adherence to a "literal" interpretation of the scriptures, as is the case with many religious groups in USA and not only. Thus, a general biology course that uses the THES as its' central theme, can lead to an improvement in the acceptance and understanding of Evolution within the framework of CEE, even if the specific group is characterized by a high level of religiosity (Papadopoulou et al., 2010).

All this indicates that, before we conclude that this way of teaching biology with the THES as her unifying theory can lead to a better acceptance and/or knowledge of the THES, it should be investigated more thoroughly whether this improvement is due to this specific mode of teaching. The later might be examined by researching some other students' audiences that follow different type of religious affair, especially if they present lower levels of thinking disposition.

The last issue that this paper is trying to bring about is the quality of knowledge about the THES that a student class or audience can acquire through this and various other methods or types of biology teaching. Can for example the students reach *a population type of thinking* through a general course of biology, merely by using the THES as its' cardinal theory? Of course, to achieve this goal, we enriched the course with some supplementary teaching components. First, we emphasized the fact, suggested previously by Mayr (1959, 1982) that biology can be classified among the social sciences in addition to science, as utilizes the history of life as its' main scientific instrument. In that way students of education not only were more interested in the role of fossils in understanding the history of life but felt more comfortable to listen and attend the specific course. In this way, they felt that someone does not need to be a biologist to conquer these concepts.

The other point that we tried to supplement the course and the mode of its' teaching with, was the effort to incorporate the term "theory" and its' true meaning in science. For this, we tried to make students familiar with the "nature of science-NOS" and the scientific method, in order to make them understand why the THES is not "just a theory". It is known from previous studies that an increase in the knowledge of NOS goes in parallel with an increase in the knowledge and understanding of the THES (Cho et al., 2011). But the evidence in **Table 2** where the understanding of the NOS by the students of this study shows identical and relatively low values, found before and after the course, suggests that we were not very much successful with this goal. Certainly, the later has very much to do with various other constrains in the organizing and application of a course, like the limited time devoted to biology in the curriculum of the Department of Education.

And probably this is one of the factors that led to a failure in one of the main goals of the course, which was to help students to proceed to the next stage of knowledge of the THES, namely, the true "*population*" way of thinking about it. It seems that during this first phase, as it is the case with the historical situation, students seem to maintain some alternative ideas where the primitive evolutionary explanations co-exist with some teleological and Lamarckian's views.

This situation, as illustrated in **Table 4**, seems to be evident in our study, where the students-beginners in evolutionary education seemed to maintain *proximate* and *teleological* explanations for the individual questions of CINS (Cummins & Remsen, 1992; Kampourakis & Zogza, 2001). We call this stage a primitive "*population thinking*", in contrast to a true "*population way of thinking"* (Dobzhansky, 1973; Mayr, 1959) that to be achieved in debt, needs a more demanding training, using educational interventions such as inquiry, problem-solving teaching (PBL), or other modern didactic approaches (Frasier & Roderick, 2011). Nonetheless, as it is explained earlier, we feel, that one of our primary goals, i.e., to make this category of students, to conquer the early and most crucial stage of a so much socially critical, and so difficult to understand theory as the THES, has been accomplished.

In our case only the 4th year biology majors that had been trained intensively with both, the various courses of general biology, zoology, botany, genetics, etc. together with specific courses on evolution and evolutionary biology during the last year of their study, were close to this sort of thinking. The rest, majors, and non-majors in biology, even when they had good backgrounds on the THES teaching, they did not yield satisfactory percentages of correct answers on population thinking.

Our results suggest that the conceptual conquest of a complete corpus of the THES is a long and holistic procedure that needs to go through all stages of evolutionary thinking before someone gets maturity and expertise. Furthermore, in addition to placing the THES in the center of any biology course, it is needed an enrichment with the teaching of NOS in concert with the introduction of modern pedagogical practices, such as *inquiry*, *problem solving*, and a *constructivist* approach of teaching.

Funding: No external funding is received for this article.

Declaration of interest: The author declares that he has no competing interests.

Ethics approval and consent to participate: Not applicable.

Availability of data and materials: All data generated or analyzed during this study are available for sharing when appropriate request is directed to the author.

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