Chapter 42
Evolutionary Theory in Secondary Schools: Some Teaching Issues

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Abstract This chapter brings out the curriculum changes in the teaching of Evolutionary Biology over 100 years in French High School. First and foremost, we examine what scientific knowledge is required and then, we wonder whether current curriculum will properly answer the questions raised by students. The first part focuses on an overall of the content to be taught and epistemological anchorages points of the curricula from 1950 to today. The second part highlights the main students' conceptions about the history of life on Earth and points out the lacks of the curriculum to meet students' questions about the relevance of the Theory of Evolution. The last part is a discussion on new prospects of Evolutionary Biology teaching, which is not only limited to the transmission of scientific knowledge but should also help students to change their misconceptions and to develop their own critical thinking with regard to creationist or intelligent design arguments.

In 1892, 33 years after the publication of Darwin's Origin of the Species, the teaching of evolution was officially recognised at the Sorbonne when Alfred Giard (1846–1908) became the first Professor of the evolution of living beings. University recognition had a rapid impact on secondary school teaching.

In 1902 the reform of secondary education established the principal teaching guidelines. A distinction was to be made between the facts and the theories of evolution (Lamarckism and Darwinism). This teaching principle has been respected until the present day. However, is this separation still valid when faced with creationist movements and proponents of Intelligent Design? Does it really help pupils to grasp the pertinence of the evolutionary theory? Numerous research papers on teaching practice, published since the 1980s, have dealt with the analysis of curricula, how pupils see the subject and teachers' epistemological constructs about evolution.

Analysis of these different approaches shows the usefulness but also the limits of teaching practice, based on facts at the expense of theory. This chapter intends to illustrate how purely fact-centred teaching about evolution can, in spite of everything, increase pupils' scepticism about the validity of the theory of evolution.

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1 From the 1902 Reform to Current Teaching Practice Concerning Evolution

The 1902 reform was to give science the same importance as the humanities and to encourage experimentation in the teaching of science. In her important work *Sciences naturelle et formation de l'esprit. Autour de la réforme de 1902* Nicole Hulin (2002) emphasised the importance of lectures given by university dons, education inspectors and teachers. They proposed new teaching practices, aimed at moving from the teaching of natural history to that of natural science. In 1904, Rector Louis Liard described this new approach, in secondary schools. "First, facts precisely observed leading to a culture of observation faculty, then comparing facts leading to a culture of comparison faculty and finally, direct connections between the facts observed leading to a culture of generalisation faculty, a first appreciation of law" (teaching lecture, 1904).

Observation, comparison and generalisation remain the three pillars of current science teaching, from primary school up to the baccalaureate (high school diploma).

Among the principal points of the reform was the desire to move away from overly directive teaching. Observation and experimentation were to be introduced into the classroom. In 1905, Louis Mangin, Professor at the *Muséum national d'Histoire naturelle* described this new requirement: "Teachers should use these illustrious examples (Darwin and Pasteur) to inculcate in their pupils respect for other people's opinions and lead them to understand that new ideas in conflict with our prejudices and beliefs should be put to the test by observation and experimentation rather than be simply rejected" (teaching lecture, 1905). In addition to observation, comparison and generalisation, experimenting was therefore a fourth instrument in the battle against unsupported assumptions.

Before the 1902 reform, the teaching of evolution was principally based on palaeontology, taught in secondary schools from 1898. The teaching of the evolution of living species was therefore based on the observation of fossils. In 1905, Louis Mangin also advocated critical teaching of evolution: "It is not as a philosophical doctrine that the theory of evolution interests naturalists, it is because it is the only hypothesis capable of explaining the relationship between life forms in space and time…However it should not be forgotten that it is a hypothesis. It is necessary therefore to be able to summarise the knowledge already acquired to confront pupils with the two fundamental hypotheses, that of creation, the oldest and the only authorised explanation until the observations of Lamarck and Darwin laid the basis of the second which has been violently attacked since its appearance. The evidence shows that the first hypothesis has no scientific basis, while the second concurs with anatomical, embryological and paleontological evidence" (teaching lecture, 1905).

In 1911, Emile Brucker, teacher of natural science at the Lycée Hoche in Versailles proposed, during a lecture on teaching practice, a positive teaching method "Positive, founded on the observation of facts, on the experience of reality, the method will lead pupils from consequence to consequence then by inference to laws of increasingly general application" (teaching lecture 1911).

At the time, teaching was heavily influenced by positivism (Kahn 2001). And it was in this epistemological framework that the teaching of evolution developed. In curricula from 1912 until the present days, facts are declared independently of theory. Three periods in the teaching of evolution in high school should, however, be noted: from 1912 until 1931 a Lamarckian vision dominated. After the Second World War there was more emphasis on Darwinism and, from 1982 to 2000, evolution at the molecular level took on more importance.

From 1912 until 1931, the curricula concentrated particularly on geological time (stratigraphy, paleontological and anatomical facts etc.). The question of the evolution of living beings was evoked through consideration of Cuvier's non-evolutionism and of acquired characteristics as expounded by Lamarck.

Between 1945 and 1966 the separation of facts and theory was maintained. On the one side there was the comparative study of anatomical, embryological and paleontological facts of evolution (archaeopteryx, evolution of horses or elephants) and on the other, an historical presentation of non-evolutionism, Lamarckism and Darwinism. The curt 1958 curriculum dealt with "the study of a paleontological fact of evolution".

Genetics and molecular biology were introduced into 1982–2000 curricula to facilitate the study of the relationship between species. From 1982, mention is made of the experimental validation of natural selection. The term "humanisation" is used to describe paleontological data specific to the human species. In 2000 phylogenetic classification was introduced for the first time. It is worth noting that, until 1988, evolution was explicitly cited as a scientific theory whereas in the period 1994–2000 the word "theory" disappears.

To resume, knowledge in the fields of genetics, molecular biology and taxonomy have enriched and renewed curricula since the 1902 reform whilst educational epistemology has remained static. In each case, observation facts or experimental results are presented to students as examples of evolution, whisle the theory and the conceptual framework of evolution are eventually evoked later (Fortin 1996).

2 The Knowledge/Education Interface

From 1902 teaching evolution was done from within a specific framework. The positivist slant begun, then was confirmed in the 1950s by Charles Brunold. Brunold, at that time Director of secondary education, introduced teaching by "discovery". His objective was to have pupils discover – or, more accurately, rediscover – the results of experiments which had played a crucial role in the construction of scientific knowledge (Gohau 1987). However, the teaching of evolution remained essentially descriptive despite the experimental work of Philippe L'Héritier and Georges Teissier in the 1930s in testing natural selection with experimental populations of *Drosophila* ***pseu****doobscura*, or Bernard Kettlewell's experiments in the 1950s on the peppered moth. It was only from 1982 onwards that an experimental dimension in the biology of evolution was presented to pupils.

In the 1970s a real change in teaching practice came about. The development of hands-on experimental science led to the abandonment of the inductive method in favour of Claude Bernard's experimental method. But, in school, this experimental approach focussed on experience rather than on theory, and always obeyed the same schema: OPHERIC.[1] The fact that Claude Bernard (1813–1878) had himself considered that the experimental approach was a learning journey within a defined framework was ignored. "The experimental method will not provide new ideas to those who have none: it is useful only to direct the ideas of those who already have some and develop them so that they give the best possible results" (Bernard 1865). So when Claude Bernard measured the dose of sugar in the blood (of an animal which had not eaten) as it entered then left the liver, he did not dwell on the anatomical structure of this organ so as to consider its function. His experiment was jointly guided by the biological problem of the "disappearance" of sugar within the liver and by a theoretical proposition concerning the concept of a "milieu intérieur" or homeostasis.

But teaching science has always needed to clarify and materialise its scientific knowledge in order to make it understandable for pupils. The ambition of Paul Bert, Minister of Public Instruction in 1881, to teach pupils "to see exactly, to see only what there is and all of what there is" still guides teaching practice. But what is "seeing" in a school context?

Looking at cells with a microscope is practiced today in science classes from early secondary years onwards, up to and including university level. But looking at animal or vegetable tissue at different levels of magnification does not give instant results. The microscope is not sufficient on its own to be able to recognise cells. To identify one (be it nervous, from the kidney or muscular) you have to know what it looks like. Otherwise there is description without understanding. This is why, when they first use a microscope, pupils quite often say that they "see nothing". Only lines, curves and colours are seen where the teacher can identify a cell (its nucleus, plasma membrane, cytoskeleton) whatever its form, shape or colour. The difficulty pupils have when trying to "see" a cell reminds us that in order to recognise it there must be a framework of analysis: cellular theory, an explanation of the cell as a living biological entity.

Encouraging pupils to go beyond immediately perceptible data and towards scientific fact, underpinned by theory, is a teaching challenge. For example, throwing an object then precisely describing the throwing and falling phases is raw information open to all. But explaining the act of falling to the ground requires recourse to the theory of gravity. This distinction between raw data and scientific fact underpinned by theory is essential in terms of epistemic knowledge.

In biology and in earth sciences, whether it is a question of cells, crossing-over, the movement of the earth's lithosphere or the evolution of the species, these teaching subjects cannot be understood only visually because each one of them is underpinned by a theory: cellular theory, chromosome theory of heredity, the theory of

[1] Acronym introduced by A. Giordan (1976) O: observation, P: problem, H: hypothesis, E: experiment, R: result, I: interpretation, C: conclusion.

tectonic plates and the theory of evolution. But how can we explain the progressive abandonment of the use of the word "theory" in the syllabus?

Firstly, it is common to call an unsubstantiated assertion a theory, which is to say pure speculation. Yet this is not true of scientific theories in general, or of the theory of evolution in particular. Secondly, choosing to cite only observed facts about evolution to legitimise its scientific validity could explain the disappearance of the word "theory". Evolution is illustrated by observable facts and experiments. Thirdly, references to theory disappear when the teaching of knowledge becomes dogmatic (Rumelhard 1979). Teaching then tends to consider scientific concepts as material things or objects. Teaching also seeks to reduce conceptual abstraction into the visibly tangible. For example, natural selection is illustrated, of course, by experimental data but often, the conclusion about the concept of natural selection is limited by a concrete object: the survival or death of organisms subject to environmental pressures. Yet the concept of natural selection is not itself observable. It is a conceptual explanation about the causes of adaptation and the variability of organisms by a biology mechanism. Only its effects can be seen (survival or death).

Another example of reification is the notion of the ideal plan of vertebrata. Comparative anatomy of different species brings out the topological unity of the organisation of living organisms. But moving from "structural homology" as identified by non-evolutionists such as Georges Cuvier and Richard Owen, towards "phylogenetic homology" which Étienne Geoffroy Saint- Hilaire and Charles Darwin proposed, requires an acceptance of a common origin.

For example, classifying man as a primate is one thing. Establishing relationships within the primate group is quite another. In the first case, there is classification and organisation in terms of common characteristics (opposable thumbs, nails, eyes etc.) without referring either to the immutability or the evolution of species. Whereas the other approach meant passing from commonly observed attributes to an arborescence of kinship. Phylogenetic diagrams are not only an illustration of evolution, they also have heuristic content. For example, they make it possible to show the point at which the chimpanzee and man diverge and thus make it possible to consider the existence of a common ancestor for the two species. Teaching using phylogenetic arborescence has clear theoretical underpinning. The teaching challenge is to pass from horizontal classification to phylogenetic verticality, which is rooted in the common ancestor. Simple observation is not sufficient to make this move. Only the combination of observation and the explanation of the evolution of species by natural selection during geological time accounts for this homology.

This is why homology is central to the teaching of evolution and is not to be confused with resemblance or similarity as a pupil of final year of high school did whilst observing the amino acid sequences of a protein common to different species and claimed that "the more the amino acid sequences are alike, the more the genes are homologous". The pupil confused similarity with homology (Fortin 2000a, b). For him, there were degrees of homology as there were of similarity. If we follow his logic, some genes would be more or less homologous because they more or less resemble one another. The remark made clearly illustrates that the concept of homology is not acquired through direct observation in contrast with resemblance which is. For the observed similarities to indicate a common source it is necessary to draw on the concept of the transformation of species. Evolutionary theory is hidden within the phylogenetic arborescence and, further, any such diagram is an encrypted version of the theory.

This is why teaching by showing, which attempts to explain the facts of evolution outside of their theoretical context, has reached its limits. It does not help pupils to go beyond the simple description of the fossils of living organisms. If separating facts from theory is justified, on the one hand there is the permanence of facts and, on the other, the partial or provisional explanations furnished by science: this dichotomy between facts and theory should not let us forget that, by themselves, facts say nothing and that it is only the explanations of scientific theories which bring them meaning. To put it another way, the theoretical explanation of evolution turns raw data into observable evolution. It makes it possible to see retrospectively, in the unity of the organisation of a living being, a common origin or, in the change of colour of the peppered moth, the action of natural selection. Seen from this point of view, theory is primarily a conceptual and explanatory operative framework.

By teaching the reversal in a way whereby the facts of evolution are stated and described as such, we take the risk of removing the inherent explanatory nature of the theory and of adopting a dogmatic teaching of evolution. The removal of the word "theory" from the school curricula marks, no doubt, the desire to reject speculation which cannot be tested experimentally. It is also a legacy of positivist teaching which emphasised only scientific results rather than the building of knowledge. But if the explicit reference of theory of evolution is absent is the pupil not obliged to "see" blindly through the prism of empirical fact? And if so, is the pupil not left to "believe" or "not believe" in evolution, given the absence of the means to combine observed or experimental data with conceptual explanations?

3 How Do Pupils Imagine Evolution?

Research in biological teaching shows that pupils come to biology classes with preconceptions about the history of life. The sources of these preconceptions are beliefs, socio-cultural origins and their imaginary (Dagher and Boujaoude 1997). What is in question here is not how the pupil thinks but how these thoughts are modelled so as to understand the discourse, thoughts and writings of the pupil. These tend to fall into five conceptions (Fortin 1993, 2000b):

- The "pseudo evolutionist conception" admits a common origin of life and the extinction of species (Fig. 42.1). Pupils generally propose mutation as the means by which species are biologically transformed.

"It must have been luck when the wheel of fortune led to the birth of man but things could have worked out otherwise because it is one chance in infinity" (pupil 17 years old, high school level, Literature option) The wheel of fortune refers to games of chance (the lottery, Russian roulette…) where from a limited number of possibilities there is, by chance, a result.

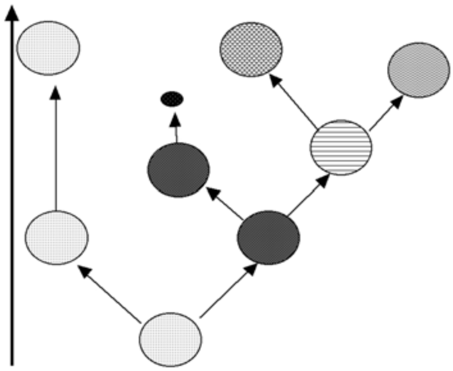

Fig. 42.1 Pseudo evolution conception. Each group or species has a common origin and can become a new group. Extinction is possible. Each *circle* represents a group or species: the *arrows* indicate their transformation (Fortin 1993)

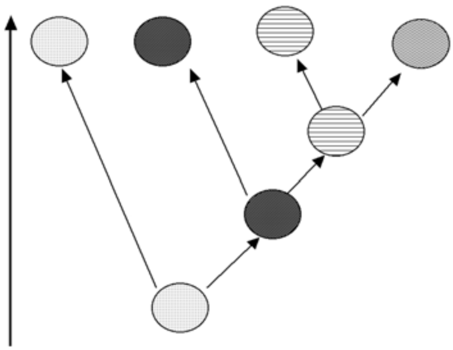

Fig. 42.2 Transmutationist conception. Each group or species can become another. Extinction is impossible

This vision integrates probability into the history of life "There could have been something else, birds with men's heads, that could have happened: personally I think luck should not be minimised, we might have lived underground if life on the surface had been impossible. Lots of things could have happened. Anything could have happened or nothing at all". (pupil 18 years old, high school level, Science option)

- The "transmutationist conception" also accepts a common origin for life but extinction is excluded. No genus or species disappears (Fig. 42.2).

For these pupils, dinosaurs became today's reptiles, mammoths became elephants, Australopithecus became modern man etc. To explain the causes of species transformation, pupils propose mutation, environmental pressure, metamorphosis such as from tadpole to frog. "Before man there were fish, reptiles and other animals which, as time passed, became men". (pupil 17 years old, high school level, Economics option)

- The "non-evolutionist conception" is characterised by the absence of relationship between the species (Fig. 42.3). For these pupils, only mutations within a species are possible, new groups or species are impossible: "All kinds of life have evolved and transformed. Before, horses were small. Now they are big. It's the same for elephants" (pupil 16 years old, high school level).

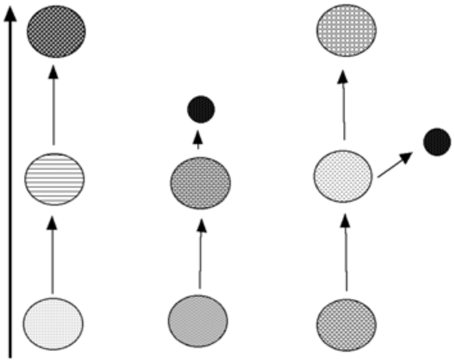

Fig. 42.3 "Non-evolutionist conception". Each group or species is separated. Extinction is possible as is transformation within a species

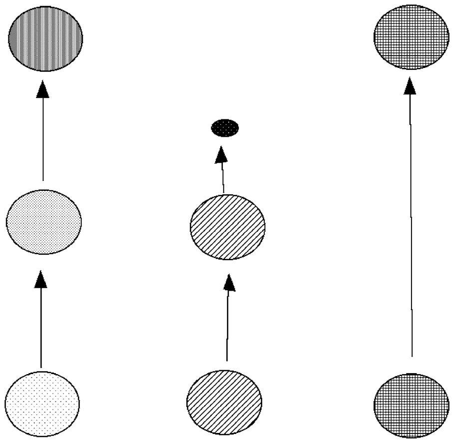

Fig. 42.4 "Creationist conception". Each group or species is created by God separately. Extinction is possible as is transformation within a species

Each group or species is independent of all others. Each lineage can be transformed or indeed disappear entirely. A group or a species can disappear.

- The "creationist conception" is of religious origin and adheres literally to the Bible. The Book of Genesis is considered to be an historical work. All species were created separately: they can have no kinship (Fig. 42.4).

  Adam and Eve are treated as historical figures that lived at the dawn of humanity. "I am a Jehovah's Witness and it is said in the Bible that God created Adam and Eve. There is no evolution" (pupil 15 years old, middle school level)

  "In my view, and according to Holy Scripture, it is entirely possible that man and the dinosaurs lived side by side until the latter were destroyed during the Great Flood and never reappeared." (pupil 17 years old, high school level, Economics option)
- The "concordist conception" accepts the idea of a common origin and of the transformation of species but it considers that the evolutionary process is part of a divine process (Aroua et al. 2002) which we do not and cannot understand: "Those who know the Koran know well that the idea of evolution is already in

the Koran" (pupil 18 years old, high school level, Science option). "God created life and he also created the modifications which transform nature". (pupil aged 18, high school level, Economics option).

These various conceptions express resistance and obstacles to the scientific idea of evolution. For example, the vividness of the Creation myth, interpreted as an historical truth, is a religious obstacle. The creative universe of science-fiction where everything is possible is a socio-cultural obstacle. Mutation seen as a way of adaptation, bypassing natural selection, is an epistemological obstacle. Amongst other obstacles encountered, vitalism and competition can also be mentioned.

The vitalism obstacle sees the adaptation of organisms as a response to their vital need. "Organisms evolve to adapt" is a frequent statement made by pupils. Vitalism also adopts the metamorphosis image, thus effacing the historical dimension of evolution in favour of a physiological process of development in which "animals transform themselves". Vitalism is often accompanied by an apocalyptic version of history in which the coming of mankind is the final stage of evolutionary development.

The environmental obstacle sees the adaptation of organisms as a response to environmental pressure. It is common for pupils to state that "the environment causes animals to mutate". Even though there are powerful environmental factors, some pupils imagine that only the environment is capable of transforming organisms "which then evolve." They reject the idea of random mutation and of natural selection on the survival or disappearance of particular allels.

Lastly, the competition obstacle refers to the "struggle for survival" as a defining law of nature, obliging organisms to adapt or die. "I think that life is governed by the law of the survival of the fittest. Extinction comes about when the weaker die and are replaced by the stronger who transform themselves, from generation to generation, so as best to adapt". (pupil 18 years old, high school level, Science option). Natural selection is seen as "the survival of the fittest" (Bishop and Anderson 1990) and not as a differential in reproduction by those allele carriers who have an adaptation advantage in a given environment.

There is another, possibly more important, obstacle – that of the word "parent" (Fortin 2009a). In common usage, parents evokes mother and father. But in scientific discourse, evolutionary is the outcome of speciation from a stem specie. Family and evolutionary relationship are not one and the same nature. Yet some pupils imagine evolutionary relationship on the twin mother and father parent model. One species breeds with another and give birth to a new species. Evolution is seen as a form of hybridisation of the species which borrows its concepts from mythology (Centaurs, Pegasus) or science fiction (cross-breeding between humans and aliens). Thus species are transformed by genetic mixing and not by genetic rupture, as was the case of speciation, by isolated reproduction of populations.

In general, the idea of the development of living beings is understood: however, the idea of a common origin remains unclear for a lot of pupils. As for the biological mechanisms of evolution (natural selection, genetic drift, etc.) they are quite often reinterpreted so as to suit the pupils' personal misconception. We can see here the distance between how pupils understand scientific concepts concerning evolution and the teaching journey necessary so that pupils can modify their own conception, indeed abandon them entirely.

4 The Representation of the Theory of Evolution Among Teachers

Teachers' epistemological views about the functionality of the theory of evolution are as important as how pupils see evolution. There is some variety. A survey undertaken within a group of 20 secondary teachers (Fortin 1993) shows that opinion is divided in two. For some, the theory of evolution "is the result of the accumulation of facts", "facts build theory", "theory is deduced from anatomical, palaeontological, embryological and molecular facts". For others "facts nourish theory and vice versa" and "everyone has different knowledge about the theories (plural) of evolution".

These differing points of view have an effect on teaching practice and, here too, the approaches contrast. "I teach facts and their scientific meaning, not philosophical explanations"; "theory only aids experimental validation occasionally"; "theory makes it possible to interpret the facts."

Studies undertaken in the United States (Osif 1997) and Europe show that teachers are often uncomfortable when explaining evolution (Rutmedge and Mitchell 2002). They are unsure that they have mastered the subject and dread pupils' questions (Griffith and Brem 2004). Some are sceptical about evolution (Munoz et al. 2007), others find it hard to separate the religious sphere from the scientific (Stolberg 2007). There is clearly uncertainty within the teaching body (Sanders and Ngxola 2009) about how to teach evolution and the importance that should be given to theory. What concerns teachers is the status of the biology of evolution as an historical science. Generally won over by a predictive or probabilist view of biology in genetics or physiology, they are uncertain about contingency.

The biology of evolution does not need of the concept of final causes. Even if the forming of a species is not predictable, speciation can nevertheless be explained rationally. As Stephen Gould said "I am not speaking of randomness, but of the central principle of all history—contingency. An historical explanation does not rest on direct deductions from laws of nature, but on an unpredictable sequence of antecedent states, where any major change in any step of the sequence would have altered the final result. This final result is therefore dependent, or contingent, upon everything that came before—the un-erasable and determining signature of history" (Gould 1989, Wonderful life).

If the biology of evolution cannot be predicted, it can be retrodicted (Gayon 1993), that is to say, it makes it possible to see what the material causes were which presided over the origin of a species. If there is a finality it is in terms of deterministic biology, where nothing is possible because of the constraints of the living organism and not because of the final cause(s) of the history of living organisms.

So the epistemological conceptions of teachers have an influence on their teaching. When the theory of evolution is seen as the end result of the collection of facts from observation and experimentation, the teaching concentrates on the description of these facts, without necessarily making any reference to the usefulness of theory in the discovery of evolution facts.

When theory is seen as a coherent model capable of showing or refuting, by means of data from observation and experimentation, that species are not immutable, teaching is organised around a 'to and fro' between the facts and the mechanisms of evolution. In this case, the teaching also touches on the possibility of amending the theory so as to introduce hitherto unknown mechanisms and new possibilities of evolution (Neo-Darwinism, Punctuated Equilibrium, Neutral theory of evolution, etc). The permanent to and fro between the explanation provided by the theory and the facts makes it possible to construct, retrospectively, the scientific fact of evolution. Without this it would just be an ordered collection of facts connected by induction and the mechanism of evolution would be a dogma.

5 Towards Teaching Effectively

Today, in the eyes of their pupils and students, neither school nor university is as serious as an internet site. Indeed, in counterpoint to teaching by showing there is another "showing" strategy, that of creationism and of Intelligent Design (Baudouin and Brosseau 2008). The pupils put what is taught in school up against anti-evolutionist discussion and decide their value on the basis of their own convictions (Fortin 2006). Given the need by pupils to criticise so as to understand, how should the pertinence of the theory of evolution be explained? In some countries, and in particular in the United States, teaching guides aimed at helping teachers to answer pupils' questions have been published.[2]

For example, to the standard creationist question "If man descended from the ape, why did all the apes not become men?" the scientific reply is that apes today (including man) are issued from fossil apes, that there are several ape lines of descent including the human one and that man and the chimpanzee have a common ancestor. However, these explanations are only comprehensible to those who already have scientific knowledge (definition of a species, distinction between current species and fossil species, degrees of relationship…). This indispensable work of scientific communication and outreach (publications, lectures) helps teachers to explain and the general public to understand the objective reality of evolution. But it is not at the centre of the act of learning.

Despite school instruction, qualified teachers, information for the general public, evolution remains suspect for many pupils (Woods and Scharmann 2001) and

[2] National Research Council (1996), National Academy of Sciences (1998, 2008).

sometimes for teachers. Here, for example, is the remark of a pupil of final year of high school after a class on homology "It's normal that there are similarities in homology between the vertebrates, because all the vertebrates develop the same way. That doesn't prove that they are related. Take the ape and man for example, even if they have similar development, the same organs, the same limbs etc… they're both mammals so they develop in the same way. That doesn't mean they have a common ancestor. A monkey's a monkey. Man is man."

In fact, contrary to the appearance, this pupil does not believe in creationism. He is just saying to the teacher that the educational objective – proving kinship between man and the other primates – has not been reached. What is the obstacle? The pupil shows that he wants to understand. For him, homology is not sufficient to prove a relationship between primates. He awaits an argument that will have sufficient weight for him and can be accepted as proof, hence his criticism of what is taught and what he perceives as an argument of authority.

The scientist and the teacher, both well-versed in the theory of evolution, both know that homology is a concept concerning the transmission of hereditary characteristics from a common ancestor. An expert can tell what can be attributed to homology and what is just similarity. But for the pupil, things are much more difficult. Distinguishing between resemblance and homology is, for him, a bridge too far.

The gap between how the expert (scientist or teacher) thinks and how the novice (general public or pupil) proceeds is at the heart of learning. Building on the observation of anatomical, molecular, experimental and taxonomical facts does not in itself lead to the idea of a common origin. Otherwise Cuvier, Owen and von Baer would have been proponents of evolution. The anatomical unit, indeed the embryological unit of organisms, do not lead to a common ancestor. Even more so, given that it is a reconstructed concept within the framework of the theory of evolution. Teaching by showing has its limits (Keynes 2009). By wanting to show and show again, one neglects to refute the non-evolutionist way of thinking.

And yet the confrontation between non-evolutionism and the transformation of species from a common origin obliges us to clarify the epistemological status of the raw data, to explain the concepts being used, to justify the need for rational and scientific debate (Mc Bride et al. 2009). From this, comes another way of teaching evolution, not just based on results but on groping, dead-ends and how the construction of scientific knowledge is validated.

Teaching by refutation should look at the supposed non-evolution of species and put it in doubt. It should be examined in the same way as was the idea that the sun revolves around the earth. Refutation does not replace demonstration: it is another valid way of teaching. It aims at requiring the pupil to follow his own reasoning until the end, while knowing perfectly well that the idea of evolution will not be spontaneously discovered. The teacher accompanies the pupils. Questioning by the teacher encourages questioning by the pupil. The result will not be for – or against – evolution, as one might be for – or against – genetically modified foods, nuclear power, but the fruit of a reasoned argument using shared knowledge in which natural phenomena are explained by natural causes.

6 A Conclusion of Sorts

It is common practice to confine the teaching of evolution within the belief/science opposition. In the last few years, this old conflict between science and personal belief has been reactivated by the partisans of creationism and of Intelligent Design so as to destabilise the teaching of evolution. This conflict has no place in a biology class because creationism and Intelligent Design are not scientific theories.

The principal difficulty in teaching evolution is not the rift between belief and science but the inherent difficulty to articulate a teaching showing anatomical, embryological and molecular data with a teaching of refutation of non-transformation of species (Fortin 2009b).

Teaching by showing evolution fact has the merit of making evolution visible and of sharing knowledge recognised by the scientific community. It also carries the heritage of teaching evolution which has renewed and absorbed corrections from the biology of evolution for more than a 100 years, from Lamarck until the present day. Yet this form of teaching prioritises the description of the history of living beings over explanation. Indeed, it prefers to make assertions about evolution before even explaining it.

But teaching evolution is not just reciting the history of living beings and waiting to be ambushed by other history discourses such as those of the creationists or Intelligent Design. There should be no epistemological confusion between facts and theory, rather what is needed is teaching which considers the articulation between the conceptual framework and factual data. That is to say, teaching where the concepts of evolution, of natural, selection, of homology, etc. are not reduced to simple observable facts but integrated within the theory which explain the transformation of species.

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