Acta Biotheoretica 33: 35–50 (1984).

Can the theory of evolution be falsified?

PAUL A.M. van DONGEN* and JO M.H. VOSSEN

Department of Comparative and Physiological Psychology, Catholic University of Nijmegen, P.O. Box 9104, 6500 HE Nijmegen, The Netherlands

(Received 4-III-1983; revised 23-VI-1983)

Key words: Evolution, falsification, Darwinism, philosophy of science

Abstract. In this paper we discuss the epistemological positions of evolution theories. A sharp distinction is made between the theory that species evolved from common ancestors along specified lines of descent (here called "the theory of common descent"), and the theories intended as causal explanations of evolution (e.g. Lamarck's and Darwin's theory). The theory of common descent permits a large number of predictions of new results that would be improbable without evolution. For instance, (a) phylogenetic trees have been validated now; (b) the observed order in fossils of new species discovered since Darwin's time could be predicted from the theory of common descent; (c) owing to the theory of common descent, the degrees of similarity and difference in newly discovered properties of more or less related species could be predicted. Such observations can be regarded as attempts to falsify the theory of common descent. We conclude that the theory of common descent is an easily-falsifiable & often-tested & still-not-falsified theory, which is the strongest predicate a theory in an empirical science can obtain. Theories intended as causal explanations of evolution can be falsified essentially, and Lamarck's theory has been falsified actually. Several elements of Darwin's theory have been modified or falsified: new versions of a theory of evolution by natural selection are now the leading scientific theories on evolution. We have argued that the theory of common descent and Darwinism are ordinary, falsifiable scientific theories.

1. Introduction

The discussion on the value of the theory of evolution has restarted [14, 15, 16, 20, 21, 22]. This discussion is confused, because key concepts such as "empirical sciences", "true", "false", "falsified", "tautological" and "the theory of evolution" are not used clearly enough as will be shown below. This contribution consists of attempts to clarify these concepts, and to use the clarified concepts thereafter in a number of statements on evolution, which are now intended to be

* to whom correspondence should be directed, present address: Department of Histology, Karolinska Institute, P.O. Box 60400, S-104 01 Stockholm, Sweden.

meaningful, unambiguous and exact. Other authors suggested that the evolution theory is another type of theory than "ordinary" theories in science [18, 19], but we want to demonstrate that evolution theories are just ordinary scientific theories.

2. Formal and empirical sciences

Introduction. The demarcation between formal and empirical sciences appears to be crucial for a further treatise on the theory of evolution. Empirical and formal sciences will be distinguished here according to their subjects. The subjects of empirical sciences (like physics, chemistry, biology, or psychology) are concrete elements, and the subjects of formal sciences (like mathematics and logic) are abstract elements.[1]

Popper's demarcation criteria. In the paragraph above, demarcation criteria were formulated to distinguish empirical and formal sciences. The system of concepts developed by Popper [17, 18] is often mentioned in papers regarding the status of the theory of evolution [16, 22]; therefore his demarcation criteria will be mentioned here. *"To distinguish between the empirical sciences on the one hand, and mathematics and logic as well as 'metaphysical' systems on the other* [17: 34] ... *not the VERICABILITY but the FALSIFIABILITY of a system is to be taken as a criterion of demarcation* [17: 40] ... *it must be possible for an empirical system to be refuted by experience"* [17: 41]. Both Popper's and our system of demarcation have their specific advantages. We distinguish sciences on the basis of their subjects, thereby making the distinguished systems intuitively homogeneous, but in our system the place of metaphysics or ethics, for instance, is not obvious. Although Popper's system of demarcation is intended to distinguish empirical from non-empirical sciences, it is actually suited to characterize statements or theories rather than sciences [cf. 18: 81–84], for falsifiable statements on various subjects within an empirical science can be made non-falsifiable by slight modifications.

Implications: Absolutely certain knowledge. Given the appropriate axioms and definitions, a statement in a formal science is true or false (or undecided), and we know that it is true if it is proven. In other words, absolutely certain knowledge is possible within the domains of a formal science, since its subjects are chosen and fully determined by the scientist. On the other hand, because of the limitations in human

knowledge about the world, absolutely certain knowledge is not possible in empirical sciences, not even about the existence of their subjects, let alone on their properties.[2] Popper also struggled with the problem of absolutely certain knowledge, as is evident from the following two citations. *"The use of the concepts 'true' and 'false' is quite analogous to the use of such concepts as 'tautology', 'contradiction' ... and others of the kind. These are non-empirical concepts, logical concepts"* [17: 274–275; in the 1972 edition of his 1934 book]. *"I accept the common-sense theory ... that a theory is true if and only if it corresponds to the facts"* [18: 44]. Evidently, in these two citations, the words "true" have different meanings. In a formal science, many statements can be proven true or false, and then they are absolutely true or false. When, however, in an empirical science a theory has been falsified, it should not be called "proven false", for tomorrow the falsification can be demonstrated to be wrong. Popper seems to accept that a falsification can never produce absolutely certain knowledge [17: 42], but he still treats falsified theories as absolutely false and compares them with extinct species [18: 19].

Implications: Predicates in formal and empirical sciences. Absolutely certain knowledge is possible in formal but not in empirical sciences. Statements in empirical sciences should therefore get other predicates than "true", "false", "proven" or "tautological", otherwise these predicates would be ambiguous. In an empirical science, the following predicates are appropriate.

1. Results are *reliable* or not; results are reliable when essentially similar observations yield similar results (i.e. a positive correlation is found between the results of similar observations).
2. Concepts are *valid* or not; concepts are validated when essentially different observations yield similar conclusions[3] (i.e. a positive correlation is found between the conclusions from different observations).
3. Theories are *falsified* or not; a theory is falsified when (crucial or too many) discrepancies have been found between the results predicted according to the theory and the actual results (i.e. the absence of a positive correlation between predicted and observed results).

Statements in an empirical science are essentially probabilistic; therefore it would be a categorial mistake to apply the predicates "true" of "false" to them.

Example: A sphere is round / The earth is round. In mathematics, the

statement "a sphere is round" is true by definition; it is necessarily true. Given the appropriate axioms and definitions, many statements in mathematics are necessarily true (i.e. true by definition, or tautological), but sometimes it is difficult to prove this tautology. But what about the statement "the earth is round"? In this statement "round" can be defined as having a certain radius showing variations of less than say 1%. (Note that the meaning of "round" is different in formal and empirical sciences.) The statement "the earth is round" can then be tested in several ways by making measurements of the curvature of the earth surface at various places from either (a) the position of stars, (b) from sunbeams in vertical wells, or (c) from pictures of the earth taken from a space vehicle at various locations at great distance. The observations can be done reliably: the outcome remains the same when done by different observers. It is validated that these observations regard the three-dimensional shape of the earth, since different types of observations lead to the same conclusion. The theory that the earth is round is easily falsifiable, often tested and still not falsified; it is now generally accepted. But note that even such a conclusion can never be absolutely certain knowledge. A theory is "easily falsifiable" when it permits the predictions of attainable, new results that would be unlikely without that theory. The predicate "easily-falsifiable & often-tested & still-not-falsified" is the strongest predicate a theory in an empirical science can obtain. The predicate "demonstrated" is the usual predicate for the subject of such a theory: it is demonstrated that the earth is round. It is only a matter of taste whether one wants to use the word "verification", and how easily falsifiable and how often tested an easily-falsifiable & often-tested & still-not-falsified theory must be, before the predicate "verified" is appropriate [cf. 13: 53–54].

Theories: Consistency and falsification. Theories in an empirical science must be internally consistent, i.e. their formal basis must be true. For instance, Newtonian mechanics can be expressed in necessarily true Euclidean mathematics, but this never can make Newtonian mechanics necessarily true. Mechanics based on either $F = Ma$ or $F = Ma^2$ (in which F is force, M is mass and a is acceleration) can be expressed in true Euclidean mathematics in both cases. Both are easily falsifiable, and $F = Ma^2$ has been falsified, and $F = Ma$ has not; at least for velocities far below the speed of light. The prestige of Newtonian mechanics greatly increased since it made possible the discovery (i.e. the successful prediction of the presence and position) of Neptune in 1846. It is a minimum requirement for an acceptable theory in an empirical science that it is based on a necessarily true (or at least consistent)

formal basis, but further requirements are that it is (at least in principle) falsifiable, and that it is as simple as possible.

3. The status of the theory of evolution

3.1 *Introduction*

"The" theory of evolution. The concept "the theory of evolution" is ambiguous: it denotes the theory that different species descend from common precursors (i.e. evolution), and also a number of theories intended as causal explanations [8] of evolution (i.e. the mechanism of evolution). In a treatise on the status of the theory of evolution, the meaning of the concept "the theory of evolution" should be clear. In this paper, the theory that different species descend from common ancestors is called "the theory of common descent", or more precisely, it is "the theory that the living organisms on earth descend from a limited number of common ancestors along lines of descent essentially in agreement with generally accepted phylogenetic trees". (This is not circular since phylogenetic trees can be validated as will be shown below.) After comments on the status of the theory of common descent, the status of some theories intended as causal explanations of evolution will be discussed.

3.2 *Did species evolve?*

Introduction. The status of the theory that organisms descend from a limited number of common ancestors along specified lines of descent will be discussed in this chapter. The question that matters in the discussion between evolutionists and creationists is WHETHER organisms descend from common ancestors, and it is not the mechanism of this presumed process. Is then the theory of common descent falsifiable or, in other words, does the theory that organisms descend from common ancestors along specified lines of descent permit the successful prediction of otherwise improbable outcomes of new observations? Initially, two questions will be discussed. Can theories on past events be falsified? And can lines of descent be demonstrated?

Theories on past events. Present and past events can be well demonstrated; an event occurring now and well demonstrated now will tomorrow still be called well demonstrated unless new, more convincing

observations have yielded contradictory results. For instance, historians trying to make generally acceptable reconstructions of past events have a hypothesis or theory in mind on which they base predictions that would be improbable without their theory. They might predict specified discoveries to be done at specified locations or in specified archives, or at least they assume no discoveries to be done conflicting with their ideas. Hypotheses or theories on past events are "genetic explanations" [8] of the data available. Such genetic explanations are weaker than causal explanations [8], but being explanations of present data, they allow predictions about future findings. Actually, many theories of historical events have been falsified, so theories on past events can be falsifiable essentially. For instance, for many years it was the generally accepted opinion that Albert Speer was an apolitical technocratic minister in Hitler's government, who did not know what was actually going on in the concentration camps; this opinion has been convincingly falsified [24]. Note, however, that neither the old, nor the new opinion can be absolutely certain knowledge. Many historical events are called "demonstrated": the theories on these events are then falsifiable, satisfactorily tested and still not falsified. The point we want to make here is this: the opinion that the theory of common descent can not be falsified since it is a theory on past events, does not hold.

Can lines of descent be demonstrated? Lines of descent can be demonstrated at present. When a woman designates a certain man as the father of her child, a judge will decide whether he is the father, taking into consideration the results of investigations about genetic properties. Unless these results indicate that the relationship is highly improbable (or unless other strong contra-evidence is available), the judge will decide in favor of this man's fatherhood, for it is highly improbable that an arbitrary man can be the father with respect to many genetic properties. So this is an instance in which one can speak of falsification as a method of decision. Fatherhood is easily falsifiable now, and when it is not falsified after several tests, it is considered to be demonstrated. Comparison of heritable properties of individuals and their presumed offspring can convincingly demonstrate lines of descent. (When, however, a mutation has occurred in one gene of the biological father related to a genetic property investigated, his fatherhood will wrongly be regarded falsified; a falsification in an empirical science is essentially probabilistic.) The point to be made here is this: if recent lines of descent can be demonstrated, more remote lines of descent must essentially be demonstrable by the same method: comparison of heritable properties.

Fossils and the theory of common descent. As Ruse [22] and Rootbernstein [21] already remarked, a certain degree of continuity in the fossils of species discovered since Darwin's time could be predicted from the theory of common descent.[4] For instance, human-like fossils must not be older than, say, 4 million years. The discovery of an unequivocal human fossil of 8 million years would be unexpected, but it would still be possible to modify phylogenetic trees so that such a fossil does not contradict the theory of common descent. Without evolution, however, a new human-like fossil could well be as old as 400 million years, i.e. older than the oldest fossils of amphibians. Suppose now that such a 400-million-year-old human-like fossil will be discovered: the existence of such a fossil would be in conflict with a lot of data which were thought to support the theory of common descent. Investigators will probably not succeed in bringing all data again in accordance with a new plausible phylogenetic tree. But actually, all human-like fossils appear to be relatively recent. From the theory of common descent it could be predicted that fossils of new species discovered since Darwin's time fit into lines of descent, and they do indeed. The only scientific theory explaining this order in the fossil record is the theory of common descent. Traditional phylogenetic trees based on morphological properties of living and extinct species have been validated now, since they are essentially identical to phylogenetic trees based on biochemical data [1, 29]: without evolution there is no reason why phylogenetic trees constructed by such different methods are essentially identical. The theory of common descent could predict such data obtained since Darwin's time; therefore these data could be gathered as if it were an attempt to falsify the theory of common descent.

Similarities and differences between species. It can be predicted from the theory of common descent that newly discovered species that are similar to other, already known species in "crucial" morphological respects (called "related species"), are also similar in biochemical, anatomical and other respects; common descent is the simplest scientific explanation for such resemblances. It can be deduced from the theory of common descent that organisms resemble each other ultrastructurally, and they do indeed. From the theory of common descent it is predicted that future investigations of birds of any species, not investigated up to now, will reveal the presence of cells with a nucleus containing chromosomes made of DNA. We can successfully predict the presence and most of the amino acid sequences of haemoglobine in the blood of a not yet investigated mammal: thanks to the theory of common descent. Without common descent there is no reason why the chro-

mosomes of apes and man should be so strikingly similar as they are [31]. From the theory of common descent we can predict the degree of similarity and difference between homologous and analogous properties of different species. We are so used to a large number of similarities and to only a few differences between related species that we are inclined to forget how unlikely such similarities are without common descent. The theory of common descent is the scientific theory that offers the simplest genetic explanation of similarities and differences between species.[5] Being the genetic explanation of present data, it can predict new data. In the past, many properties of species, not investigated till then, were investigated and expected to be similar to properties of known related species: the expected similarities between related species were found. These investigations can be regarded as attempts to falsify the theory of common descent. So the theory of common descent is an easily-falsifiable & often-tested & still-not-falsified theory. It is easy to formulate similar new tests and to carry them out.

Theoretical example: The prediction of amino acid sequences. Several proteins have been found in every investigated species of the whole animal kingdom, as well as in plants, fungi and bacteria. Variations in the amino acid composition and sequence occur, which are larger when the organisms are more remotely related. For instance, a diagram of the degree of difference in the amino acid sequence of cytochrome *c* between various species *"agrees fairly well with evolutionary relations inferred from the fossil record and other sources"* [1]. Take now, for instance, the mammalian orders A, B and C, with their corresponding characteristic forms of cytochrome *c*: α, β and γ respectively. Suppose now that no differences have been found in the enzyme-activities of α and β, and that γ is less active than α and β. It is predicted now that not yet investigated species of the orders A and B have variants of cytochrome *c*, α and β respectively, while the expected degree of variation can also be specified. Without common descent there is no ground for such distribution of apparently identically working enzymes, while this distribution is in agreement with theories of molecular evolution [10, 11]. Perhaps more convincingly, owing to the theory of common descent, we can predict variants of the inferior enzyme γ in not yet investigated species of the order C. These are suggestions for future attempts to falsify the theory of common descent.

Evolution is demonstrated. It has been concluded above that the theory of common descent is an easily-falsifiable & often-tested & still-not-falsified theory. When a theory, regarding the occurrence of an event,

fulfills these requirements, the event is called "demonstrated". Such an event needs not to be directly observed; its occurrence may also be the compelling conclusion from other data. Many events in empirical sciences and in everyday life are called "facts", although they are less strongly demonstrated than evolution. Saying that common descent has not been demonstrated is only paying lipservice to creationists.

"Evolution is not proven." A common objection is: *"The theory of common descent is not proven, and therefore it can be neglected as a scientific theory"*. The theory of common descent is a theory of an empirical science to which the predicate "proven" is not applicable. Therefore, the statement that this theory is not proven is meaningless. The theory of common descent should be taken as seriously as other scientific theories that have been demonstrated with comparable strength.

Is creationism wrong? If evolution is demonstrated, is creationism wrong consequently[6]? The creationistic theory is a hybrid collection of statements, consisting of statements about concrete elements, like the organisms on earth, and statements about a Creator. The statements about the concrete elements are essentially falsifiable, but the more fundamental statements about the Creator are not. Therefore, creationism eludes all criteria mentioned before: it is neither true, nor false, nor proven, nor demonstrated, nor falsified, nor falsifiable.

3.3 *How did species evolve?*

Introduction. Once the evolution of species from common ancestors along specified lines of descent is accepted, the status of theories intended to be causal explanations of this process will be mentioned. It will be argued that the falsification of such theories is possible but more difficult than that of the theory of common descent. Theories on the occurrence of an event are easier to falsify than theories intended as causal explanations of such event.

The transfer of acquired properties. Lamarck has formulated a theory intended as a causal explanation of the evolution of living organisms. Properties of organisms change during life because of use or something else, and it is an essential element of Lamarck's theory that these acquired properties of an organism are transferred to its offspring. The formal basis of this theory is consistent or tautological. From Lamarck's theory it is predicted that acquired properties are heritable; but if such acquired properties are transferred, the changes might be

very small indeed when only a few generations are taken into consideration. Many attempts have been undertaken to demonstrate transfer of the acquired properties Lamarck considered to be heritable, but no reliable accounts have been presented in favor of such a transfer.[7] Eventually, the theory of evolution through transfer of acquired properties was abandoned; it was refuted by experience, and in Popper's terminology, "refuted by experience" is identical to "falsified" [17: 41].

Is Darwinism falsifiable? Various arguments have been presented why Darwinism would not be falsifiable. The objection was made that Darwinism is (almost) tautological [18, 19, 22]. Moreover, evolution is a process covering billions of years, while experimental investigations can only give direct evidence for changes within a short time and over relatively few generations. Therefore, it was considered that results from experimental investigations could not be reliably generalized to the actual process of evolution. Both types of objections will be discussed in the next two paragraphs.

"Darwinism is tautological". The objection was made: *"(i) Darwinism is tautological, and (ii) therefore it is an irrelevant theory that does not offer new knowledge."* The first part (i) of this sentence is complicated: its meaning might be either (a) *"The formal basis of Darwinism is tautological"* or (b) *"Key concepts of Darwinism are 'fitness' and 'survival'; in empirical investigations, 'fitness' of an individual due to a specified trait can only be measured by its 'survival value'; therefore, the basic concepts of Darwinism can not be validated (or in other words, are circular)".* These interpretations will be discussed separately.

1. "The formal basis of Darwinism is tautological." This is true; the formal basis of every acceptable theory must be necessarily true or tautological. A theory in an empirical science should, however, not be called irrelevant when its formal basis is tautological. On the contrary, a tautological formal basis of an empirical theory is a minimum requirement for its acceptance, but its acceptance or rejection depends thereafter on empirical investigations.
2. "The basic concepts of Darwinism can not be validated", which is a statement on Darwinism as a theory in an empirical science. In contrast to the above mentioned opinion, 'fitness' and 'survival value' can be defined and measured independently from each other. In an analytic approach, a causal explanation can be given why some traits are evolutionary advantageous[8] above other specified traits in a particular environment. Analysis of the costs and benefits of various

traits in a particular environment provides a measure of their relative evolutionary advantage; this can be validated by determining their actual survival value, in which survival of individuals or genes can be measured. The statement "Darwinism can not be validated" is false: the basic concepts of Darwinism can be defined with preservation of their originally intended meaning such that they can be measured independently, and thereby validated or not: their validation is an empirical question.

From experiment to evolution? It has been argued that the mechanism (i.e. the causal explanation) of a very long-lasting process like evolution can not be falsified by experiments, since the period of time covered by experiments is too short. If this objection should be conclusive, it would be impossible to falsify hypothetical explanations of evolution. Lamarck's theory, however, has been falsified now. Therefore, the opinion that Darwinism can not be falsified because the duration of evolution is too long for experimental testing, does not hold. Several elements of Darwin's theory have been falsified now, as will be shown further on.

Neutral mutations. According to neo-Darwinism, new mutations penetrate into the population when they make their bearers fitter than the bearers of the non-mutated genes. Arguments have been adduced in support of the idea that also "neutral mutations" can penetrate into a population, i.e. mutations whose bearers are equally fit as the bearers of the non-mutated genes. When two different forms of a protein have been found, it is very difficult indeed to demonstrate that such distribution is NOT evolutionary advantageous, i.e. to demonstrate that such mutation is neutral. It is, however, implausible that all existing properties of organisms are "better" than the properties of their precursors [cf. 10, 11]. Phylogenetic trees based on biochemical data start from the tacid assumption of a fairly invariant rate of change in the genetic properties of organisms, whereas several new mutations are apparently irrelevant for the fitness of their bearers. The presence of differences between species based on neutral mutations is widely accepted now, but it is not yet certain how often this occurs.

The "units" of natural selection. "Evolutionary biologists are divided on the question of the referents ('units') of population genetics and of the theory of evolution ... Is it individual organisms, species, or populations?" [2: 33]. Some behavior of animals can be best understood when the individual organisms of a population are considered as

competitors against each other promoting their own survival and/or reproduction at the expense of other individuals of their population. Other animals, however, for instance social insects, sometimes completely seem to disregard their own survival, promoting the survival of other individuals of their population [30]. Other animals again sometimes kill individuals of their own populations (e.g. infanticide [9]). The problem whether natural selection works on individuals, populations or species, is (at least partly) solved by the inclusive fitness theory [7] or "sociobiology". According to this theory, evolution can be best understood by accepting that natural selection works on genes rather than on individuals, populations or species: the "units" of natural selection are genes. From the inclusive fitness theory, the prediction follows that animals showing altruistic behavior selectively favor co-specifics sharing relatively many genes with them. These favored co-specifics are often relatives ("kin selection"), as has been found in many species [30]. Kin selection does, however, not explain all altruistic behavior [12]; the question whether a property has emerged due to kin selection or to classical Darwinian individual selection is always an experimental question [12]. Both the classical individual selection and kin selection are in agreement with the inclusive fitness theory.

Modifications of Darwinism. The hypothetical mechanism of evolution as proposed by Darwin has been modified since its first publication. Like Lamarck, Darwin thought that acquired properties are transferred, but this theory has been abandoned now. Genetic theory has been integrated together with Darwin's theory into a new theory, the so-called "new synthesis" or "neo-Darwinism". And again, neo-Darwinism has been modified: (a) neutral mutations are now accepted to occur relatively frequently, and (b) genes rather than individuals or populations are regarded by many evolution biologists as the units of natural selection. Some arguments have been presented in favor of step-wide rather than gradual evolution ("punctuated equilibria"), but discussion continues whether this is only a modification of neo-Darwinism or an alternative theory explaining evolution [28]. The point to be made here is: some elements of Darwinism have now been refuted by experience (or falsified), so Darwinism is falsifiable, although its falsification is not easy.

Conclusion. We hope to have demonstrated that elements of Darwinism have been falsified and that Darwinism is falsifiable. It certainly seems strange to hear the opinion that Darwinism cannot be falsified, now that elements of it actually have been rejected. New versions of a theory of evolution by natural selection have been formulated which are now

widely accepted as the most plausible scientific explanations of evolution, and which are again open to falsification.

4. Appendix: The basic structure of this paper

In the present paper, the meaning of the predicates "true", "false" "reliable", "valid", "falsified" and others of the kind is discussed. Just how "true" are the statements that are used in this paper? Probably the reader is rendered a service when the basic structure of this paper is made clear.

1. *Premises.* A subset of experiences can be distinguished, so-called "inter-subjective experiences" of states and/or events of elements which are perceived outside the observer. Most of such elements are "concrete elements", which are the subjects of empirical sciences like physics, chemistry, biology of psychology. We do not bother whether such concrete elements "really exist", but for convenience's sake we formulate our statements as if they existed. Non-concrete elements are abstract elements, and these are the subjects of formal sciences like mathematics and logic.

Premises. Absolutely certain knowledge is possible in formal but not in empirical sciences.

Implication. The predicates "true" and "false" are predicates of statements in formal sciences; such statements must be proven or disproven.

Implication. The predicates "reliable", "valid" and "falsified" refer to probabilistic knowledge about concrete elements; such statements can go together with descriptions of observations (references to literature) in which the reliability, validity or falsification is demonstrated.

Definition. A theory is falsified when a positive correlation is absent between the results of actual observations and the results predicted from the theory.

2. *Definition.* The theory of common descent is the theory that the organisms living on earth descend from a limited number of common ancestors along lines of descent essentially in agreement with generally accepted phylogenetic trees.

Implications. The theory of common descent permits many predictions of results that are improbable without evolution; for instance, about similarities and differences between species, about the continuity

in the fossil record, and about validation of phylogenetic trees.

Conclusion. The theory of common descent is an easily-falsifiable & often-tested & still-not-falsified theory.

3. *Definition.* Darwinism is a theory formulated by Darwin that is intended to offer a causal explanation of evolution; essential elements of Darwinism are heritable variations between individuals of a species, natural selection, and the survival of the fittest.

Modifications. Several elements of the original theory of Darwin have been modified or falsified. (1) Darwin assumed (like Lamarck) the transfer of acquired properties; this theory has been falsified. (2) Knowledge on heredity, mutations and population genetics is incorporated into Darwinism. (3) Neutral mutations are now accepted as occurring relatively frequently. (4) Recently, a theory has become popular that genes rather than individuals, populations or species are the units of natural selection (i.e. the inclusive fitness theory).

Conclusion. Darwinism is falsifiable and elements of it actually have been falsified.

Present evolution theories. New versions of Darwinism have been formulated, which are now the leading scientific theories to explain evolution by natural selection.

Conclusion. Theories on the occurrence and scientific explanation of evolution are ordinary falsifiable scientific theories.

Acknowledgements

Owing to many discussions with Paul J.A. Timmermans, several errors have been removed from earlier drafts of this text. Positive criticism by Hanneke P.M. Receveur and Marijke J.M. van der Kant is greatly appreciated.

Notes

1. The concept "concrete element" is identical to "substantial individual" as used by Bunge [3]; all non-concrete elements are "abstract elements" or "constructs"; for further comments on this subject see ref. 3.
2. "Property" is a difficult word [3]; the words "property" and "trait" will be used as synonyms in this paper, whereas some comments on the use of "property" have been given earlier [27: 56].
3. For a more elaborate comment on the meanings of "validity" see De Groot [5]: tests are called "valid" when they are either internally consistent, or give similar results

as other tests intended to measure the same property, or predict successfully the results of other observations, or when they "really" measure what they are intended to measure. Since absolutely certain knowledge is impossible in empirical sciences, we can never be certain whether an observation "really" reflects what it is intended to reflect. In the practice of experimental investigations, however, an independent "test" for the widely accepted measurement is generally regarded as sufficient for validation. Examples of the actual use of the words "valid" and "reliable" are to be found in the following papers [6, 25, 26]. In this paper we require a considerable difference between the types of observations, before we use the word "valid" (cf. the following paragraphs: *'Examples: A sphere is round / The earth is round'*, *'Fossils and the theory of common descent'* and *'"Darwinism is tautological"'*).

4. Circular arguments should be avoided: Darwin based his theory on data known to him at his time; these data were not predicted by the theory of common descent, only newly discovered data are. Moreover, note that this applies only to similarities between species, for similarities between subspecies can still be caused by an exchange of genes within a species, as is also accepted by creationists.
5. Creationists might object that such similarities and differences have been created to make all organisms better off with their own special properties, but then the burden of demonstrating this rests upon them (see also the paragraphs on neutral mutations, and on the theoretical example, the prediction of amino acid sequences).
6. Various variants of creationism are encountered [16], but the remarks in this paper are very general, and are intended to apply to all variants.
7. OTHER acquired properties evidently are transferred (e.g. cultural transmission, ref. 4), but Lamarck's theory was not meant for such properties.
8. A definition of "evolutionary advantage" has been given earlier [27], together with reasons to prefer it to "adaptation" and "fitness".

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Note added in proof:
Since the submission of this manuscript, two papers by Van der Steen have appeared (Acta Biotheoretica 32 (1983) 207–215, and 217–222), which treated partly the same subject, and which contained several pertinent remarks.