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Viruses are real, virus species are man-made, taxonomic constructions*

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Scientists are committed to the study of real, tangible objects and tend to rely on facts rather than on speculation. This steadfast commitment to the real world partly explains the reluctance of some scientists to become involved in classifying the objects they study. Classifications tend to be perceived as purely conceptual constructions of the mind, useful for bringing some semblance of order into the bewildering variety of natural phenomena, but essentially arbitrary and unworthy of serious attention by scientists engaged in the study of nature. As stated by Milne [22] many are bored by taxonomy because they think it means spending a lifetime on whether a certain kind of beetle has five hairs on its bottom or seven – and then splitting the hairs. To many virologists, the current debate [2–5, 31, 33] on the appropriate way of writing the names of virus species may seem equally abstruse and boring, especially if they have never given a thought to the reason why virus species were introduced in viral taxonomy in the first place [30].

Concrete objects and abstract concepts should not be confused

Virologists need to refer in their publications to the viruses they study and they are obliged to follow the rules of typography and orthography of virus names edicted by the International Committee on Taxonomy of Viruses (ICTV), a body empowered by the International Union of Microbiological Societies to have authority on matters of virus classification and nomenclature [20]. Since the names of viruses and virus species are written differently, it is in fact necessary to appreciate that viruses and virus species belong to two different logical categories, i.e. the concrete and the abstract. Viruses are intracellular parasites and are tangible, concrete entities, located in space and time, that can be handled experimentally. Virus species, on the other hand, are abstractions that exist only in the mind; like other taxonomic categories

*Editor's footnote: Professor Van Regenmortel is a former President of the International Committee on Taxonomy of Viruses (ICTV) and has had seminal influences on the taxonomic thinking in virology during recent years. Nonetheless the views expressed in this article are his and not necessarily those of the Executive Committee of ICTV. These will be published at the end of an on-going consultation exercise.

(families, genera) they cannot be encountered physically and cannot be centrifuged, purified or visualized in an electron microscope.

As virus diseases became recognized, the causative viruses were given names in different languages that often reflected the symptoms of the corresponding diseases as well as the hosts or organs that become infected. These common names of viruses were coined long before virus classification and taxonomy came into being and they are devoid of any taxonomic connotation. The names are simply signs or labels that refer to physical entities responsible for a particular disease. Since names and labels are man-made tokens made up of letters that bear no resemblance to the objects they denote, some people are led to the erroneous conclusion that all names, including those that refer to physical entities like viruses, actually denote abstractions. Bos [3, 5] for instance, maintains that a virus such as the venerable tobacco mosaic virus, is an abstraction and he justifies this curious assertion on the basis that we can, allegedly, neither see nor physically handle a virus, only its particles. It seems that Bos fails to appreciate that a virion is only one stage of the concrete entity called a virus and that this entity can take on a variety of forms and manifestations, for instance as a replicating nucleic acid. The replicating form is no less real than the virion, as demonstrated by the ability of certain drugs to interfere with viral replication. It would be equally absurd to maintain that insects are non-existent abstractions because one usually encounters pupae, caterpillars and flying moths.

It is important to realize that abstractions are concepts that are not located in space and time and exist only in the mind. Examples of abstractions are beauty, honesty, redness and a taxonomic category such as species. The term "virus" on the other hand, corresponds to what logicians call a general term, i.e. a word that denotes any number of concrete entities [26–28] in contrast to a so-called "singular term" that refers to a single object, for instance the Eiffel tower. The word "pipe" for instance, is a general term that denotes any number of concrete objects that are used for burning tobacco and for smoking and it would be odd to consider a pipe as an abstraction. The fact that the term pipe can refer to many different objects does not make the word pipe an abstraction. A pipe is no more an abstraction than a virus or a virus-infected host. The painter René Magritte highlighted the distinction between an object and its pictorial representation in his well-known painting of a pipe which included the caption "This is not a pipe" (Fig. 1). Only confusion results if viruses or pipes are considered to be abstractions because humans need to use words or pictures to refer to objects and to communicate with each other. When we think of a virus, the thought we entertain in our mind should not be confused with the virus itself which remains a concrete entity.

On the other hand, when we think of a species, that particular thought is about an abstract concept that is not located in space and time. All thoughts are mental constructs but this does not mean that the thought of pipes or viruses transforms these concrete objects into unreal, abstract entities. Since Bos is convinced that a common virus name like tobacco mosaic virus stands for an abstraction, he is led to the belief that common virus names can be used in an abstract taxonomic sense and he even states that the corresponding viruses existed as abstract taxonomic entities long before virus taxonomy came into being [5]! It is true that common names mostly preceded scientific names but this would not justify the conclusion that the name tobacco, for instance, has a taxonomic connotation which does away with the need to distinguish taxonomic species like *Nicotiana tabacum*, *N. glutinosa*, *N. rustica*, *N. sylvestris* or *N. benthamiana*.

Early ICTV reports listed the names of many viral entities, i.e. viruses, strains, serotypes and isolates of unspecified taxonomic status. It was only when the ICTV decided that the lowest taxonomic category to be considered should be the virus species, that it became necessary to allocate certain names to this taxonomic category. Only in the 6th [23] and 7th ICTV reports [35] did the approved species names acquire a taxonomic sense [33].

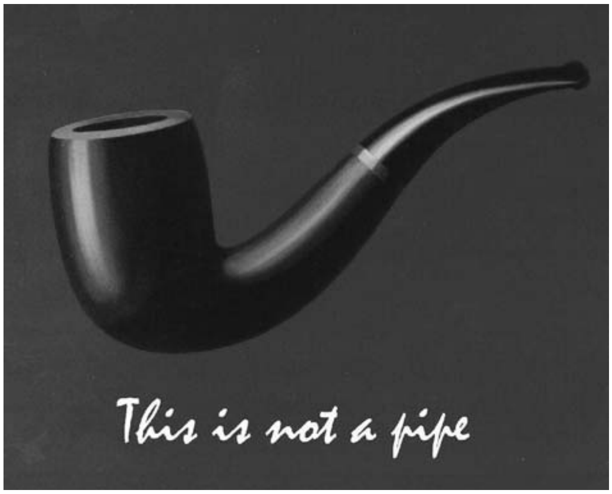

Fig. 1. Illustration of the importance of distinguishing between an object and its representation, based on the many paintings of a pipe by René Magritte with the caption: "Ceci n'est pas une pipe". It is equally important to distinguish between the object, the names it has in different languages and the thought we entertain in our mind when we think of it

It is important to realize that all biological classifications are conceptual constructions created by scientists for the purpose of introducing order in the bewildering variety of biological objects. Of equal importance is the fact that the categories used for building a classification such as families, genera and species are not found in nature but are abstractions invented by human minds. Species are thus not objects that will ever be encountered by virologists in their handling of viruses. It is therefore also impossible for a virus species to cause a disease. Unfortunately, for the sake of convenience in writing, authors frequently write that the species *Mus musculus* has been inoculated with a particular virus species instead of saying correctly that a mouse (a member of the species *Mus musculus*) has been inoculated with a member of a particular virus species (i.e. with particles of an isolate of a virus species). In his discussion of the need for linguistic precision, Bos [5] disagrees with this viewpoint and maintains that a virus can actually be a "part" of a species. This is not the case since it is logically impossible for a concrete object to be part of an abstract entity, i.e. of an entity of different logical type. It is equally impossible for an idea to be part of a concrete object. As discussed for instance by Buck and Hull [7] and Mahner and Bunge [15, page 230], it is essential to distinguish the logical relations of class membership, class inclusion and part-whole relationship. Only a concrete entity can be "part" of another concrete entity, in the way that cells and organs are part of an organism. In a classification scheme, however, an organism or a virus can only be a "member" of an abstract class such as a species since only the logical relationship of class membership is able to establish a link between concrete and abstract entities. Viruses are thus members but not part of a species. Furthermore no species can be a member of a genus since the relationship between abstract classes can only be class inclusion [15]. It is thus a double logical mistake for Bos [5] to state that abstract viruses are part of abstract species.

As pointed out by Mahner and Bunge [15, page 7], we all use logically ill-formed statements because they often are convenient ways of speaking. For intance we talk of burrowing species instead of burrowing animals belonging to some species. Such habits of speech facilitate writing and reading and are harmless in most contexts; however they can be misleading in a text where key concepts are being elucidated and defined as in the example discussed above. It is obviously incorrect to write that the species *Tobacco mosaic virus* spreads from cell to cell (instead of the virus) but this loose way of speaking does not necessarily involve a logical muddle. It simply corresponds to a shorthand contraction of: "particles of an isolate of the species *Tobacco mosaic virus* move from cell to cell". Although purists might argue otherwise, the shorthand version need not be a source of conceptual confusion as long as one recognizes that it is simply a convenient way of speaking. It is the context that will determine if the ill-formed statement is ambiguous and is likely to create confusion.

What names should be given to virus species?

The ICTV decided in 1998, to confer the status of official species names to the English common names of viruses and introduced a typography using italics and a capital initial to indicate that these names correspond to abstract taxonomic entities rather than to concrete viral objects [25]. The use of English names instead of Latin names for species is in line with the fact that English has replaced Latin as the language of international communication used by scientists [31]. All virologists are in fact conversant with the English names of viruses because the major journals in Virology are written in English.

In an effort to promote the use of latinized binomial names for virus species, Gibbs [11] recently tried to downplay the primacy of English in contemporary communications about viruses. He felt compelled to disagree with the observation [31, 33] that English has replaced Latin as the *lingua franca* of scientists and he went on to make the preposterous claim that "Latin never was the language of communication between scientists"! Latin, in fact, was the universal European language of learning well into the 18th century. Newton's *Principia Mathematica* which is generally considered to be the greatest scientific work ever written was written in Latin; it was published by The Royal Society in 1687 and did not appear in English until 1729. Newton's *Opticks*, published in 1707 was written in English but was soon translated into Latin so that it could be read outside of England. To take another example, the father of taxonomy, Linnaeus (1707–1778) spoke only Swedish and Latin and wrote all his works in Latin (*Systema Naturae*, *Species Plantarum*, *Philosophia Botanica*).

Linnaeus invented the Latin binomial system, universally used for naming the species of animals, plants and microorganisms. However, the Linnaean system was not accepted by virologists who have remained steadfastly opposed to the latinization of virus names [16, 17, 31]. One of the reasons it took many years before the concept of virus species was accepted by the virological community was the opposition of many plant virologists, who argued that the acceptance of virus species would inevitably lead to the latinization of virus names, a change which they strongly opposed [17, 22, 29].

In recent years, a few authors [1, 2, 11] have advocated the use of binomial Latin names for virus species, on the grounds that it would bring virus nomenclature in line with the Codes of Biological Nomenclature used for organisms. This rationale requires of course that one accepts that viruses are microorganisms whereas the view of ICTV over the years has been that viruses occupy a unique position in biology which justifies the policy of not following the traditions of biological nomenclature in virus taxonomy.

Viruses do belong to biology since they possess some of the properties of living systems, such as having a genome and being able to adapt to particular hosts. However, this does not mean that viruses should be regarded as organisms. Viruses do not possess several of the essential attributes of living organisms, such as the ability to capture and store free energy and they lack the characteristic autonomy that arises from the presence of a set of integrated, metabolic activities. Viral replication is only made possible by the metabolic activities of the infected host cell. It is generally accepted today that the simplest system that can be said to be alive is a cell. Only unicellular and multi-cellular organisms possess the property of being alive, whereas the individual macromolecules, the organelles and the genes found in cells are not themselves considered to be alive.

There is thus no justification for regarding viruses or other sub-cellular entities like plasmids or transposons as living microorganisms. Some authors [11] argue that viruses should be considered organisms because they share with certain parasitic organisms the property of being obligate parasites. However, the dependency of viral genes on their cellular hosts is a totally different type of "parasitism" from the dependency shown for instance by bacteria which colonize the gut of certain animals. Obligate parasitism on its own is not a sufficient criterion for establishing that an entity is alive. Viruses contain no energy-producing enzyme systems, they possess no ribosomes or other cellular organelles, they do not grow in size and do not possess the biochemical machinery necessary for reproducing themselves. Viruses are clearly not living microorganisms and they can be said, at best, to lead a kind of borrowed life [30]. The unique position of viruses in the biological realm is recognized by most virologists and this explains why the ICTV, as the voice of the international virological community, has chosen to follow its own rules rather than to adhere to the Biological Nomenclature Code.

Following the 1998 revision of the International Code of Virus Classification and Nomenclature [21] the currently approved international names of virus species are italicized mononomials corresponding in most cases to the English common names of viruses. The use of italics provides a visible sign that species approved by ICTV correspond to taxonomic classes, just like genera and families.

It should be stressed that it is only the names of viral taxonomic classes that are written in italics, not the names of the viruses which denote concrete entities [9]. In a scientific paper it will be necessary to refer only once, in the Materials and methods section, to the taxonomic name (i.e. *Measles virus*). In the remainder of the text the virus under study can be referred to by its common name written in Roman characters (i.e. measles virus) Since it is the common names that are used repeatedly in a text, they are the ones that require acronyms rather than the names of virus species. At present in the vast majority of cases, the common names of viruses are the same as the species names, except that the species names are italicized, and the abbreviations will thus be mostly the same. However this would no longer be the case if a binomial system of species names were introduced [32, 33].

Since the name of the virus species (e.g. *Measles virus*), differs only in typography from the name of a particular viral agent (e.g. measles virus), it is necessary to know to which of the two one wishes to refer to in a given text. This requirement to distinguish abstract species from concrete viruses has been explained at length in several recent publications [9, 32, 33] but according to Gibbs [11] this presents insurmountable difficulties to many authors. One way of overcoming this difficulty would be to change the current mononomial names of virus species into non-latinized binomials that have been popular with plant virologists for many years [3, 32, 33]. In this system, the word virus appearing at the end of the current species name is replaced by the genus name, which also ends in – *virus*; *Tobacco mosaic virus* for instance becomes *Tobacco mosaic tobamovirus.*

The advantages of such a system are well-known and Gibbs [10] has previously criticized the ICTV for not having enforced this binomial system for all virus species names, even when no proper consultation process had taken place in the virological community. The reluctance of the ICTV in the past to introduce such a system for all viruses was due to the opposition of many animal virologists as well as a general uncertainty regarding the acceptability of non-latinized binomials for a majority of virologists [36]. During 2002, efforts were made to canvass the opinion of virologists about this issue and the results of two ballots showed that a sizeable majority (80–85%) of the 250 virologists who expressed an opinion were in favor of this binomial system [19, 33]. This is the first time that the ICTV has obtained some indication about the way virologists feel about a particular taxonomic issue and one might have expected Gibbs to be pleased that the system he had been campaigning for, was now receiving such clear support. On the contrary, in his latest contribution to these columns Gibbs [11] bemoans the results of these ballots, which according to him, will further increase the confusion surrounding virus species names! He mentions that there may now be four variants of each virus name, i.e. tobacco mosaic virus for the virus, *Tobacco mosaic tobamovirus* for the species, tobacco mosaic tobamovirus for those who dislike using italics and capital initials, and the current species name *Tobacco mosaic virus*. He forgot one more variation which he has used himself [6] namely Tobacco mosaic *tobamovirus*! In actual fact, if non-latinized binomial species names became official names, one would retain only tobacco mosaic virus (the current common virus name) and *Tobacco mosaic tobamovirus* as species name (or measles virus and *Measles morbillivirus*) [33]. This would make it easier to differentiate between virus and species while at the same time ensuring the advantages provided by a binomial system based on existing species and genus names rather than on newly coined Latin names.

Abstract concepts like species can be defined, concrete objects like viruses can only be named and identified

Whereas the categories of family and genus were readily accepted by virologists, it took many years before the species category gained acceptance by the virological community. As recounted elsewhere [29] there was considerable opposition among plant virologists to the idea that the concept of species could be applied to viruses [16, 22]. Arguments against the use of the term species were reinforced by the absence of an appropriate and generally accepted definition of the term. A definition of the type: "species are strains whose properties are so similar that there seems little value in giving them separate names" [11] begged the question since it did not explain the meaning of the term species. In order to emphasize the cohesive forces present in ancestral descendant clones that share a common biotic niche, the following definition was proposed in 1989 and endorsed by the ICTV [24]: A virus species is a polythetic class of viruses that constitute a replicating lineage and occupy a particular ecological niche [29].

The concept of polythetic class was used to differentiate species from classical, so-called universal classes like genera and families that are defined by properties that are both necessary and sufficient for membership in the class [30]. A polythetic class consists of members that have a number of properties in common but which do not all share a single common property that could be used as a defining and discriminating character of the species because it is absent in other species. This means that it is possible to include in the species individual viruses that lack one or other character normally considered typical of the species which is an advantage in view of the variability of viruses. A single discriminating character such as a certain percentage of genome sequence similarity or a particular host reaction will thus not be a valid criterion for differentiating two species within the same genus. The erroneous claim of Gibbs [11] that virus species can be defined monothetically by the presence of one property present in all its members and absent in other species is reminiscent of the widespread tendency in recent years to confuse the classification of genomes with the classification of viruses [8, 36]. Difficulties in defining species are not unique to virology as shown by the fact that as many as 22 different definitions of species have been used in biology [18].

The acceptance of a definition of virus species by the virological community was an important step in establishing a virus classification based on traditional taxonomic categories. However, it did not solve the problem of demarcating individual virus species. It is a common misconception to believe that the existence of a definition of a concept like species (as a category of classes comprising all recognized virus species) should make it an easy matter to decide whether or not a virus isolate is a member of a certain species.

Such an unwarranted expectation arises when one fails to appreciate that it is only the meaning of the concept species itself, as a class of classes, that is explained by the definition. A definition only explains the meaning of a concept but it does not provide the means to decide which concrete entities are members of an abstract class. It is important to realize that it is not possible to "define" a concrete entity like a virus. Individual viruses just like individual people or any other concrete objects cannot be "defined"; they can only be named in a manner reminiscent of baptism [14] or they can be pointed at ostensively. Although viruses cannot be defined, they can be identified by a small number of so-called diagnostic properties [12, 29, 30] i.e. by characteristics that make it possible to recognize concrete, individual members of a species. The identification of a virus isolate is usually based on a comparative process that assesses to what extent an isolate is similar to a known member of an established species.

Notwithstanding the claim of Gibbs [11] to the contrary, ICTV Study Groups have been using the polythetic species concept in order to delineate individual species and they have relied on a number of properties rather than on the presence or absence of a single discriminating feature. Individual species are created by virologists on the basis of characters like genome sequence, host range, pathogenicity, mode of transmission, physicochemical properties of virions, antigenicity of viral proteins etc. Since species are actually fuzzy sets [30], i.e. polythetic classes, creating and delineating a virus species is more a matter of opinion and convenience rather than of logical necessity. If the presence of a single defining character would have been sufficient for species demarcation, the species issue in taxonomy would indeed have been much less problematic and controversial.

Once a species has been established on the basis of a combination of properties, it becomes possible to identify a virus isolate as a member of that species by considering only a few diagnostic properties. For instance, if a virus isolate reacts with a panel of monoclonal antibodies in the same way as an established member of a given species, the isolate will be identified as a member of that species. If the genome sequence of an isolate is 99.9% identical to that of a known member of a species, it will equally be identified as a member of that species. This, however, does not mean that the species itself can be "defined" solely in terms of a particular level of genome or antigenic similarity. This apparent contradiction between the need for many characters to define and delineate a virus species and the fact that a single property may sometimes suffice to identify a member of a species disappears when it is realized that defining an abstraction like a species is a different task from identifying a concrete entity like a viral isolate. Definition of an abstraction should not be confused with identification of a concrete object.

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