



## Towards an Evolutionary Perspective in Teaching and Popularizing Microbiology

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**Microorganisms are extremely abundant on our planet, and, as a result, they interact with many others forms of life. Today, science recognizes the essential role of these organisms in the emergence and maintenance of life on Earth. Nonetheless, misconceptions about microorganisms in the imaginations of students and the lay audience persist. A major challenge in teaching and popularizing microbiology is to provide students and the general public with a varied understanding of microbes in nature to reinforce their importance in a multitude of processes. In this perspective article, I discuss the persistence of the association between microbes and disease in laypersons' views. Moreover, I advocate for the adoption of a perspective anchored in evolutionary biology for teaching and popularizing microbiology to minimize this problem. To do so, I present several topics that interconnect evolution and microbiology and discuss how these topics could increase the general public's understanding of the microbial world.**

### INTRODUCTION

Microorganisms are the most abundant type of life on Earth, including tremendously varied forms, and they play key ecological roles in maintaining life on the planet (1). Although invisible to the naked eye, microbes occupy diverse habitats, and they are constantly interacting with other groups of living beings. These interactions are extremely variable depending on the context and species involved; importantly, in most cases, these interactions do not harm the organisms (2). However, the association between microorganisms and disease is still predominant in the thinking of the general public. When questioning a lay audience about the role microorganisms play in their lives, it is not uncommon for responses to refer to illnesses or “dirt” (3). This fact indicates that there is a discrepancy between the discourse currently adopted by science about the importance of microorganisms and the prevailing lay view on this subject. On the one hand, science shows that microbes are fundamental to the existence of life on Earth; on the other, the predominant association of microorganisms with harmful processes seems to persist among nonspecialists. Thus, providing a broader view of the

diversity, importance, and abundance of microorganisms in nature has become a key issue for a better understanding of the microbial world. This article first presents an overview of the deep association between microbes and disease in laypersons' views. Then, a brief discussion of the possible origins for such association is presented, followed by a suggestion for the adoption of a perspective anchored in evolutionary biology for teaching and popularizing microbiology to help to minimize the problem.

Microbiology is the field of biological sciences that examines the occurrence, structure, and function of microscopic organisms. It is an authentic scientific field, with knowledge produced by a community of experts who use specific methods, concepts, codes, and vocabulary to investigate and describe the microbial world (4). The adoption of a scientific discourse which is often complex and restricted to specialists can create barriers for the lay audience that cause difficulties in understanding both the basic concepts and the relevance of scientific activities (5, 6). In this scenario, communicating science to the public is an essential activity in bridging the knowledge gap between scientists and nonscientists. Additionally, this can help overcome misconceptions (7, 8).

The association of microbes with disease is still quite prevalent. The predominance of this perception, which I will call here “the pessimistic view of microbiology,” is noticeable in the discourse of people in informal situations and has also been described by researchers in the scientific literature. The pioneering study by Nagy (9) showed that children aged 5 to 10 lacked an understanding of microorganisms,

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and many children ended up categorizing germs as a type of animal (akin to small insects). Even though they incorrectly defined microbes, they always associated the organisms with disease. More recently, Byrne (10) investigated students aged 7 to 14 and concluded that one of the most frequent ideas in all groups was the connection between microorganisms and disease. Simonneaux (11) has shown that even among older students who have received initial instruction in microbiology, this association may occur; Simonneaux emphasizes that this makes it difficult to properly understand current scientific topics, such as biotechnology. In addition to reporting the prevalence of this same association, Jones and Rua (3) discuss that elementary school teachers who are not experts in the biological sciences have mistaken preconceptions about microorganisms which persist into adulthood.

The examples mentioned above indicate that both children and adults have alternative conceptions about microorganisms that differ from the scientific conception of the subject (3, 9, 10, 11). When the public has alternative perceptions about a phenomenon or scientific concept that differ significantly from the explanations adopted by science, these are referred to as scientific misconceptions (12). In microbiology, the prevalence of a pessimistic view of the role of microbes can be considered an important misconception which is likely to have diverse origins, ranging from the microscopic nature of microorganisms to their representation in the media. To minimize these conceptual misconceptions, I propose teaching and popularizing microbiology anchored in the perspective of evolutionary biology as a way to broaden the view of the microbial world.

### Why evolutionary biology?

Evolutionary biology has a unifying role in the biological sciences (13–15). From evolutionary biology, it is possible to understand biological diversity and the relationships among all living beings. In this sense, an evolutionary perspective can help people understand microorganisms as living beings that have value in their own right, moving away from the current anthropocentric views (16). Additionally, evolutionary biology is a field that presents many themes that can be related to microorganisms and can soften a pessimistic perception of microbiology.

Despite having a central role in the biological sciences in the last 150 years (14), evolutionary biology remains a topic that is rarely discussed in the teaching of microbiology (17). It seems that only the well-explored theme of antimicrobial resistance encourages strong interconnections between microbiology and evolution (18). In a previous study, texts related to microbiology in a Brazilian popular science magazine were investigated (19), and it was found that words such as evolution, natural selection, and adaptation were not mentioned in any of them. The reasons for such a paucity of examples of connections between evolution and microbiology in formal and informal education seem to be related to factors such as curricular compartmentalization (including

higher education), differences in the specific concepts applied in each area, and the lack of specific didactic materials that link evolution and microbiology (17).

Here, I present three major possible issues leading to a pessimistic and limited view of microbiology: 1) invisibility to the naked eye, 2) representation in the media, and 3) the early history of microbiology. I discuss how introducing themes related to evolutionary biology could help minimize the problems associated with each issue. Alongside the themes, I include references in the scientific literature and suggestions for possible approaches to broaden students' and laypersons' understanding of microbes.

### Invisibility to the naked eye

The inability to naturally see microbes in the world around us without special equipment hinders a wider perception of their abundance and diversity and can reinforce the notion that microbes only occur in dirty places or in disease situations. During childhood, our first experiences with microbes are typically related to disease. These experiences are striking because they cause significant changes in our body that, soon afterwards, we will associate with the presence of microorganisms. The impossibility of visualization with the naked eye and the indirect perception of a microbe's presence through the symptoms it causes are the basis of the conclusions we draw about microorganisms. Jones and Rua (3) described that even the perceived size of microorganisms can be altered based on the severity of the symptoms they cause. The authors noted that children may represent viruses as being larger than bacteria because the symptoms the viruses cause are generally perceived as more severe.

Difficulties related to the unicellular nature of microbes are also present in formal education. When studying mammals, for example, students will quickly begin to make inferences about this group in their daily life because direct observation of mammals in nature occurs frequently. This is different with microbes due to the need for specific instruments for visualization.

### Suggested approach to address this problem

To eliminate the under-representation of microbes, fundamental concepts of evolutionary biology such as common ancestry can be used to show how all life on Earth is related, as represented in the phylogenetic tree of life (20). Exploring the presence of microorganisms in the Bacteria, Archaea, and Eukarya domains of the phylogenetic tree of life helps reinforce the diversity of the microbe group. In addition, highlighting that two out of these three domains exclusively contain microbes helps demonstrate the abundance of microbes on the planet (1). To parallel this theoretical approach, it is possible to develop hands-on activities to show microbes in a multitude of environments. Specific protocols to evaluate the diversity of symbiotic microorganisms (21)

and a video protocol to isolate soil bacteria (22) are available online. Engaging young people in citizen science initiatives or even exploring data from projects such as the Earth Microbiome ([www.earthmicrobiome.org](http://www.earthmicrobiome.org)) or Project MERCCURI (<https://spacemicrobes.org/>) as a class can be great alternatives to show that microbes are abundant and can be found everywhere from nature to spacecraft. These activities can be very productive and lead students to other questions, such as Why are there so many kinds of bacteria? Why do they differ from one place to another? At this point, it is interesting to point out that, although similar at first sight, microorganisms exhibit a variety of forms and present a huge metabolic diversity (23); this is related to their individual evolutionary histories. Microbes with specific adaptations that allow them to inhabit extreme environments (24) can be used to exemplify this metabolic diversity.

### Representation in the media

The media is another important way to obtain information about the microscopic world. It is important to consider that the first explanations of and references to microorganisms young people are exposed to occur prior to any formal education and are often obtained through TV programs, the Internet, magazines, and advertisements. As discussed by other authors, the media seems to be an important source for the formation of conceptions about microorganisms (3, 11). In some cases, the ability of the media to dynamically transmit topics related to human health and disease is quite evident. Although the classification of viruses is the subject of ongoing debate in the scientific community (for an in-depth discussion of the topic see 25, 26), approaches involving viruses will be mentioned because of their great relevance to microbiology. In Brazil, for example, in the last three years, newspapers have been inundated with news of three major diseases caused by viruses: Zika, Dengue, and Chikungunya (27). It is vital to inform the population about the transmission of these diseases. Nevertheless, it is essential that ecological and evolutionary approaches also be addressed to assist in understanding the possible causes and preventive measures associated with infectious diseases.

### Suggested approach to address this problem

Addressing the way in which the media focuses on certain topics is quite difficult due to the multitude of issues involved. However, when using media information in the classroom (like microbiology popularization texts and videos), a way to minimize the pessimistic view many have of microorganisms is to contextualize the topics covered in an evolutionary perspective. Specifically, in the case of viruses, it is important to discuss their existence beyond the negative perspective that is usually presented. One way to achieve this is to explore hypotheses about the role of viruses in the origin of life and the evolution of the first cells (28), as well as discussing the ability of viruses to introduce new information into the host

genome, emphasizing their co-evolution and their major influence in the evolutionary history of several living beings (29, 30). Another approach to changing the common view of viruses is to introduce new topics, such as the occurrence of giant viruses in nature (31). In addition to being an excellent example of the enormous morphological and genetic diversity of viruses, these viruses are usually associated with amoebae (32), which helps to change the perception of viruses as being only human pathogens.

For unicellular microorganisms, one possibility for diversifying educational approaches rather than simply focusing on disease is to show how studies of the evolution of complex behaviors in these organisms have changed their status in the biological sciences (33). One of the major changes in contemporary microbiology has arisen from the understanding that most microorganisms in nature live in complex communities called microbial biofilms. This lifestyle has been widely described among diverse members of the microbial world, including archaea (34), bacteria (35), and even eukaryotes, such as fungi (36) and algae (37). Taking a better look at communication through Quorum-Sensing systems (38) helps to highlight that, although small, bacteria are much more complex than previously thought. Additionally, a broader view can be achieved by looking at the various ecological interactions established in multispecies biofilms in nature (39) and the implications for the survival of microbial populations (35).

### The early history of microbiology

It is also possible to find reasons for the current prevalent association between microbes and disease by looking at the early development of microbiology as a science. Although infectious diseases have been a part of humanity's history for thousands of years, knowledge of the involvement of microorganisms in these processes is a relatively recent development. The initial explanations given for disease symptoms attributed them to other sources. One quite popular explanation in the 17<sup>th</sup> and 18<sup>th</sup> centuries in Europe was the miasma theory, according to which miasma originated from organic matter in putrefaction and spread through the air. People who came into contact with this miasma or "bad air" would be contaminated and fall ill (40). In the 19<sup>th</sup> century, many scientists began to demonstrate the relationship between microscopic living beings and diseases. The discoveries made by prominent researchers such as Louis Pasteur (1822–1895), Joseph Lister (1827–1912), Robert Koch (1843–1910), and Martinus Beijerinck (1851–1931), among others, served as the basis for the currently established Germ Theory (41). Since then, much of the research in microbiology has investigated the causes and control of infectious diseases. Knowledge about the microbial world and infectious diseases has undergone so many advances that the early 20<sup>th</sup> century became known as the Golden Age of microbiology ([www.asm.org/index.php/choma3/71-Membership/archives/7852-significant-events-in-microbiology-since-1861](http://www.asm.org/index.php/choma3/71-Membership/archives/7852-significant-events-in-microbiology-since-1861)). The importance of investigating

infectious diseases, both when microbiology was being established as a science and at present, is indisputable. However, from that time to the present day, microbiology has diversified and expanded its activities to produce knowledge that should be broadly addressed in teaching and popularizing microbiology.

### Suggested approach to address this problem

In the last decades, areas such as microbial ecology, genomics, and evolution have provided a plethora of new knowledge in microbiology and have changed the way we understand microbes. The impact of these changes is so great that some authors refer to this period as the “third Golden Age of microbiology” (42). Below, I present some topics that can help broaden classes beyond a perspective of microbiology focused solely on diseases.

First, to soften the pessimistic perception of microorganisms, it is helpful to show that their impact on the Earth extends far beyond the diseases they cause in humans. Thus, it is a priority in teaching and popularizing microbiology to provide an overview of the prevalence of microorganisms and to emphasize their importance for the maintenance of life on Earth. In this sense, the study of microbial ecology has shown us much about the role of microbes in the evolution of life on Earth. A suggested teaching approach here is to explore what is new in the research relating to the role of ancestral microorganisms in the emergence of life on Earth and reinforce the existence of a “microbial world” during much of the existence of the planet (43). Additionally, exploring the ancient impact of microbes in biogeochemical cycles (44) and explaining how they caused major changes in the Earth’s atmosphere (45) that facilitated the emergence and evolution of other groups of living beings (46) could be very useful. These events began long before any sign of human life; this may help make it clear that microbes are involved in many other important activities on the planet and not just those that concern humans.

Another crucial point is to teach that microbes can interact with hosts not only in detrimental ways, but also in beneficial and neutral ways. A topic that can be very useful here is to explore Endosymbiotic Theory (46) and explain how organelles (e.g., mitochondria and chloroplasts) and major metabolic pathways evolved from early prokaryotic cells. Although the symbiogenesis process may raise some questions at first, it is possible to discuss with students many pieces of biochemical and genomic evidence that support this theory (47). To avoid the idea that this is a rare event restricted to the past, it is important to show recent examples involving protists (48) and the close relationship between insects and bacteria of the genus *Wolbachia* (49).

Finally, understanding the relationships between humans and microorganisms remains fundamental, and data from genomic studies have contributed significantly to this knowledge. Giving lay people updates on the discoveries

made from efforts to map the human microbiome can be very interesting, but to truly change their view of microorganisms, it is important to highlight the ecological and evolutionary roles of microbes. Several studies have shown that associations between humans and bacteria are intricate, and the diversity of species involved is enormous (50, 51). When using data from these studies in the classroom, it is possible to highlight that microbiomes have co-evolved with their human hosts for a long time and are essential for health and maintaining the balance of the enormous ecosystem that is the human body (52).

The examples mentioned above certainly do not cover all possible relationships between microbiology and evolutionary biology, nor do they claim to limit them. These example approaches are intended to encourage researchers, educators, and scientific journalists to utilize the relationship between evolutionary biology and microbiology as a way to broaden the view of the microbial world

The predominance of the association between microbes and disease in the minds of lay persons demonstrates the persistence of an important misconception. As discussed throughout this article, the causes of this association are diverse, ranging from the microscopic nature of microorganisms to their representation in the media. Adopting a perspective anchored in evolutionary biology to help broaden the understanding of the microbial world and presenting key themes that are at the interface between microbiology and evolution can serve as a starting point to eliminate these misconceptions. I believe that by shortening the distance between evolutionary biology and microbiology in teaching and popularizing microbiology, it is possible to broaden understanding beyond a “pessimistic view of microbiology” and to emphasize the role of microorganisms as fundamental agents of life on Earth.

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