The role of teachers in students' education for antibiotic use

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Antibiotic resistance is a public health world problem that calls for a global response. The question was already identified several years ago and is, for a large part, driven by misuse and abuse of antibiotics. There is a need for urgent action and numerous health related entities in each particular country, as well as world global entities, have repeatedly issued recommendations for intervention. The public and primary care professionals need education in order to make correct use of the antibiotics and secure the long-term availability of effective antibiotic treatments. Several misconceptions regarding the infections treatable with antibiotics, the role of these drugs, the duration of treatment, and others, lead to attitudes ultimately detrimental to public health. Making as many people as possible aware of these misconceptions can help to transform perceptions about correct use of antibiotics. Since transforming is more difficult than shaping ideas, learning from early ages the basic concepts about antibiotic mechanisms of action, antibiotic-resistant microorganisms and the correct use of antibiotics can help to change public awareness and reduce the misuse of these drugs and improve the knowledge on how to fight pathogens correctly. Teachers should look for strategies to effectively help students on the shaping of the ideas and on developing attitudes towards the prudent use of antibiotics.

Keywords science education; antibiotics misuse; misconceptions; public awareness

1. Antibiotics not ever but forever

The development, production and widespread use of antibiotics since the 1940s has changed medicine from a diagnostic, non-interventional to a therapeutic, interventional discipline. Millions of lives have been saved due to infection control and several medical advances, which would have been otherwise impossible, have occurred and improved peoples' quality of life [1, 2].

Presently, there are still populations that have no access to antibiotics [3]. According to the last reporting data in 2009 of the European Surveillance of Antimicrobial Consumption, the use of antibiotics in the EU and EAA/EFTA countries, both in the community and the hospital sector expressed in defined daily doses per 1,000 inhabitants per day (DDD), ranged from 10.5 DDD in Latvia to 38.6 DDD in Greece [4]. Even with the availability of effective antibiotics, infectious diseases are the second leading cause of death worldwide [5]. However, pharmaceutical companies are not investing in new antibiotic research because the pursuit of antibiotics offers a significantly low return on investment [1].

The loss of effective antibiotics will result in a great increase in morbidity and mortality from infections [2]. In a one-day study conducted in May 8, 2007, approximately half of the patients in more than 1,000 intensive care units in 75 countries suffered from an infection, and infected patients were twice as likely to die as uninfected patients [2, 6,]. In the EU, at least 25,000 people are estimated to die each year from an infection caused by multidrug-resistant bacteria [7] and almost 2 million Americans per year develop hospital-acquired infections, resulting in 99,000 deaths [8], the vast majority of which are due to antibiotic-resistant pathogens. Without effective antibiotics, diverse fields of medicine will be severely hampered.

Collectively, highly problematic antibiotic-resistant organisms are summarized by the ESKAPE acronym: *Enterococcus*, *Staphylococcus*, *Klebsiella*, *Acinetobacter*, *Pseudomonas*, and ESBL (*Enterobacter* and *Escherichia coli*). ESKAPE indicates that these bacteria have developed defences that permit them to escape the actions of available, effective therapies. The ESKAPE pathogens are currently the most important causes of the antibiotic resistance crisis in the US and other developed countries. Besides developed countries such pathogens are also spreading through developing countries, which are already experiencing significant public health problems caused by extreme drug-resistant or pan-drug-resistant *Mycobacterium tuberculosis* [9, 10].

A unique convergence of overuse and misuse of antibiotics, the remarkable genetic plasticity of bacteria, the acquisition of resistant bacterial infections in both community and hospital settings, and a market failure of antibiotic development has created an enormous public health concern regarding antibiotic resistance in bacteria [2].

In 2009 the World Health Organization declared antibiotic resistance as one of the three greatest threats to human health [11, 12]. In 2011 the European Commission action plan against the rising threats from antimicrobial resistance identifies seven areas where measures are most necessary including improving communication, education and training [13]. Most educational efforts have been targeted on physicians after their training but multi-faceted interventions must focus on the undergraduate healthcare professionals who should learn the necessary principles of microbiology, infectious diseases, clinical pharmacology, and prudent prescribing [14, 15].

To spread the message about the risks associated with inappropriate use of antibiotics and how to take antibiotics responsibly among the adult public, a number of initiatives, usually national public campaigns, took place since 1990 [16] and some are still ongoing across 29 countries of Europe [17] and in the US with the *Get Smart: know when antibiotics work* programme [18]. However, such concern is not common to several other countries, as in Asia where antibiotic resistance is the most serious in the world [19]. Evaluated campaigns seem to have reduced antibiotic use [16], and some decrease in antibiotic consumption was observed within a decade in countries like France, Portugal, Slovak Republic, Slovenia and Hungary [20].

Though the information is available, adults are usually not as receptive to change in their practice as children, who are usually more willing to learn. In the past few years, specific campaigns designed to educate children have been presented and some are still ongoing as *Do Bugs Need Drugs?* [21] and *e-Bug* [22]. In both there are several educational resources available that teachers can use in the classroom for children of different ages. Education on prudent use of antibiotics at the primary and secondary school levels offers the opportunities to shape the behaviour of the individual who later might become a patient or, more importantly, the anxious parent of a sick toddler. In addition, it provides the basic education of the future professional [14].

Although the natural ability of microorganisms to evolve genetically and become resistant to the drugs is inevitable, such capability is over-triggered in response to excess of prescription and improper use of antimicrobials. The need for global policies regulating the use of antibiotics is compulsory and involves different groups of people. Educational programs targeting young pupils can be expected to contribute to a future generation of scientifically literate antibiotic users; teachers should have a positive role in students' education for antibiotics use.

2. Current trends in science education

The success of the teaching and learning processes depends upon a variety of intricate factors. Nevertheless, research in education has provided considerable insight and a number of teaching approaches and learning models are currently available. The present mini-review describes briefly some of these approaches and models in order to support the suggestions made to help teachers develop their positive role in educating for prudent use of antibiotics.

The attention given by Piaget to the children while learning has focused subsequent research on what the pupil brings as knowledge when entering school or advancing in his school years. Special attention has been given to alternative interpretations concerning the natural phenomena, and their relevance to learning science and mathematics. These alternative interpretations have been named differently according to the emphasis given by the research. In particular they were designated: naïve theories, preconceptions, misconceptions, private concepts, underlying sources of error, inappropriate propositional hierarchies, student frameworks, alternative frameworks, and children's science [23].

Many studies show that students do not come into science classrooms without any pre-instructional knowledge or beliefs about the phenomena and concepts to be taught. Rather, students already hold deeply rooted conceptions and ideas [24] and prior concepts developed in the context of everyday life located within and belonging to whole alternative non-scientific frameworks of thinking about the natural world [25]. Much of the research confirms that these prior concepts are resistant to extinction or change [e.g. 24, 26], and they may even ossify into layman's science later on [27 cit in 23]. A conception is not only a product of mental activity, but is also generated by it. It is always a process of elaboration, which itself originates in information which learners receive through their senses, and also through the relationships they have with others - whether individuals or groups - in the course of their personal history, and which are etched in their memory [28].

While in many other biology topics everyday life provides good opportunities to develop alternative conceptions, the topic on mechanism of action of antibiotics and their effect on bacteria comes into children's and youngsters' life mostly through instructional activities and visits to the doctor's office, *i.e.*, through intended scientific explanations, where the proper conceptions should be retained. However, for some students, misconceptions remain after school. On the other hand, the need for antibiotics and their consumption comes into children's lives mostly from parents' attitudes and behaviours regarding cleanliness, protection against dirty things, and the use of antibiotics [26, 29]. Additionally, we cannot dismiss the influence of what the child listens to and watches in the media on the alternative conceptions about antibiotics and infections.

For the purpose of teacher action, it is important to mention what a number of authors, both from the science education and the cognitive psychology fields, have been finding [24]. Developing proper scientific conceptions, besides the learner's willingness and motivation to learn, calls for: the realization that the alternative conception exists; the frustration in effectively explaining with that conception all the connected phenomena; and the comprehension about the potential of the newly proposed idea as being a better and more fruitful explanation. Also, the concept to be learnt should be meaningful for the student, creating links to prior knowledge, in order for the learning process to occur. This conceptual change is not a simple swap of concepts but a pathway of cognitive and sometimes also sociocultural modifications [24, 28]. If the conceptual change is not achieved the outcome can even be the coexistence of both sets of conceptions.

The research on the relevance of concepts and beliefs to science education also drew attention to the importance of the concepts and beliefs portrayed by teachers in their practice and in launching or nourishing pupils' alternative conceptions. Approaches to conceptual change, as developed in the 1980s and early 1990s, contributed substantially to improving science learning and teaching, and some of the limitations of those approaches have been addressed and more multi-dimensional frameworks are currently considered [24].

Teaching and learning styles are always changing and in recent years there has been a noticeable move from lecture-based activities towards more student-centred activities. Case study teaching provides a means by which to accomplish this because it provides multiple approaches for effective teaching through "real life" examples, while students learn how to evaluate a problem and take decisions [30]. Students can learn more effectively when actively involved in the learning process [31].

A recent study with high school levels students (15-17 years), based on a program aiming to promote the participants' understanding of biological concepts and the processes underpinning the notion of antibiotic production and activity, by eliciting their engagement in microbiology procedures, indicates that the participants developed a more comprehensive picture of antibiotic resistance and the importance of judicious antibiotic use [32]. Activities providing hands-on experience with microorganisms, such as isolating and determining the antibiotic resistance profile of microorganism from the student's cell phone, not only allowed the perception of hygiene needs but also motivated students to launch a health education campaign designed to target their local college population on proper antibiotic usage [33].

Additionally, taking into account relevant research fields in science education, the Programme for International Student Assessment (PISA) 2006 specified the perception of "Students' willingness to engage in science" through three main aspects: interest in science, support for scientific enquiry, and responsibility towards resources and environments [34]. Within person-object theory, interest is seen as a dynamic relationship between a person and a specific object. This object may be a generic object, such as the school subject of science, or it may be a specific scientific phenomenon or concept, such as the use of antibiotics [35, 36].

Within the recommendations of the 2009 report for Science Education in Europe there is the notion that emphasis in science education before 14 should be on engaging students with science and scientific phenomena and methods should be devised to develop in students the skills, knowledge and competencies expected of a scientifically literate citizen [37]. Understanding the mechanism of action of the antibiotics and their pertinence to fight common diseases fulfils these recommendations.

3. Presenting and clarifying ideas about the use of antibiotics

3.1. Conceptions about microorganisms and antibiotics

Some years ago a young scientist was spreading bacterial cells on the culture medium in a Petri dish and a five-year-old child asked "What are you doing?". The best answer she came up with was "Well, I am putting some bacteria over this surface but they are too small and so you cannot see them". Then the child asked "And you, can you see them?". Teaching about what is not visible to the naked eye can be challenging but also very interesting because we can introduce a new world to the students. The action of antibiotics on microorganisms is one such challenging topic.

As pointed out earlier, students' alternative conceptions influence significantly how students learn, and knowing those alternative conceptions can help teachers in developing and implementing successful science teaching strategies. With regard to the antibiotic topic teachers should be aware of the most frequent students' preconceptions. A great deal of research about preconceptions, misconceptions and conceptual change concerns Physics topics, but studies on Biology topics have been increasing [23, 38]. In fact, in the very comprehensive Duit's bibliography on this subject, 1107 references out of 8338 are related to Biology topics. The number of studies referring specifically to students' conceptions on antibiotics, infections, diseases or 'germs' is low (only eight in the Duit's bibliography have these terms in the title), as also occurs with regard to the topic of socio-scientific issues, where antibiotics are frequently absent.

In Table 1 we list some of the most relevant and interesting students' and children's preconceptions and misconceptions found in the literature.

Table 1 Children and young students' conceptions about microorganisms and antibiotics.

Code	Conception	Age group	Reference
S1	Microorganisms are small living things; they cannot be seen with the naked eye	14/7;11;14	[28]/[26]
S2	Microorganisms considered to be living organisms	18-25/7;11;14	[29]/[26]
S3	Being dangerous, or causing diseases to humans, is a sufficient reason for considering microorganisms to be alive	7;11;14	[26]
S4	Microbes are cells	18-25	[29]
S5	Bacteria drawn as eukaryotic cells	14	[26]
S6	Bacteria are germs	15/14/14;17/7;11;14	[25]/[28]/[39]/[26]
S7	Germs, bugs or viruses considered as malevolent little	5-11/15/18-25/7;11;14	[40]/[25]/[29]/[26]

	animals/or animal-like		
S8	Bacteria confused with fungus	14	[28]
S9	Viruses and bacteria are identical	15/14/11;14;17/11;14	[25]/[28]/[39]/[26]
S10	Bacteria cause viruses	11;14;17	[39]
S11	Bacteria are present everywhere	14/11	[28]/[26]
S12	Bacteria are exogenous and their presence in the body causes problems and ailments	5-11/18-25/14/7;11;14	[40]/[29]/[28]/[26]
S13	Contact with bacteria, viruses and fungus cause disease	8-14/6-7;10-11;14-15	[41]/[42]
S14	Harmful/bad and useful/good bacteria coexist	18-25/14/11;14;17/11;14	[29]/[28]/[39]/[26]
S15	Bacteria are useful in the digestive process	14	[28]
S16	Yoghurt making is associated with bacterial development	14	[28]
S17	Bacteria are seen as decomposers of organic matter	18-25/14/7;11;14	[29]/[28]/[26]
S18	Bacteria thrive in damp conditions, and in the soil	18-25/14/11;14;17/ 7;11;14	[29]/[28]/[39]/[26]
S19	Bacteria, seen as dirt, are associated with pollution and the urban environment	14/7	[28]/[26]
S20	Ways of eliminating exogenous bacteria: obeying rules of hygiene, sterilization, disinfection	14	[28]
S21	Bacteria, viruses and fungus cause disease	11;14;17/18	[39]/[43]
S22	Not very aware of other causes of disease (microorganisms are main cause)	18-25/11;14;17/7;11;14	[29]/[39]/[26]
S23	Fevers are caused by germs, bugs or viruses	15	[25]
S24	Like viruses, bacteria attack the human body	5-11/18-25/14	[40]/[29]/[28]
S25	Microbes (seen as bits of dust), when they form a group within a bacterium, will cause mild health problems (colds, fever, sneezing)	14	[28]
S26	Bacterial infections are caused by doing unsanitary things while viral infections come from other people	12	[44]
S27	Causes of disease are primarily concentrated on the outside world and external situations (exogenous)	8;12	[45]
S28	Bacterial infections can only be spread by sneezing but viral infections can be spread by touching	12	[44]
S29	Not knowing what causes colds	20	[46]
S30	Virus was the illness that was the result of infection by microorganisms	11;14;17	[39]
S31	Viruses are germs	14;17	[39]
S32	Viruses are bigger than bacteria	11;14;17	[39]
S33	Bacteria are perceived as less dangerous than viruses	14/11;14;17	[28]/[39]
S34	Bacteria are not very harmful and only likely to become dangerous when there are many of them	14	[28]
S35	Virulence and rapid proliferation is equated to size	11;14;17/7;11;14	[39]/[26]
S36	More concern about colds and flu than with contracting major disease or disability	8-14	[41]
S37	Colds can be caused by germs and by alternative causes	15/11;14	[25]/[26]
S38	There's something you can do to get rid of a cold	15	[25]
S39	Cold remedies contain "chemicals"	15	[25]
S40	There are "chemicals" that kill the germs	15/14;17	[25]/[39]
S41	Antibiotics are drugs used to treat infections	15	[25]
S42	Flu vaccination protects us from the flu by giving us antibiotics	15;18	[47]
S43	Not knowing that antibiotic action is limited to bacteria	15/15-18	[25]/[47]
S44	Antibiotics are associated with serious diseases	15	[25]
S45	Antibiotics can make you get rid of HIV	12	[48]
S46	Even knowing that antibiotics are not suited to viral infections students think they need antibiotic when perceiving a viral infection	20	[46]
S47	Eating well protects from infections	15/18-25/14	[25]/[29]/[28]

At this point, a good idea teachers should consider is precisely to evaluate how each one self-positions regarding the conceptions in Table 1. Which of those are understood as proper conceptions, misconceptions or incomplete conceptions? In which topics do the teacher's ideas contradict or resemble the ideas found in the literature? This reflective approach should help each one to consider more critically what one believes to know about antibiotic action.

The conceptions displayed in Table 1 include misconceptions, partially incorrect or incomplete conceptions and proper conceptions. They are roughly ordered in categories of conceptions: microorganisms and attributed characteristics; locations where microorganisms can be found; the link between microorganisms and diseases; and finally the use of antibiotics. In general, the studies referred to in the table discuss thoroughly the students' conceptions in relation to their possible causes and the students' cognitive development and mental models, but do not approach in detail the proper conceptions. In this chapter we try to clarify some notions regarding chosen examples of the students' and adults' misconceptions.

Several of the ideas in Table 1 suggest a frequent confusion of terms (S6-S9, S23), some of which can be seen as in some way equivalent, but not all of them. When starting a new topic involving words with precise scientific meaning the teacher should present and clarify the definition of such words. Usually the distinction between definition and conception is not mentioned, but when a student thinks he already knows about the subject being taught that means he already has a conception, but that does not imply he knows the right definition. A conception is an understanding retained in the mind and is idiosyncratic of the individual that builds it under the pressure of the physical and social realities surrounding him [29]. A definition is usually a statement expressing the essential nature of something; the action or power of describing, explaining, or making definite and clear. It will be coherent with the official knowledge about that something, whether it is the official scientific knowledge or the official public knowledge [29].

When words such as microorganisms, microbes, germs and bacteria are used commonly and interchangeably, presenting the definitions and explaining why all these words are usually associated can be a good approach to an apparently complex subject. The distinction between bacteria and fungi and viruses should also follow on shortly thereafter in order to correctly set apart the different groups of microorganisms (S5, S8, S9).

Another problem teachers' face is to present illustrations of the microorganisms. Presently, there are several microscopic images available that represent correctly bacteria, fungi and viruses and that should be selected in preference to too many wrong drawings that usually spread misconceptions. Conceptions such as S5, S7 and S8 may result from, besides the anthropomorphic stage of cognitive development, images spread through the media where microorganisms are represented with human or animal features, or even from informative material intended to promote proper conceptions but passing other misconceptions, like posters about bacteria where fungi are represented [49]. By showing good photographs and diagrams teachers can make use of the zoom-in notion that most students, even children, will recognize from software features. Care should be taken not to show in one single sequence of magnification images of exemplars of the different groups of microorganisms to avoid promoting ideas like S8, S9, S19, S25 and S32.

While the idea that microorganisms are too small to be seen without a microscope is generally true (S1), students portray an incomplete notion about the size of microorganisms [26, 28,]. Teachers, whenever possible, should make students observe a diversity of microscope samples and realise that the suitable magnification to be used varies with the object to be observed. Bacteria observation requires a larger magnification than, for instance, tissues from eukaryotes, or even some of the organelles displayed by the eukaryotic cells. Light microscope is not suitable for the very small size of viruses. Gaining a notion of scale is important, but should be approached together with the understanding of the definitions; otherwise children can misplace items in a scale diagram - mental or drawing.

Different organisms can have different optimal conditions or even favourable conditions, which means that not all bacteria will be able to live and reproduce inside the human body. And the same bacteria can behave differently if exposed to different conditions, being possibly perceived as useful or harmful. Students should therefore be aware that harmful and useful bacteria can indeed coexist (S14, S16), not only in the environment but also inside their bodies, like the bacteria contributing to the synthesis and uptake of vitamin K in the large intestine (S15). Eating live bacteria in some specific foods helps children to be healthy, as opposed to the idea of bacteria always making you sick (S12, S21, S25). From an environmental point of view the notion in S17 also needs to be explained for a global understanding of how bacteria grow and this idea links to disease or, in other words, bacteria growing in a human body. This approach may reduce the misconceptions regarding the way diseases evolve (S22, S24-S28, S30, S33, S34).

The idea of bacteria being ubiquitous (S11), as is usually assumed by microbiologists, is commonly found, but the notion that bacteria can be found on the exterior of the body where they cause no harm is also common, revealing that contact with them or their presence inside the human body is usually associated with disease (S12, S13). The conceptions that bacteria are living organisms (S2, S3) that they are present in unclean environments (S18, S19, S25, S26) and that a way to eliminate them is to obey to the rules of hygiene (S13, S20) is a good starting point to discuss how to avoid certain bacterial infections.

It seems common that youngsters do not know the cause of the most frequent disease they usually get, *i.e.* the common cold (S29, S37). However, the conception of colds being caused by microorganisms (S37) is associated with the misconception of eliminating these microorganisms with antibiotics (S38, S39, S40). Though many students mention that antibiotics are used to treat infections (S41), the mode of action is not properly understood [26]. Considering that antibiotics will treat most of the common diseases might be related to thinking that most or all microorganisms are identical, due to the fact that they are microscopic, and not understanding them as different organisms (S43, S46). Even when the use of antibiotics is "thought of as being wasted on everyday illnesses like colds" this is based on the conception about the use of antibiotics only in serious diseases (S44). On the other hand, some students consider antibiotics to be universally effective (S39-S46). In the cases where students distinguish bacteria from viruses, it can be found that the former are perceived as less dangerous than the latter (S32-S35). Another few misconceptions are associated with the dangers of bacteria only if in great number (S34).

Most research conducted with students adopts an educational approach and emphasize what students know about microorganisms, ‘germs’ or bacteria. Several studies with adults identified lay citizens’ misconceptions and provided the basis for some key ideas in the campaigns directed to antimicrobial stewardship. These studies mainly focus on the adults’ understanding of the action, pertinence and consumption of antibiotics [39, 46, 50-60]. Besides a few culture or group specific conceptions, the results mostly reveal similar ideas across the countries and years. Some of those ideas may have evolved from children alternative conceptions that turned into layman’s misconceptions.

In agreement with Jones and Rua [39] some gaps in knowledge, both in students and in adults, appear to emerge: distinction between bacteria and viruses, how bacteria cause harm to the human body, how viruses replicate, the size differences between bacteria and viruses, and the mode of antibiotics action. The frequent confusion between bacteria and viruses might be responsible for considering that many common diseases are due to bacterial infection, and hence that antibiotics are suited to treat all those diseases. It is therefore urgent to diffuse the correct information about the problem of antibiotic misuse and increasing infections since studies from American, Asian and European countries indicate that between 22 and 70% of parents have misconceptions about the appropriate applications and efficacy of antibiotics [54, 61] and often use them without a prescription [62]. These represent the ill-informed adults who contribute to the misuse of antibiotics and who may pass on misconceptions to today’s children – the adults-to-be, thus perpetuating the wrong attitudes towards antibiotics.

3.2. Clarifying concepts

Misconceptions regarding the use of antibiotics are intertwined with the ideas of health, infection, infectious diseases and microorganisms. Understanding how children view the processes of causation, prevention and treatment of illness is needed to help educators in their work with children [28, 45]. Before presenting the subject to students, identifying their conceptions is needed in order to use them as a starting point. Teachers with limited microbiology knowledge may face some difficulties in teaching about microorganisms and antibiotic use, but they need to be positive about the topic and show self-confidence to alter children's misconceptions. With this in mind we present some correct conceptions about it. Although the information presented in the next paragraphs can be found in any microbiology book we based it on the text by Madigan *et al.* [63].

3.2.1. Microorganisms

Microorganisms are single-celled or cell cluster microscopic organisms and viruses. All microbial cells share certain basic structures such as the cytoplasmic membrane and ribosomes; most have a cell wall. Two cell structural patterns are recognized: the prokaryote and the eukaryote. Viruses are not cells but depend on cells for their replication. Metabolism and reproduction are key features associated with the living state, and cells can be considered both chemical machines and coding devices. Diverse microbial populations were widespread on Earth for billions of years before higher organisms appeared, and today the cumulative microbial biomass on Earth far exceeds that of higher organisms.

From an anthropocentric point of view, microorganisms can be both beneficial and harmful to humans. Although we tend to emphasize harmful microorganisms (as infectious disease agents), many more microorganisms in nature are beneficial than harmful. From a bacterial centred point of view, other organisms can be beneficial or harmful if they, respectively, favour or hinder the growth of bacteria. From an ecological point of view, all organisms are important in an ecosystem and the usefulness/harmfulness dichotomy vanishes.

The healthy human body presents a variety of nutritional and environmental conditions but globally is a favourable environment (skin, mouth, respiratory tract, gastrointestinal tract, urogenital tract) for the growth of microorganisms, most of which are harmless. The presence and maintenance of a population of normal non-pathogenic microorganisms in the respiratory and urogenital tracts is essential for normal organ function and often prevents the colonization by pathogens.

3.2.2. Microorganisms and disease

A host is an organism that harbours a parasite and if the parasite does harm to the host it is called a pathogen. The ability of a microorganism to cause or prevent disease is influenced by complex interactions between the microorganism and the host. Most pathogens are rejected by a variety of host defence mechanisms.

A pathogen may first gain access to host tissues by adherence to specific host molecules. In most cases, in the human body, this requires the organism to penetrate the skin, mucous membrane, or intestinal epithelium, surfaces that normally act as microbial barriers. Invasion starts at the site of adherence and may spread throughout the host via the circulatory system. After a pathogen gains access to host tissues it must multiply in the host (colonize). The initial inoculum is rarely sufficient to cause damage; a pathogen must grow within host tissues in order to produce disease. Infection is the process by which a parasite becomes established and grows in its host. Microbial growth involves an increase in the number of cells rather than in the size of individual cells.

Thus the progression of a disease state includes entry, colonization and growth, and the use of several strategies to establish virulence, the ability of a pathogen to cause host damage through toxicity and invasiveness. A number of pathogens produce extracellular virulence factors designed to protect the pathogen from host defences, by interfering with normal host defence mechanisms, or to provide increased access to nutrients by breaking down or altering host tissue; these factors enhance colonization and growth of the pathogen.

3.2.3. Microorganisms and antibiotics

Chemicals are often used to control microbial growth. Chemicals that kill organisms are called –cidal agents; those that inhibit growth are called –static agents; those that lyse organisms are called –lytic agents. Antibiotics are a chemically diverse group that functions by inhibiting in the target microorganisms cellular processes and functions, not present in the host. Antibiotics can be classified based on their molecular structure, mechanism of action, and spectrum of antimicrobial activity. In bacteria the important targets of antibiotic action are the cell wall, the cytoplasmic membrane, and the biosynthetic processes of protein and nucleic acid synthesis. In a global way, when an antibiotic acts on the target the bacterial growth stops. An antibiotic acting on the cell wall inhibits cell-wall synthesis; binding to the bacterial ribosomes stops the protein biosynthesis and when DNA and RNA are the targets no new molecules are produced. Bacteria, in order to grow must maintain all metabolic pathways active and produce new molecules.

When in the presence of the antibiotic, as when a person begins to take the prescribed medication, most of the bacteria stop growing but some might escape. If the dose of antibiotic is not the right one, as when people do not take all the medication with the correct intervals or until the end of the period prescribed, the bacteria that escaped resume growth. Moreover, this repeated misuse favours the increase of stronger and more resistant bacteria.

Antibiotic resistance is the ability of a microorganism to grow in the presence of an antibiotic to which the microorganism is usually sensitive. Antibiotic resistance can be an inherent property of a microorganism, or it can be acquired. The development of resistance can be attributed to mutations in chromosomal genes that lead to a modification in the target of antibiotic action. On the other hand, the majority of drug resistant bacteria contain the drug resistance genes in R plasmids (R for resistance). These plasmids harbour genes encoding new enzymes that inactivate the drug, or genes that encode enzymes that either prevent uptake of the drug or actively pump it out. The misuse of antibiotics can lead to the development of resistance due to selection of the existing resistance genes. Additionally, antibiotic therapy can significantly reduce the number of microorganisms residing in the gastrointestinal tract. In consequence, infection by opportunistic pathogens often follows long-term antimicrobial therapy.

3.2.4. Antibiotics and viruses

Viruses are highly complex molecular assemblies made mostly of proteins and nucleic acids (RNA or DNA). They are therefore microscopic but not cellular. Though viruses are characterized by having an extracellular state, genetic elements contained in viruses can only replicate inside the host cells. The extracellular form enables viruses to easily transfer from one host to another and permit some viruses to replicate themselves in a host in a way that is destructive to the host cell. The destructive replication accounts for the fact that some viruses are agents of disease.

Since viruses use host metabolic machinery for multiplication it is difficult to use selective chemotherapy for inhibition of virus growth. Existing effective antiviral agents selectively target virus-specific enzymes and processes. Antibiotics are not effective against viruses because the latter lack the targets for antibiotic action. Many respiratory infections are caused by viruses, with colds being the most common viral infection diseases. Other common illnesses caused by viruses are influenza (flu), runny noses, most coughs, most bronchitis, most sore throats, most sinus infections, and some ear infections.

3.2.5. Antibiotics: when they do more harm than good

Antibiotics do not cure viral infections, keep other individuals from catching the illness, nor help the patient feel better. However, their use can prevent the natural microorganisms in the body from growing, which may lead to complications, such as diarrhoea or yeast infection. It may also result in an antibiotic-resistant infection soon after the antibiotic use or later. Resistant bacteria can cause severe illnesses that cannot be cured with antibiotics. When in the case of bacterial infection an antibiotic is prescribed, the appropriate use is compulsory, such as recommended dosage and duration. If treatment stops too soon, some bacteria may survive and turn into a reinfection [18].

3.3. The role of teachers

The idea that proper health education in schools can really influence health knowledge, attitudes, decision-making skills, behaviour, health status and control over health and environment is not new [64, 65] and in the past 3-4 decades an increasing number of programs, projects and initiatives in and with the schools have been launched in many countries worldwide. The effectiveness of these strategies can be discussed, but the main roles of school-based health education programs in community health promotion may still be identified: 1) the provision of a fundamental understanding of health and disease concepts to large segments of the population; 2) the reinforcement of positive health attitudes; and 3) the alteration of concurrent health behaviours for significant health problems [64]. Effective health education strategies usually rely on adopting successful, student-centred, teaching and learning approaches. Frequently, the impact of school education on community health education and behaviour is either not evaluated or seems to be small, yet some studies have shown evidence of improvement in the health and well-being of the entire school community [66]. Such programs are likely to be most effective when a whole school approach is adopted [65] and when the health problem has high perceived severity and susceptibility [64]; and this is clearly one idea that is currently associated with antibiotic misuse.

General microbiology courses are perhaps the best means of teaching concepts related with antibiotic resistance and reach many undergraduate students. Biology and microbiology students have a vested interest in understanding how antibiotic-resistant bacteria are transmitted from person to person through commonly used items, how to decrease this transfer, and when antibiotic treatment is appropriate. Within lectures, discussion on control of microbial growth can be dovetailed with discussion on appropriate antibiotic use [33].

Although all teachers across Europe undergo professional training in a specific subject area for both junior and senior schools [67], the topic concerning antibiotic use and how to reduce the spread of infection may not necessarily be seen as a science subject [68], and this may be one of the reasons why it is not always considered in curricula. In fact, during development of a pan-European educational resource, teacher focus groups highlighted that, particularly in primary schools, many of the teachers do not have a science background and, as such, may feel uncomfortable in teaching this topic. Accounting for that, it was decided that the teacher section of the educational pack would contain detailed lesson plans and refresher background information on each section; in the event that the topic might be taught by a teacher with limited microbiology knowledge [68]. The training of elementary teachers in this topic should also take place within general biology and microbiology courses, but if this is not the case, alternative ways of training can be sought [44, 69, 70].

Unfortunately, even at school levels before college, learning about microbes and antibiotic mode of action might not occur. The young Canadian adults in the study [29] were not supposed to have received formal teaching on the topic, while the French youngsters of [28] study were expected to have been introduced to the topic of "how microorganisms help people", and the English children in [26] research were following a curriculum in which it was a statutory requirement to teach about microorganisms. Among the 36 biology topics for which Bahar *et al.* investigated the difficulty perceived by 207 Scottish freshmen biology students only three topics pertaining microorganisms and antibiotics are found: cellular response in defence (immune system), antibiotics and biological detergents, and fermentation of yeast and baking and brewing. The last two topics have not been previously studied by *ca.* 45% of those students. Herein it is sustained that the introduction of specific topics in the curricula helps to enhance the students' understanding of the topics [71]. Accordingly, one can expect that more time and attention devoted to teaching about bacterial infections and antibiotics action – at all levels – can improve students' knowledge and ultimately their behaviour towards antibiotic overuse and misuse.

In-depth discussions on teaching strategies and their potential to improve science learning can be found in the literature. Nevertheless, most of the references from which the students' conceptions were drawn (Table 1) provide good suggestions. Byrne suggests some approaches to developing teaching strategies, incorporating children's common life experiences [26]. Simonneaux lists a set of variables that influence students' conceptions and should be accounted for by teachers, including the social representations relating to disease, and suggests teaching strategies [28]. Haltiwanger and co-workers place the emphasis on educating students about the scope of antibiotic overuse because they are our future leaders, educators, and problem solvers [46]. Koopman *et al.* propose the Through the Eyes of the Child model to understand the development of a child's thoughts about illness. This model should be considered when planning teaching sequences for the topic on antibiotics, because when describing illness to a child the emphasis must be focused on explanations based on the child's cognitive level [45]. Jones and Rua identify the main gaps in their study participants' knowledge and suggest strategies to attempt to overcome these failings [39]. Prout emphasizes that school biology portraying the germ theory in a simplistic way may be implausible to students, and therefore supports their choice of their own alternative conceptions in explaining diseases [25]. Changing an explanatory framework towards more scientifically correct conceptions requires a cognitive struggle for the prior conception to be abandoned, but this challenge is not sufficient *per se* to warrant the conceptual change. Other factors should be considered, such as affective issues [29]. Romine *et al.* discuss several teaching strategies [47].

Even if the above proposals take the students' conceptions into account, it is important to note that contradictory ideas are often found among each individual's conceptions, and that the arguments can be altered according to the subject students are trying to explain [29]. Teachers should also be aware that students' ideas, though they may include several common misconceptions, are not necessarily identical within a group as a whole. Individual differences are found, even if a set of mental models about microorganisms can be identified [26]. Knowing these mental models can be helpful in planning teaching sequences, but misconceptions may still persist. Progression in scientific concepts does not occur simply as a result of age, maturity, or educational experience in a linear fashion and learning is not a simple or straightforward process [26]. Teaching strategies for the topic microorganisms and antibiotic action can include a variety of approaches already explored in the literature, like softwares, games, concept maps, lab activities.

It is common to all public health campaigns focused on antimicrobial stewardship to provide educational materials to health professionals and the general public. Public service announcements, podcasts, and other electronic resources may also be available. Though important, these approaches are often passive and are not as efficient as when used together with more active strategies. The programmes designed for child education, in particular, allow the teachers to have materials planned for children of different ages that can be used in the classroom. But because pupils will pick up information even from materials aimed at adult information, teachers should be attentive to the contents of the campaigns, analyse and discuss thoroughly with students in order for them to find meaning and understand the information; in the classroom they can relate the presented information with their own life experiences. Moreover, teachers could try to follow the cartoons, series and other television programs for children and youngsters because it has been found that the media influences the ideas that students reveal about microorganisms, diseases and antibiotics [26, 28, 29, 39]. Critical analysis of the contents broadcast by the media can be conducted in the classroom. These issues, as well as the idea of being able to discuss treatment options after an appropriate exchange of information [46] can easily become the topics for debates, case-studies or role-play strategies.

Teachers and schools can seek support on networks related with health education, like the Schools for Health in Europe network. The main emphasis of the network programmes has not, so far, included antibiotic action or prudent use of antibiotics. However, when planning or developing activities to improve students' knowledge and attitudes, support can be requested at the local or national levels of this network, which involves educational and health-related institutions [65]. This partnership provides access to health professionals and health-related resources as well as to educational experts and educational resources.

The choice of educational resources must be cautious, as some resources may promote misconceptions; they cannot afford to explain and explore all the details and concepts in a limited space or set of objects included in the resource. Among the educational resources worthy of consideration, a good microbiology book is always a very good ally.

4. Final remarks

It may be observed that studies on children and teenagers' conceptions and attitudes towards the antibiotic mode of action and the proper use/overuse of antibiotics have been few over the years. Nevertheless, the ideas found are quite similar across the decades, the age groups and the countries (Table 1). The results reviewed by Bader, 20 years ago, on false public beliefs and his recommendation for communicators to address them namely highlighting that viruses and bacteria are different and that is why the latter can be treated with antibiotics [72], are still completely relevant and justified, as can be seen in the conceptions underlying the worldwide campaigns on the prudent use of antibiotics. This permanence of misconceptions may justify why misuse of antibiotics persists and contributes to the global problem of increasing antibiotic-resistant bacterial infections.

Most of the human diseases caused by bacteria are, for now, treated with existing antibiotics. However, the seriousness of the aforementioned antibiotic-resistant bacteria problem poses the question of whether we will reach a moment in which antibiotics will no longer be reliable therapeutics. If that moment comes, maybe the commonly held belief among elders that dying without antibiotics would be the worst end of life situation [55] will become reality. This idea can be justified by the fact that older people are the ones that knew a world without antibiotics, and more than anyone else witnessed the marvellous consequences and medical progress due to antibiotic use.

A prudent use of antibiotics is undoubtedly a relevant topic in the framework of socio-scientific content that should be part of Science-Technology-Society types of science curricula. Surprisingly, and notwithstanding its importance, this topic is absent from a great number of general reports and recommendations about science and health education. As an example we can note that there is no inclusion of the topic microorganisms and antibiotics in a Portuguese extended report on what 21st century citizens should know [73]; in the Proceedings of the 2009 meeting of Contemporary Science Education Research: International Perspectives [74]; in the comparative analysis of textbooks and teachers' conceptions from 19 countries [75]; in the US Healthy People 2020 framework for healthcare providers and communities to improve health [76]; in the main concerns about health of the Schools for Health in Europe network [65].

We agree with Schibeci and Lee [77] in that among the relevant scientific knowledge, knowing topics that matter for people's well-being and health, for example that antibiotics attack bacteria, but not viruses, is more important. Diseases caused by microorganisms and the need to cure them are part of the issues of the everyday life of students and represent a suitable subject for a science class. It therefore seems important to link knowledge not only to the relevant scientific fields, but also to students' personal experiences [28]. It is the task of the school to take advantage of the interest that the students bring with them on a specific concept as the use of antibiotics.

As a bottom line, teachers have the responsibility and opportunity to engage students in learning about a socio-scientific topic that can be interesting, relevant and challenging for students in helping to change behaviours in their community. While the role of school health education programs in community health promotion should be recognized and supported, exaggerated and simplistic expectations regarding the outcomes of such activities should be avoided [64]. Nevertheless, several studies have conducted intervention programs related to health issues with students, and have already found significant changes in students' knowledge as well as in students' attitudes towards a healthy lifestyle with implications for community lifestyles [e.g. 78, 79].

The outcome, within the community, of the students' improved knowledge about antibiotic action and proper use can ultimately also stem from the kind of attitudes and intentions youngsters can portray, as illustrated in the Statement by the young people present at the 3rd European conference on Health Promoting Schools, in 2009: "We want school leaders, teachers and students to try to create a healthier and better society which should think about the present and the future. (…) We also must persuade parents to be active and take part in health promoting activities" [65].

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