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Research Letter – Professional Development

Microbes and us: microbiology literacy in Greece

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Abstract

Microbes are ubiquitous and provide numerous services to humans and our planet. However, a query arises as to whether these microbial services are valued by the general public especially after unprecedented conditions like the COVID-19 pandemic. In this context a survey was conducted to investigate the concept of microbe in Greece. Thematic analysis of 672 anonymous responses (age range 4–75yo) received for the open-ended prompt "What is the first thing that comes to mind when you hear the word microbe?" revealed five thematic categories: Negative emotions, Fuzzy associations, Biology, Entities and Health. Almost 80% of responses fell under "Biology" and "Health" and the general pattern of answers was the same across all age groups. Microbes took a variety of forms in the minds of respondents, however, the concept of "microbe" seems to be more unshaped at younger ages (4–11yo), as revealed in children's language choices. Overall, the often-negative perception of microorganisms seems to be confirmed in this study. Although this research was limited to participants from Greece, it remains relevant to other countries around the world as well. We discuss the reasons behind this negative perception and offer suggestions for reversing it.

Keywords: microbiology literacy; science literacy; microbe concept; thematic analysis; linguistic choices

Introduction

Microbes are ubiquitous and mediate numerous biogeochemical processes sustaining life on Earth. Several relevant examples can be cited such as the production of oxygen from algae which accounts for 50% of atmospheric oxygen (Chapman 2013), the control of greenhouse gases flux (e.g. CO_2, CH_4, N_2O, Minamisawa 2022) and the degradation of pollutants and plastics (e.g. Yuan et al. 2020, Mavriou et al. 2021). Furthermore, due to their efficiency in the production and development of biofuels and bioproducts, microbes contribute to circular bioeconomy. Third-generation biofuels depend on the metabolism of cellulolytic bacteria and the production of biodiesel from microalgae (Kour et al. 2019) and bioplastics or "green plastics" production by bacteria is under investigation (Carlozzi and Touloupakis 2021). In addition, biological processes are in use or under development to produce nutraceuticals, cosmeceuticals, or pharmaceuticals (Ullah et al. 2016, Romano et al. 2017). Microbes are everywhere including human bodies. Humans microbiota (i.e. the microbial taxa associated with human) is a diverse community which appears few minutes after birth, and which performs functions important for health maintenance but also for the appearance and progression of diseases (Ursell et al. 2016, Gilbert et al. 2018). The same applies for animals (Peixoto et al. 2021) and plants (Turner et al. 2013) microbiome; it has a determinant role on organisms' health and disease.

Despite the advances in microbiology and its applications in different fields (environment, medicine, agriculture, animal husbandry, food, drug, energy production, etc.) a query arises whether these microbial services are recognized and appreciated by the general public. The question is getting more attention in the face of unprecedented conditions for most people, such as the COVID-19 outbreak which has been shown to increase germaphobia ("COVID-19 effect", Robinson et al. 2021). Besides this, the spread of disinformation and pseudoscience is another related emerging threat for societies in Europe (Siarova et al. 2019), USA and other countries (Liu 2009). For example, several misconceptions, fraud remedies and products were identified during the coronavirus pandemic and affected individuals but also COVID-19 management by policy makers (Mostajo-Radji 2021, Chavda et al. 2022) while antivaccination misinformation led to an increase of measles outbreaks (e.g. Carrillo-Santisteve and Lopalco 2012, Zucker et al. 2020).

Scientific literacy has been considered as an important tool and life-long perspective for informed personal or collective decisions about science-related issues (Siarova et al. 2019). Under this broad context, microbiology literacy i.e. understanding and knowledge of microbial activities and their impact on the environment and humankind has emerged as a necessity in society (Timmis et al. 2019). However, there are many challenges that should be addressed to achieve science literature in general population. Among these, is the development of adequate tools which in turn requires research on how children and adults develop scientific knowledge and competences (Gerodimou et al. 2008, Siarova et al. 2019).

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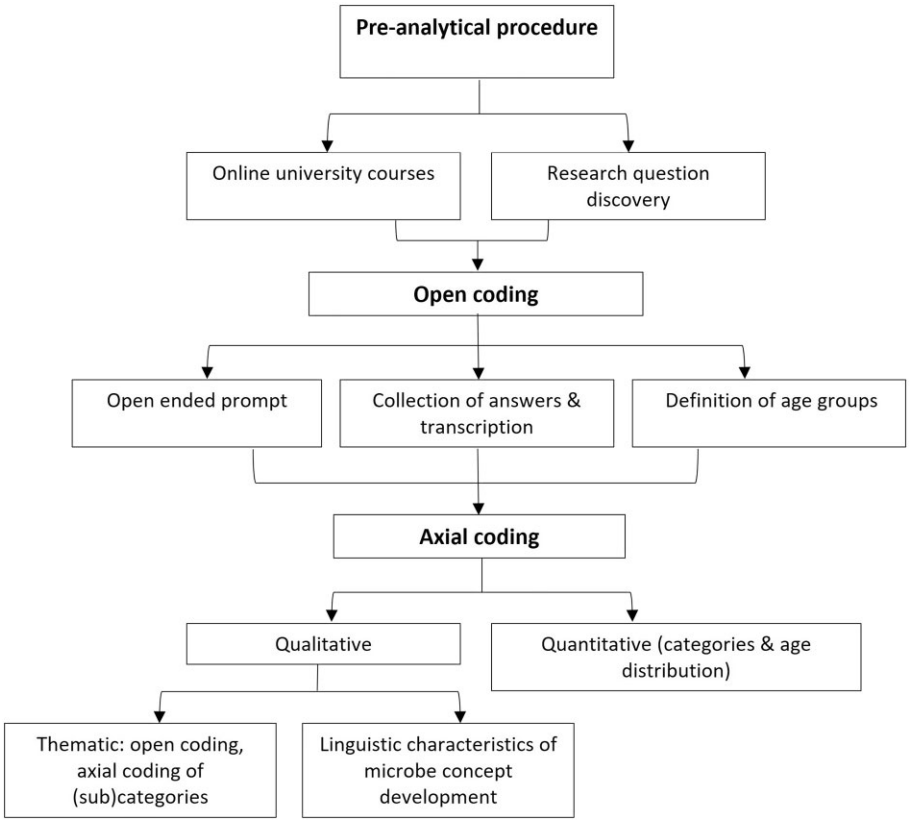

Figure 1. Flow chart of the methodology followed for data analysis.

Under this frame, we conducted a survey to investigate the microbe concept in Greece, through thematic analysis of the responses received for the open-ended prompt "What is the first thing that comes to mind when you hear the word microbe?". We investigated the associations that people of different ages make in their minds with the aim of contributing to the development of appropriate tools and resources that will advance the basic concepts of microbes and their beneficial role for individuals and societies. This is the result of a collaborative work (i.e. between aquatic microbial ecologist, microbiologist, linguist, secondary school biology teachers, undergraduate biology students) considering that as already mentioned by Bradshaw (2021), microbiological literacy in society will be enhanced through collaborations between microbiologists and other disciplines from the social sciences and education.

Materials and methods

Data collection and participants

Data were collected during the winter semester (October to February) of the academic year 2020–2021 in the frame of the undergraduate elective course entitled "Aquatic Microbial Ecology" of the curriculum of the Department of Biological Applications and Technology, University of Ioannina. For data collection, ethical approval was given by the head of the department on behalf of the general assembly. Lecturing was online due to the COVID-19 pandemic and the closure of tertiary educational institutions. During the course, students were asked to investigate the public conception of microbes in Greece. For this, participants (members of the general public) were verbally or through text messaging presented with the open-ended prompt "What is the first thing that comes to mind when you hear the word microbe?" and were asked to respond spontaneously using a few words, but no word limit was set. Data was collected by students and instructors (8 individuals in total) from different regions of Greece using a network of acquaintances, and informed consent was requested in all cases. A total of 672 anonymous responses were collected (~40% via text and ~60% orally), and the age range of respondents was 4 to 75 years old (yo). Secondary analysis of data was conducted over the following years. Respondents were grouped in five age groups: 4–11 (16.5%), 12–15 (36.0%), 16–22 (23.7%), 23–40 (11.0%) and 41–75 (12.8%). Age groups were initially defined to correspond to different stages of education (primary, secondary, tertiary, and post-education groups). However, the last group was divided roughly equally into two groups (23–40, 41–75 yo) with a view to achieving greater granularity. In addition, it was hypothesized that participants closer to school leaving age (23–40 yo) would hold different views comparative to the older group (41–75 yo). This decision was also supported by theoretical considerations as the two last groups have been taught using different curricula due to the reform that took place in 2003. Thus, the first age group (4–11 yo) corresponded to early and primary education. Compulsory education in Greece finishes after attendance of lower secondary school, at the age of 15yo. The third age group included upper secondary school (3 years, 16–18 yo) and early adulthood. The fourth and fifth age groups included adults (23–40 yo) and middle age and senior adults (41–75 yo).

Data analysis

Regarding the analysis of the results, a combination of qualitative and quantitative methods was applied (Tashakkori and Teddie 1998). The qualitative research orientation was chosen, as it is well

suited to developing phenomenologically valid understandings that are grounded on the experiences of our research participants. Consequently, data were analyzed at first qualitatively using thematic analysis (Braun and Clarke 2006; Lacey and Efthimiou 2022). The analysis involved the following steps (Fig. 1):

(1) Pre-analytical procedures: These included applying chronological and thematic inclusion criteria, creating a data index, anonymization, and familiarization with the dataset. Verbal answers (in Greek) were immediately transcribed by the interviewers and entered into an excel worksheet: each response constituted one thematic unit.
(2) Open coding: This involved close, line-by-line reading of the data, during which we assigned a descriptive code to each thematic unit.
(3) Axial coding: At this stage, the coded data were grouped in thematic axes (i.e. categories and subcategories). This stage was reiterated multiple times, until a stable theoretical frame was generated using constant comparison procedures.

Next, the coded data were subjected to quantitative analysis. The frequency distribution (as a percentage) of different thematic categories/subcategories was calculated and ANOVA was performed to determine whether there are statistically significant differences between the various age groups. Statistical analysis was performed using Excel and PAST 4.09.

To add nuance to our understanding of the manner of microbe perception and how the concept is gradually formed/shaped we focused in more detail on younger ages (up to the level of compulsory education). The responses in each category were subjected to a supplementary qualitative analysis to interpret the findings in an inductive way: the main aim was to identify linguistic characteristics with a view to approach differences in understanding the microbe concept through language. The data analysis was conducted using data in the original (e.g. Modern Greek Language). The extracts presented here were translated post analysis.

Results

The final overview of the answers received enabled all codes and, subsequently, emergent subcategories and categories. The final grouping includes five categories: 1) Negative emotions, 2) Fuzzy associations, 3) Biology, 4) Entities and 5) Health. The categories "Negative emotions" and "Fuzzy associations" were candidate categories retained after review. The categories "Biology", "Entities" and "Health" resulted from the grouping of 15, 7 and 6 subcategories respectively (Table 1). Almost 53% of the total number of answers fell under "Biology" and 29% under "Health" (Fig. 2). "Entities", "Negative Emotions" and "Fuzzy Associations" represented 8.5, 6.1 and 3.4% of answers respectively. Under "Biology" 24% of answers were associated with subcategories "Biological features of Microorganisms" (Fig. 3) mainly with the codes "infection" and "pathogenic" while a small number of answers were related to size. Subcategories "Virus" and "Coronavirus" shared equal percentages reaching almost 19% each. "Habitat" (2.7% of total number of answers) was associated mainly with human-animal body. The category "Health" included answers related mainly to the subcategories Illness (~61%), Hygiene (12.8%) and Preventive measures against disease (12.2%, Fig. 4). Examples of codes under "Negative Feelings" were damage, disgusting, bad, danger, fear. Finally, the category "Fuzzy associations" included codes like color, size, object.

Table 1. Categories and subcategories resulted from the grouping of a total of 672 answers. Subcategories are presented in order of decreasing abundance.

Categories	Subcategories
Negative emotions	Negative emotions
Fuzzy associations	Unclear associations
Biology	Biological features of microorganisms, Virus, Coronavirus, Microorganisms, Bacterium, Habitat, Biological functions of organisms, Technical Equipment for Biological Sciences, Biology, Biological functions of humans, Fungi, Protista, Cell, Microbiology, Mitochondrion
Entities	Individual, Animal, Unclear entity, Size, Cartoon, Harmful entity, Imaginary entity
Health	Illness, Hygiene, Preventive measures against disease, Disease treatment measures, Viral infection, Health

The pattern of answers was the same across all age groups and did not show any statistically significant differences (ANOVA, $p > 0.05$). However, age groups 12–15 and 16–22 yo percentage of answers under the theme "Biology" was ~1.5 times higher compared to other groups reaching ≥ 60% of total number of answers (Fig. 2). For the age group 41–75 yo "Biology" and "Health" had similar percentages. Furthermore, for this age group "Health" represented 38.4%, while for the other groups it did not exceed 29%. "Entities" accounted for ~20% of the responses of the 4–11 and 16–22 age groups while for the other age groups this was ≤ 10%.

The responses of the two younger groups were subjected to qualitative data analysis (data reduction, classification, and theoretical abstraction) to tease out their linguistic properties. More specifically, the analysis of the linguistic characteristics of the answers aims to highlight the underlying schematization/perception of the concept "microbe", as it is encoded in the children's language choices. Most responses in all age groups and for all topic categories were basically one-word (e.g. coronavirus, microorganism, disease). The one-word answers mainly concerned the "Biology" and "Health" categories, while the multi-word ones mainly concerned the "Entities" and "Fuzzy Associations" categories. The most multi-word responses, and in fact, in all categories, are observed in the youngest group of participants (4–11 yo and, in particular, ages 4–8):

tiny objects with lines and a small circle in the middle (Entities, Unclear entity)
they are on the cats (Biology, Habitat)
they get into our nose and we get sick (Biology, Biological features of microorganisms)
if we don't wear a mask they will enter our mouth (Health, Preventive measures against disease)

Multi-word responses offer a more systematic analysis of children's language characteristics. In particular, in the categories of "Entities" and "Fuzzy Associations", there is an extensive use of adjectives concerning physical properties (size, color, shape) · properties-evaluative judgments are also found:

big ball
black little creatures
small and ugly

In the category "Biology" the adjectives denoting size (e.g. small) also predominate, while in the other categories the answers are

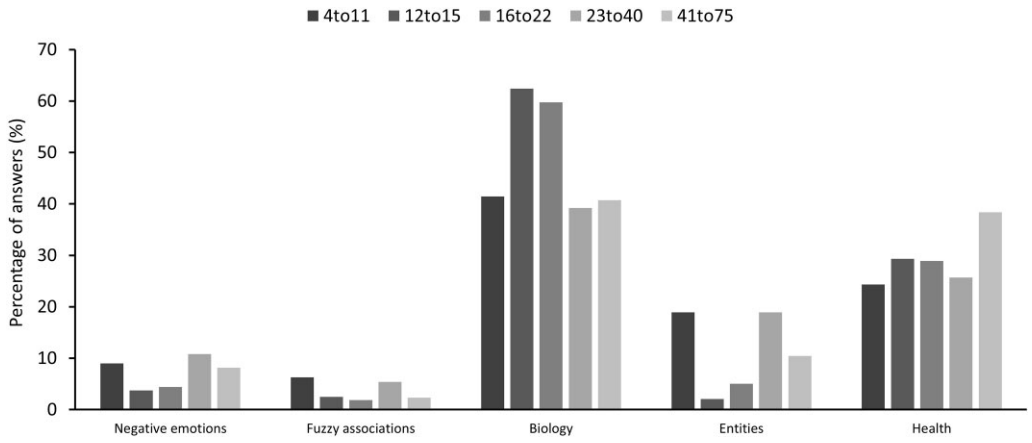

Figure 2. Percentage of answers under different categories for the five age groups defined in the study.

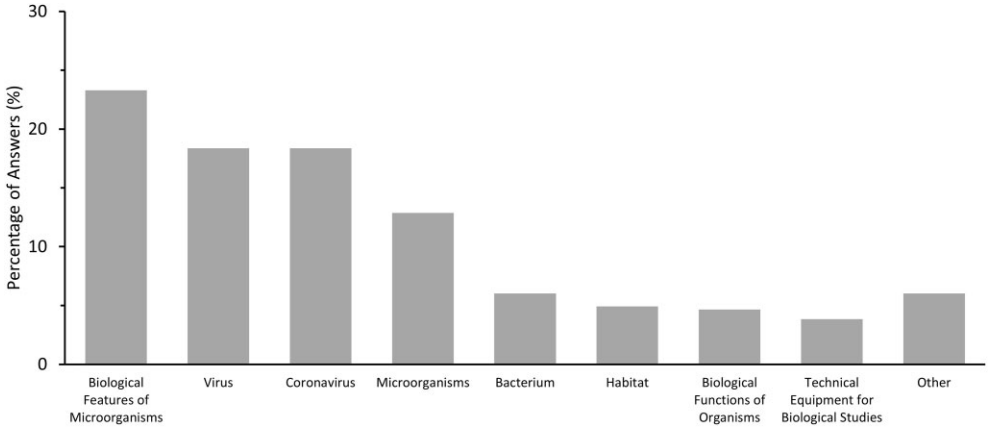

Figure 3. Percentages of answers corresponding to different subthemes grouped under the category "Biology" which represented ~53% of total number of answers. "Other" includes answers with frequency ≤ 1.4%.

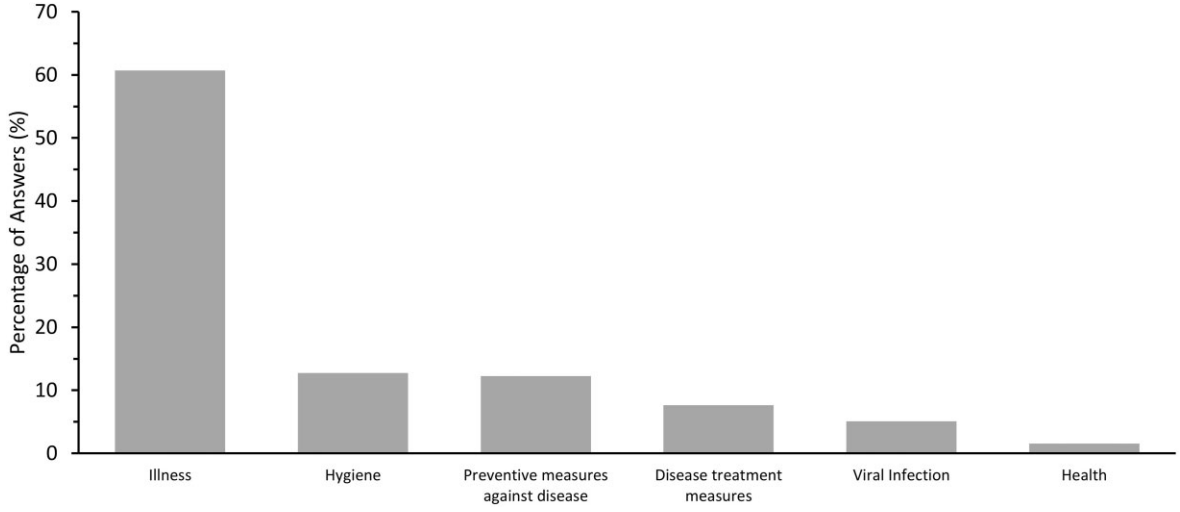

Figure 4. Percentages of answers corresponding to different subthemes grouped under the category "Health" which represented ~29% of total number of answers.

basically one-word, common nouns: disease, virus, coronavirus, dirt, vaccine, etc.

From a functional perspective, some multi-word children's responses offer denotative-referential descriptions:

something inside us that bothers us
something small, green, with many little claws

other responses are connotative, with reference to personal experience:

do not touch our nose with our hands
that I didn't wash my hands

and sometimes evaluative ones:

bad virus
disgusting

Denotative-referential descriptions are characterized by the frequent use of the indefinite pronoun "something", in an attempt to define an unclearly perceived entity.

Also of interest is the "Negative Emotions" category: responses either name the emotions (direct labelling/description) caused be the prompt (e.g. fear, terror, disgusting) or evaluate/interpretate the cause of the emotion (indirect labelling/description):

they do a lot of harm to our body
like thorns that catch your throat and cut off your breath, your eyes close and you have no life
it drools and stinks

Regarding the group of older children (12–15 yo) the answers given are mainly one-word, in all categories. They mainly concern nouns (e.g. bacterium, infection, microorganism, virus, epidemic, etc.). Compared with the younger group, an increase in special/scientific vocabulary (terminology) is noticed. In all categories, adjectives referring to physical properties are decreasing, while adjectives referring to evaluative judgments predominate (annoying, harmful, serious, bad etc.). This can be especially observed in the "Negative Emotions" category where the emotion of fear is not directly labelled, in contrast to the youngest children. Finally, from the point of view of the type of descriptions, we can also find denotative (e.g. billions upon us, tiny, green fluorescent jelly), connotative (e.g. cough, antibodies, microscope, antiseptic) and evaluative descriptions (e.g. causes problems, bad, serious, harmful).

Discussion

In this study we investigated the public's perception of microbes in Greece considering that our attitude towards them can affect decision making at individual or community level. Biology accounted for the largest percentage of responses. In this topic the most frequent answers (~40%) were Virus and Coronavirus (~20% of total responses) followed by Biological features of microorganisms mainly infection and pathogen. It has been suggested that due to the COVID-19 pandemic the general public and especially younger generations will be more aware of microbes and hygiene practices that prevent the spread of diseases (McGenity et al. 2020, Çakar et al. 2021). The survey was conducted during the second national COVID-19 lockdown and by the end of the survey cumulative confirmed cases in Greece were ~185.000 and estimated cumulative excess deaths per 100.000 inhabitants was ~45 (data from https://ourworldindata.org/coronavirus). In this context, given that the survey was conducted during the COVID-19 lockdown and similarly to Robinson et al. (2021), it is perhaps expected that the above answers are the most frequent.

The often-negative perception of microorganisms seems to be confirmed by the categories/subcategories that emerged during the survey. Besides the afore-mentioned answers, ~30% of respondents associated Microbe with disease and ~6% expressed immediate Negative Emotions. Health in particular included answers related mainly to Illness (~61%), Hygiene (12.8%) and Preventive measures against disease (12.2%). Overall, >50% of total respondents had a negative reaction. Microbes are considered by the public disease-causing agents (Trudel et al. 2020), so direct associations are illness and ways of prevention and treatment. There were no answers indicating that microbes can promote human health.

Age groups 12–40 yo are expected to have relatively good biology training from school. However, although Biology is the main category for all age groups, the percentage of answers related to it is higher for the age group 12–22 yo corresponding to secondary education and early adulthood and drops in all other cases. These findings highlight the need for continuous learning as well as the need of developing curricula for primary and preprimary education (Scalas et al. 2017, Timmis et al. 2019). In a recent study aiming at determining whether an advanced microbiology undergraduate course increases understanding of the COVID-19 pandemic and its impact on student behavior in relation to public health practices, the importance of continuous learning was also appreciated by students (Çakar et al. 2021). On the other hand, our data show that secondary school curricula in Greece provide fundamental information about microbes and their features. The Greek national curricula introduce the concept of microbes fairly early in the formal education system, already in upper elementary school (age 11yo). However, the provided information is sparse and inadequate, as it emphasizes the microbes' role as pathogens. Proper knowledge on the microbes' importance begins in the compulsory lower secondary education (mostly ages 13–15 yo), when students are introduced to the beneficial roles of microbes to our health and the environment. Still, limited knowledge is acquired. More detailed information is available in the non-compulsory upper secondary education curricula (mostly ages 16–17 yo). Students learn about different categories of microbes, pathogens, the human microbiome, decomposers and microbes in biogeochemical cycles. Furthermore, the biology course, available only for students pursuing a future career in health or environmental sciences, highlights the use of microbes in biotechnology and genetic engineering.

A number of factors are related to young adults not been able to hold on to the knowledge they acquired as students. Research shows that the majority of Greek students in the upper secondary education find school biology courses difficult, while the Greek educational system itself failed at least the previous decades to enhance the students' interest in biology altogether (Mavrikaki et al. 2012). Moreover, microbiology and especially the beneficial role of microbes is not highlighted enough in primary or secondary education (Ampatzidis and Armeni 2024), letting information from mass media cause misconceptions about microbes. In Italy, for example, advertising spots and television programs are the main source of misleading information regarding microbes, so educating lower secondary school students on microbiology is recommended (Bandiera 2007). The spread of misinformation remains a drawback, although the science communication landscape has changed with the development of social media and social messaging platforms (Rosenthal 2020). Thus, existing curricula should probably be expanded and restructured at

all educational levels to promote beneficial roles of microbes (Timmis 2023, Ampatzidis and Armeni 2024).

Despite the very important discoveries of recent years about microbes and their role for the environment and humans, they remain abstract entities (Timmis et al. 2019). We found microbes to take a variety of forms in the minds of respondents, and thus Entities was a theme that emerged through our analysis (~8.5% of total responses). The entities were imaginary or real. Probably the fictional forms (green circular with antennae, green small gel or ball with legs, small evil etc.) are related to the depiction of viruses in advertisements or in public information campaigns and especially during the COVID-19 pandemic (e.g. https://learning-corner.learning.europa.eu/news-and-competitions/eu-coronavirus-information-and-online-learning-children-2020-03-20_en). Real entities included Centipedes, Insects, Worm, Transparent animal, Individuals, and others. Thus, it is necessary to present and visualize the microbial world to people to move from the abstract and invisible to the real, and combat misconceptions (McGenity et al. 2020).

Although in the youngest group of participants, as well as in the other groups, the answers falling into the categories "Health" and "Biology" are the most—which may be due to the increased information during the pandemic—the concept "microbe" seems to be more unshaped at younger ages. This is particularly evident in the categories "Entities" and "Fuzzy Associations" where the responses are multi-word and lack the use of special/scientific vocabulary, exhibiting thus an attempt to give as much information as possible in order to achieve complete and accurate answers describing the semi-structured concept. Directly related to the above finding is the observation that these multi-word descriptions are characterized by a great number of adjectives denoting physical properties (mainly referring to size in all categories, but also color and shape for Entities and Fuzzy Associations categories): it seems that these linguistic devices help to structure and clarify concepts that are still being formed. From a functional perspective, the same effort can be detected in connotative and evaluative descriptions, formed with the help of personal and subjective criteria/experiences.

Noteworthy is that in the category of Negative Emotions the youngest age group uses a high percentage of direct labelling: it can be stated that the youngest children are largely content with naming the emotional reaction caused by the prompt "microbe". Yet another part of the answers falls in the category of indirect description/reference, connecting cause or effect to negative emotions (Motsiou and Valetopoulos 2022). In contrast, the older group uses mostly indirect labelling/descriptions for the negative emotion, revealing an increased focus on evaluation and not naming, reflecting thus acquired knowledge about the possible causes and effects associated with the prompt: in fact, the reference to the results seems to prevail, a finding that agrees with previous research (Stein and Levine 1989). The same observation applies to the type of adjectives used (evaluative, especially negative) in contrast to the younger group (descriptive).

Our data indicate that it is important to strengthen the positive image of microbes, since only 1% of microorganisms are pathogenic to humans (Zobell and Rittenberg 2011). This becomes even more urgent if we consider that the younger age groups (4–22 yo, closer to school age) are overrepresented in our research compared to the age distribution of the population in Greece. Timmis et al. (2019, 2023) proposed a teaching concept adaptable to all education levels to improve society's microbiology literacy. These include child/student centric curricula covering different generic knowledge topics which raise awareness and emphasize interconnectedness between microbes and the environment or other life forms and processes (e.g. planet, plants, animals, food, health, climate, past and future). Exposure to microbes, through carefully planned field trips (e.g. labs, industry), can also be instrumental in introducing microbes into children's lives (McGenity et al. 2020). Time spent in nature in particular has been shown to help develop a positive attitude towards microbes (Robinson et al. 2021). Trudel et al. (2020) designed a university course ('Microbes and You') which is offered across the student broad and thus allows students of different majors to discover the positive and negative impact of microbes on our planet. Games (e.g. Efthimiou and Tucker 2021) and art (Madhusoonanan 2016) as well fiction (https://fems-microbiology.org/femsmicroblog-learning-about-microbes-from-popular-fiction/) can be also used to promote microbiology literacy of students but also the general public. In recent years, microbiologists and microbiological associations have been particularly active to raise awareness on the impacts of microbes on the biosphere and the environment. This effort should be enhanced by involving professionals from different disciplines (Bradshaw 2021) for knowledge dissemination and informed decision-making by citizens and policy makers. As philosopher Deleuze (2000) said, the "encounter between two disciplines doesn't take place where one begins to reflect on the other but when one discipline realizes that it has to resolve for itself and by its own means a problem similar to the one confronted by the other."

Although our survey was limited to participants from Greece, it remains relevant for other countries around the world, especially to those that were seriously affected by the coronavirus pandemic. Similar strategies for monitoring microbiology awareness in different populations can be followed at a larger scale for confirming if public responses about the word "microbe" will be in agreement with our results. In addition, our conclusions about the importance of microbiology awareness in establishing a better understanding of personal hygiene habits such as washing hands or keeping indoor areas clean can be beneficial for thousands of individuals around the world.

Author contribution

HK conceived and coordinated the study. EM coordinated the thematic analysis. HK, SZ, SA organized raw data into spreadsheets. HK, EM, VS, LM, MP, AT, AKM conducted the secondary analysis of data. HK, EM, GE interpreted the data. HK, EM, SZ wrote the original manuscript. All authors reviewed and edited the manuscript.

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