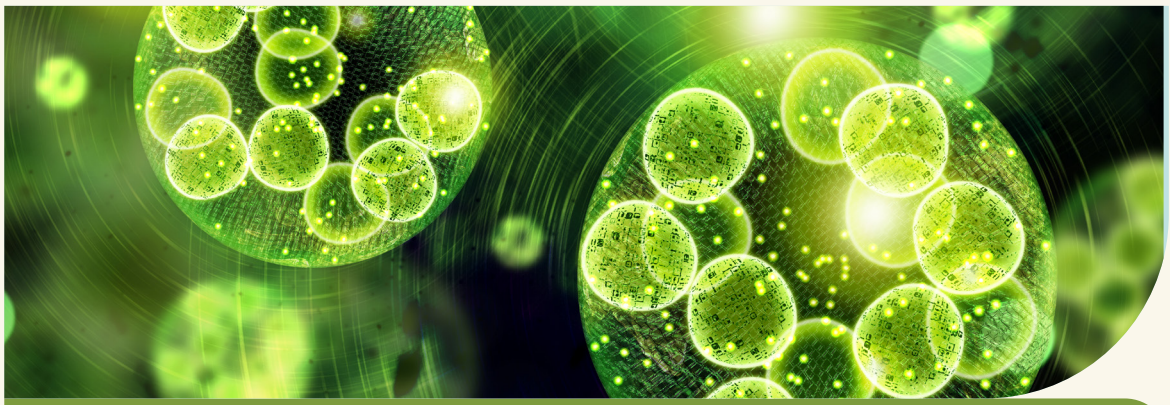
Assessing the impact of an enquiry-based learning intervention on primary school students' conceptions about microorganisms



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Abstract

Microorganisms are almost ubiquitous, but their small size often makes them difficult for children to conceptualise. This study aimed to assess the impact of an enquiry-based learning intervention on the conceptions of primary school students (ages 9-10) regarding microorganisms. The intervention included practical activities involving the cultivation of microorganisms in Petri dishes, collected from various surfaces. The students' ideas were gathered through drawings and their descriptions before and after the intervention. The results indicated that, post-intervention, the association of bacteria and viruses with microorganisms increased, demonstrating a deeper understanding of specific types of microorganisms. Additionally, there was an increased awareness of the actions of microorganisms, with students illustrating specific diseases caused by them, as well as recognising their general and specific beneficial effects on humans.

Keywords

Conceptions, enquiry-based learning, microorganisms, primary school

Introduction

Microorganisms are ubiquitous, found in nearly every environment on Earth. Despite their prevalence and the fact that they play crucial roles in ecosystems, human beings are unable to perceive them with the naked eye. Instead, specialised magnification instruments, such as microscopes, are required to observe these micro life forms, contributing to the awareness of their existence.

Understanding microorganisms is particularly challenging for children, as shown by Nagy's (1953) pioneering study about the representation of germs by children. These challenges are due to their invisible nature, the complex scientific concepts involved and the existence of myths and misconceptions that make them difficult to understand and learn about (Ballesteros *et al,* 2018; Carvalho, 2017; Fraga, 2018; Navy, 1953; Simard, 2023), as discussed further below.

Although some research has been conducted to better understand children's conceptions of microorganisms (e.g. Ballesteros *et al,* 2018; Carvalho, 2017; Fraga, 2018; Navy, 1953; Simard, 2023), it is still necessary to change the teaching and learning process about microorganisms at the level of the primary school (Carvalho *et al,* 2017). This study aims to contribute to that goal, presenting part of a research project designed to identify children's initial conceptions about microorganisms and the impact of an enquiry-based science learning sequence on their prior ideas. The following research question (RQ) guided the study:

RQ: *How does an enquiry-based learning intervention affect primary school students' conceptions about microorganisms?*

The importance of science teaching about microorganisms

Experimental science activities, such as those involving microbiology, significantly boost students' interest and motivation (Brown, 2002; Xu, 2024). For instance, the use of a co-operative learning approach in an oral microbiology laboratory course at Wuhan University led to improved student performance and positive feedback (Xu, 2024). Similarly, a study involving primary school students in Portugal showed that practical microbiology activities helped students to understand the importance of dental hygiene and the role of microorganisms in dental caries (Mafra *et al,* 2014). However, teachers conduct few practical microbiology activities, citing a lack of knowledge, technical difficulties and health or safety concerns (Redfern *et al,* 2013). For this reason, it is necessary to address teachers' negative emotions regarding microorganisms so that they do not transmit these feelings to their students, and to promote positive emotions that facilitate their teaching (Marcos-Merino *et al,* 2019).

"Introducing science education in primary schools can include activities focused on microorganisms, thereby enhancing children's understanding of the world around them"

In Portugal, the study of microorganisms is not explicitly outlined in the curriculum of Environmental Studies for primary school (ages 6-10), although it can be associated with several indirect themes (Mafra & Lima, 2009). What is evident is the existence of implicit content when addressing issues related to hygiene and health, with no direct reference to microorganisms (Mafra *et al,* 2016).

However, Mafra and Lima (2009) suggest that these themes can be explored with students through hands-on experimental activities. Introducing science education in primary schools can include activities focused on microorganisms, thereby enhancing children's understanding of the world around them (Mafra & Lima, 2009). In other countries, microorganisms are included in the science curriculum, thereby acknowledging their importance (Byrne & Sharp, 2006).

Conceptions of primary school students about microorganisms

Microorganisms are very small living beings, most of which are invisible to the naked eye and only observed using a binocular loupe or microscope. Microorganisms are part of the three domains of life: *Archaea, Bacteria* and *Eukarya.* Microbiology, the science that studies microorganisms, organises them into various groups: algae, bacteria, fungi and protozoa. They can be unicellular (like bacteria) or acellular (viruses) (Parker *et al,* 2018). Viruses are considered acellular organisms because they do not have cells and thus depend on other living cells to reproduce (Parker *et al,* 2018).

Although many microorganisms play an essential role for life on the planet (Gonçalves, 2012), children tend to have a negative perception, limited and distant from scientific knowledge. Children tend to classify microorganisms as a type of animal, such as small insects (Nagy, 1953), and associate them with diseases and lack of hygiene (Ballesteros *et al,* 2018; Byrne, 2011; Nagy, 1953; Ruiz-Gallardo & Paños, 2018). According to Ruiz-Gallardo and Paños (2018), this negative connotation is due to the frequent association of microorganisms with pathogens. Byrne *et al* (2009) point out that this view can become more pronounced with age. This limited perception may be related to the way in which microorganisms are approached in the primary school curriculum, such as in the Spanish curriculum, which tends to emphasise their harmful aspects while omitting their benefits. For this reason, most children are unaware of these benefits (Ruiz-Gallardo & Paños, 2018).

Some studies on this topic highlight students' conceptions about these organisms in terms of classification, the environments in which they live, connotation, and application in health. According to Byrne (2011), children classify these organisms as abstract entities or animals, specifically insects or caterpillars. Through their drawings, Byrne (2011) also identified that some students associate microorganisms with small monsters. Additionally, the study by Gonçalves (2012) showed that most students depict microorganisms with anthropomorphic traits.

"Students tend to perceive microbes as a human concern rather than recognising microorganisms as integral components of the ecosystem"

Students often associate microorganisms with the human body, especially the hands (Faccio *et al,* 2013), but they tend to relate them mainly to dirty, poor hygiene and dangerous places for health (Byrne *et al,* 2009; Karadon & Sahin, 2010). According to Ruiz-Gallardo and Paños (2018), students also refer to environments such as the ground, the schoolyard and the air as places conducive to the transmission of diseases, which contributes to reinforcing their negative perception of these living beings for humans (Gonçalves, 2012). Students tend to perceive microbes as a human concern rather than recognising microorganisms as integral components of the ecosystem (Jones & Rua, 2006).

However, students aged around 14 years are more aware that not all microorganisms are pathogenic (Byrne, 2011). The results from Ruiz-Gallardo and Paños (2018) also show that, while children from the two age groups studied (ages 7-8 and 11-12) recognised the existence

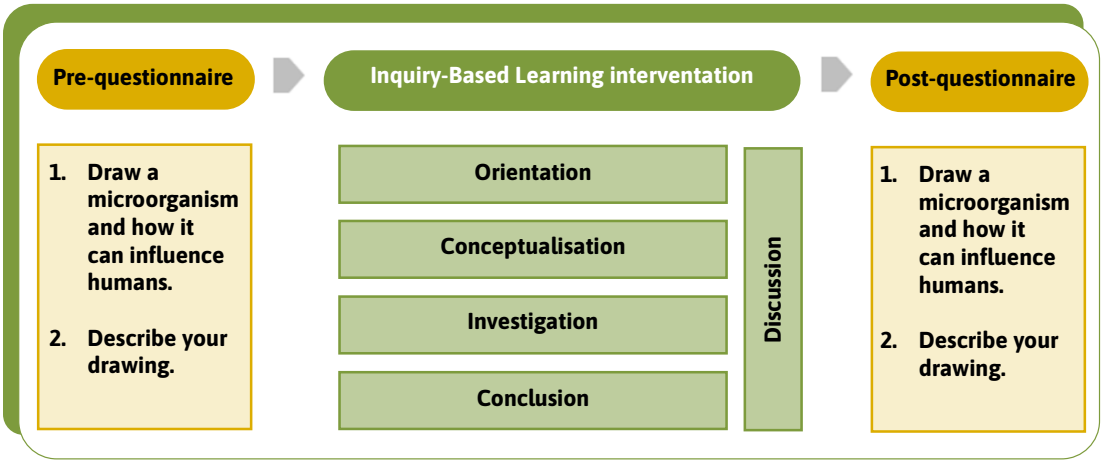
of beneficial microorganisms, only a small fraction, from the 6th grade (ages 11-12), could identify some functions, particularly those related to food. Nonetheless, many students were unaware of the applicability of microorganisms in medicine or of their role in chemical cycles and environmental protection (Ruiz-Gallardo & Paños, 2018).

An aspect that students appear to perceive clearly relates to the size of these living beings, with some students highlighting their microscopic nature (Byrne, 2011; Ruiz-Gallardo & Paños, 2018; Simmoneaux, 2000).

Research methodology

The present research, based on an intervention study, aims to develop a didactic experience and reflect on its impact on student learning. The research design used is presented in Figure 1. It consists of three main phases: pre-questionnaire, enquiry-based learning intervention, and post-questionnaire.

▼**Figure 1** Research design.



In the first phase, *'Pre-questionnaire'*, students were asked to create a drawing about microorganisms and explain it. This phase was crucial for assessing the students' prior knowledge.

Following this, the enquiry-based learning intervention was implemented based on the five main phases of enquiry proposed by Pedaste *et al* (2015). In the orientation phase, essential concepts related to the meaning of microorganisms, the types of microorganisms, their beneficial effects, harmful effects and their locations were introduced. Next, in the conceptualisation phase, students were asked to define what a microorganism is and where microorganisms can be found.

Subsequently, in the investigation phase, students participated in a practical activity organised in two parts, in which the notion that unicellular microorganisms can be seen with the naked eye when organised into colonies was mobilised. In the first part, students used a cotton swab to collect samples from various surfaces, objects and parts of their bodies into a Petri dish. The students used their swabs to swipe across a Petri dish containing sugar-free gelatine. The second part corresponds to the study of the results, where students analysed and interpreted the outcomes, particularly the development of microorganism colonies in the Petri dishes. In the conclusion phase, students needed to identify which reasons explain the colonies' formation on the Petri dishes.

Finally, the process concluded with the post-questionnaire, which asked students to create a new drawing about microorganisms and explain it again. This last stage serves to evaluate the students' learning and compare it with the knowledge presented in the pre-questionnaire to determine if conceptual changes have occurred.

Participants and ethics

The study was conducted in a 4th grade (ages 9-10) class in a Portuguese public school. The classroom teacher authorised the students' participation. Written permission was requested from tutors to allow their children's participation in this research, according to the school protocols. Children were also informed about their role in the activities. The participants from primary school comprised 19 students, aged between 9 and 10 years old. The identities of the participants were kept confidential to ensure the privacy and anonymity of their contributions. To achieve that aim, students were identified as S1 to S19.

Data collection

The data collection instrument used was a questionnaire. The same questionnaire was administered before the intervention (pre-questionnaire) and after the intervention (post-questionnaire). The questionnaire aimed to collect students' conceptions of microorganisms. It included two tasks: a drawing prompted by the instruction '*Draw a microorganism and [explain] how it can influence humans*' and a written description about the drawing, using the students' own words.

"The students' explanations of their drawings were utilised to further clarify their reasoning and refine the categories and sub-categories.."

Data analysis

The drawings were subjected to content analysis. The categories and sub-categories were developed *a posteriori*. Specific misconceptions identified in the literature review were carefully examined and gave origin to some categories and sub-categories. The careful examination of the patterns across students' drawings produced other categories and sub-categories of analysis. The students' explanations of their drawings were utilised to further clarify their reasoning and refine the categories and sub-categories. Initially, one author created the initial categories and performed the first round of categorisation. Subsequently, this work was reviewed by the second author, with any discrepancies discussed and resolved. The number of occurrences of each sub-category was quantified in the pre- and post-questionnaires.

Results and discussion

The results are presented and discussed in this section. The categorisation of the primary school students' drawings is presented in Figure 2 to facilitate a comparison between the pre-questionnaire (PreQ) and the post-questionnaire (PostQ). Whenever necessary, students' explanations of their drawings have been included to provide better insight into their thinking.

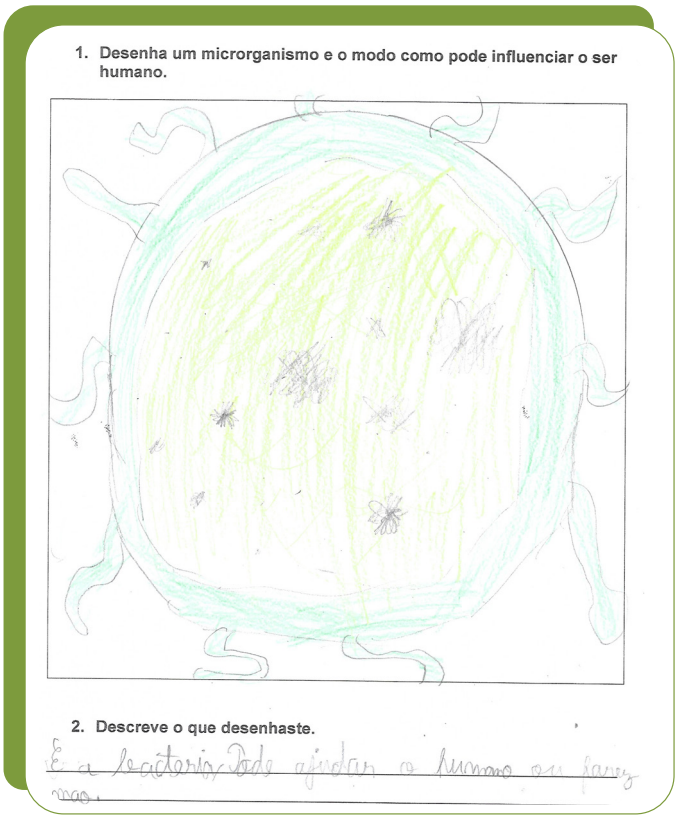
▼**Figure 2** Categorisation of primary school students' drawings regarding the meaning of microorganisms and their influence on the human body, in the pre- and post-questionnaire.

Categories	Subcategories	PreQ	PostQ
1. Representations of microorganisms			
	• Unidentified microorganism	4	3
	• Bacteria	1	3
	• Virus	5	11
	• Associations of microorganisms with cells (unidentified)	5	0
	• Attribute of microscopic dimensions to microorganisms	4	0
	• Microorganisms organized in colonies	0	1
2. Representations of the actions of microorganisms			
2.1. General harmful effects		1	4
2.1.1. Causes of diseases			
	• Infections or disease caused by viruses	2	2
	• Infection or disease caused by bacteria	0	1
	• Specific infectious diseases caused by microorganisms	0	9
	• Transmission	1	0
2.2. Beneficial effects			
	• General beneficial effects	0	3
	• Specific beneficial effects (e.g., assisting digestions)	0	2
3. Representations of the locations of microorganisms			
	• Human body	5	2
	• Other locations	0	1
4. Other representations of microorganisms			
	• Instruments used to observe microorganisms	2	0
	• Researchers who study microorganisms	1	0
5. Representations not related to microorganisms		3	0

Representations of microorganisms

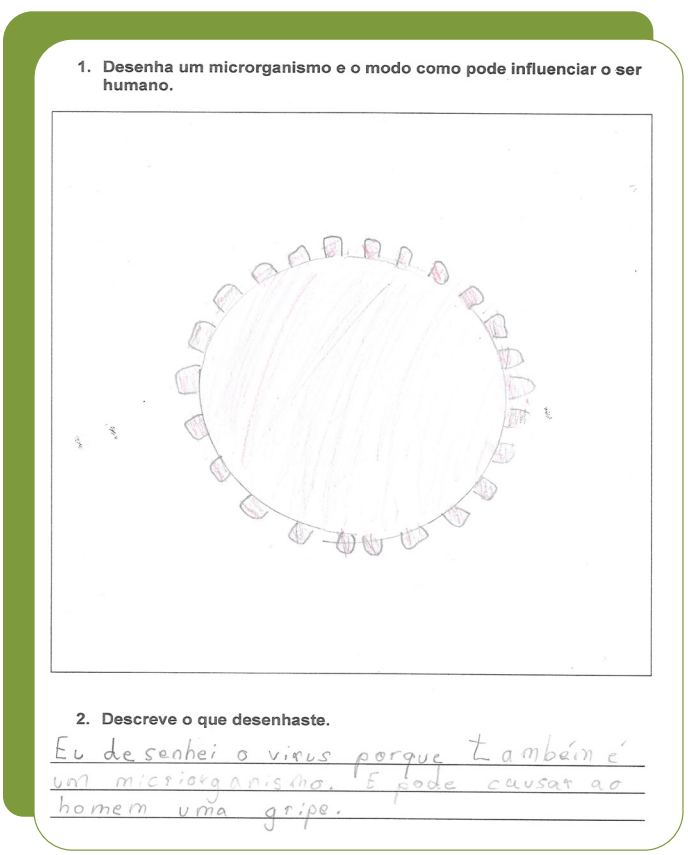
The sub-category 'Unidentified microorganism' saw a slight decrease from the pre-questionnaire to the post-questionnaire, indicating an improvement in students' ability to identify specific types of microorganisms. In contrast, the association between microorganisms and bacteria increased in the post-questionnaire drawings. For instance, student 19 (S19) described their illustration as *'It is the bacteria; it can help humans or cause harm'*, suggesting that the intervention effectively reinforced students' understanding of bacteria as a type of microorganism (see Figure 3).

▼**Figure 3** Post-questionnaire drawing from S19.



The sub-category 'Virus' showed an increased presence in the post-questionnaire drawings. Student 6's (S6) drawing illustrated their understanding of viruses as microorganisms and highlighted one of their effects on humans – causing diseases, specifically the 'flu (Figure 4). These changes are likely a result of the intervention, which included discussions about viruses as examples of microorganisms.

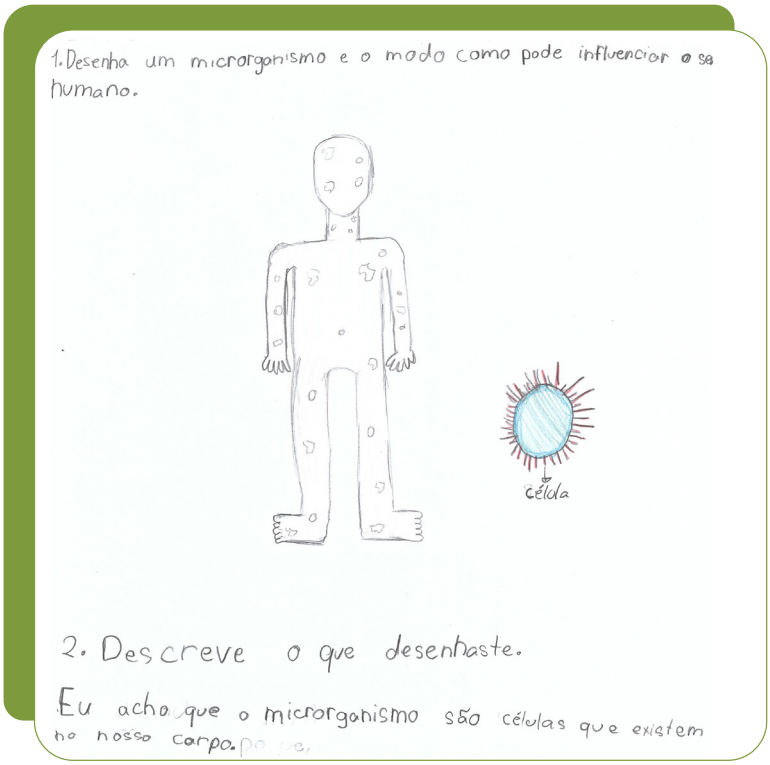
▼**Figure 4** Post-questionnaire drawing from S6.



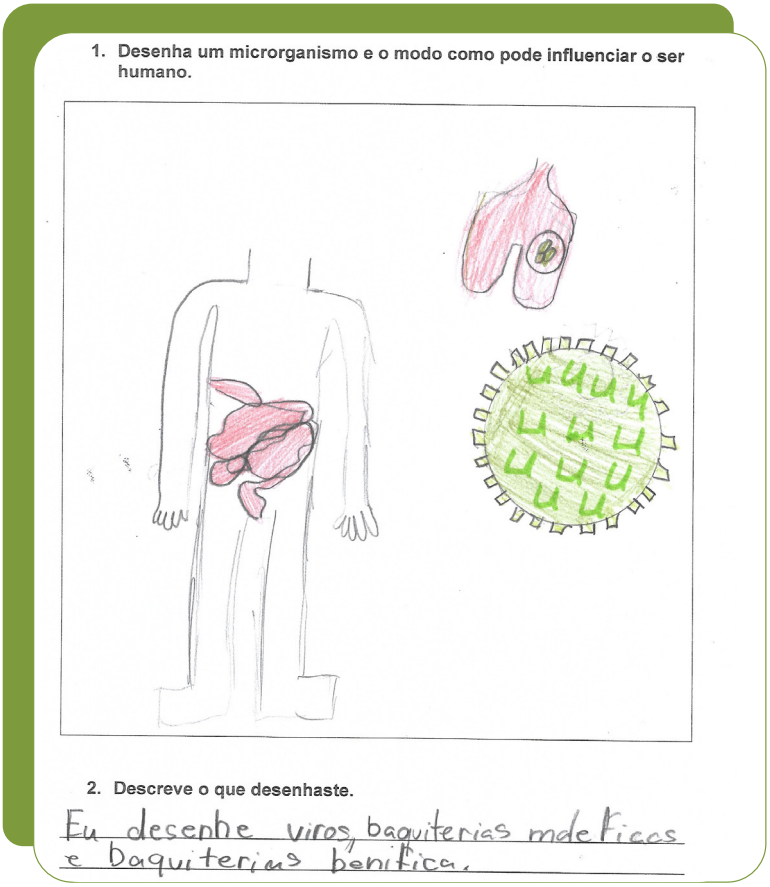
In the pre-questionnaire, five students drew structures resembling cells but did not identify them as bacteria. For example, student 1 (S1) noted: '*I think microorganisms are cells that exist in our body*' (PreQ). However, this idea did not appear in the post-questionnaire, indicating that the intervention may have facilitated learning about the association of microorganisms, such as bacteria, with cells. Figure 5 (see next page) demonstrates this conceptual change for student S1.

Figure 5 Pre-questionnaire and post-questionnaire drawings from S1.

PreQ



PostQ



In the pre-questionnaire, there are four representations in which some students associate microorganisms with microscopic size. For example, student 12 (S12) described their illustration as follows: *'[...] when I read the word microorganisms, I thought that "micro" meant small, so I tried to think of small organisms in the human body'* (PreQ, Figure 6). The association of microorganisms with microscopic size was not mentioned in the post-questionnaire, because the intervention did not focus on their size but highlighted other characteristics.

▼**Figure 6** Pre-questionnaire drawing from S12.

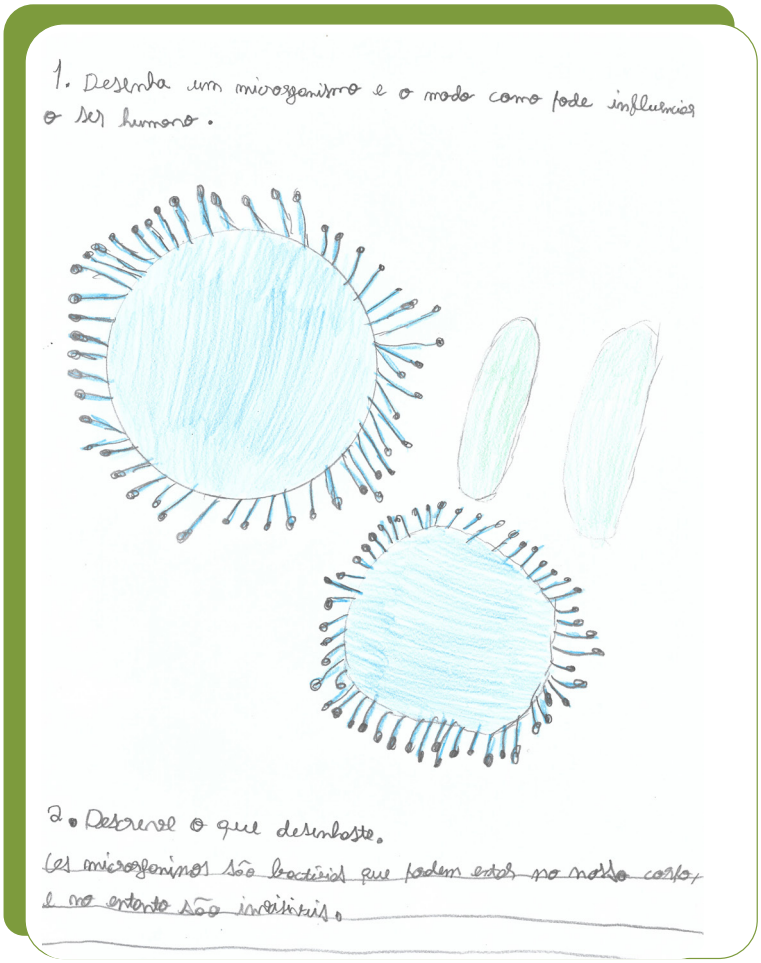
The organisation of microorganisms into colonies was noted in the post-questionnaire by student 13 (S13), who stated: '*I drew a colony of microorganisms*'. This understanding likely emerged after the practical intervention, where students observed the growth of microorganism colonies on Petri dishes associated with various body parts and objects.

Microorganisms such as fungi and algae or microorganisms with anthropomorphic traits were not mentioned in pre- or post-questionnaires.

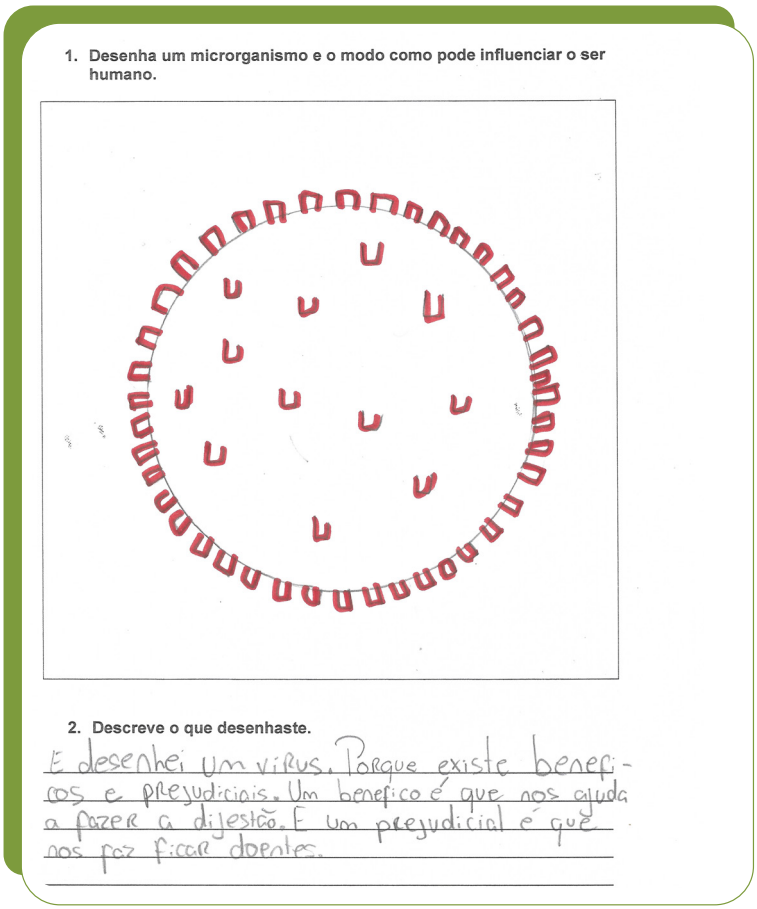
Representations of the actions of microorganisms

The harmful effects of microorganisms were represented in the students' work in both questionnaires. In the pre-questionnaire, student 8 (S8) noted: '*Microorganisms are bacteria that can be in our body and are invasive*' (Figure 7). In the post-questionnaire, student 14 (S14) mentioned: '*[...] one harmful effect is that it makes us sick*' (Figure 7). The increased occurrences in the post-questionnaire may be linked to the learning from the intervention, which covered a discussion about diseases caused by microorganisms.

▼**Figure 7.** Pre-questionnaire drawing from S8 and post-questionnaire drawing from S14 (on next page).



PreQ (S8)


1. Desenha um microrganismo e o modo como pode influenciar o ser humano.

2. Descreve o que desenhaste.

Eu desenhei um vírus. Porque existe benefícios e prejudiciais. Um benefício é que nos ajuda a fazer a digestão. E um prejudicial é que nos faz ficar doentes.

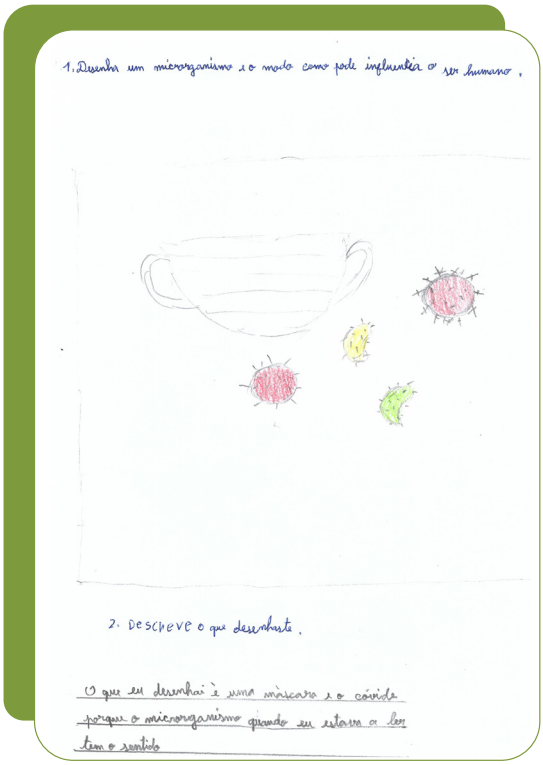
PostQ (S14)

The sub-category 'Infection or disease caused by viruses' showed consistent occurrences in both the pre- and post-questionnaires. In the pre-questionnaire, student 5 (S5) noted: '*What I drew is a mask and COVID*' (Figure 8) while, in the post-questionnaire, student 10 (S10) stated: '*I drew a virus that can make people sick*' (Figure 8). The lack of increase in occurrences may indicate that some students began to associate microorganisms with specific diseases, such as the 'flu, instead of a general notion of causing illness.

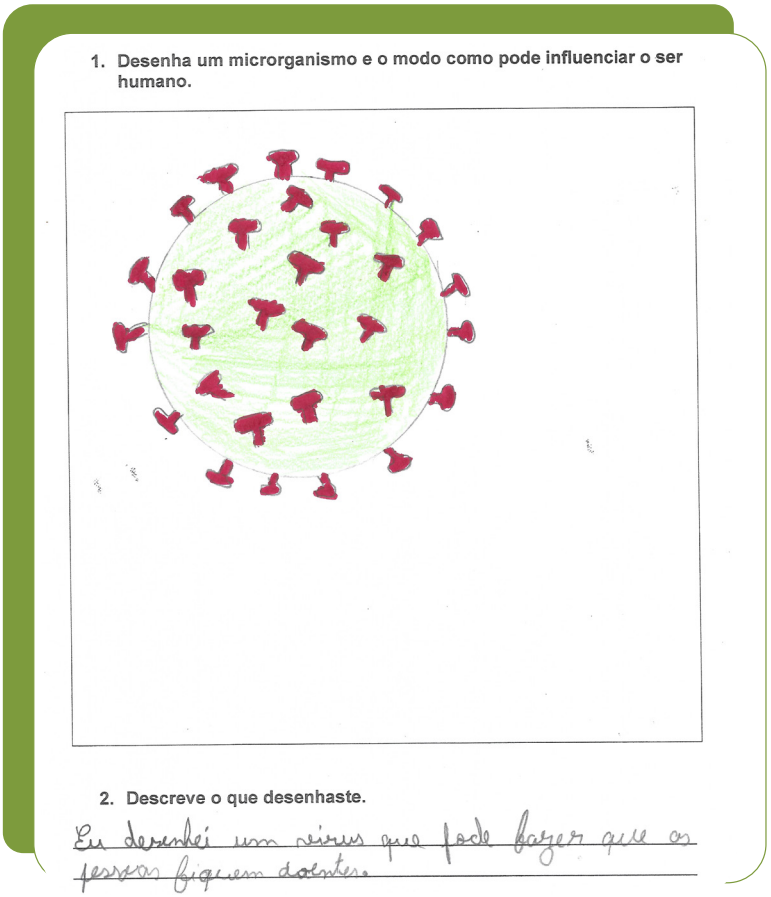
"Regarding infectious diseases, nine students specifically identified some caused by microorganisms. Examples include descriptions such as: 'I drew a virus. The virus can cause the flu' (PostQ, S13; Figure 10) and 'I drew a boy with a fungal infection' (PostQ, S12; Figure 10). These findings are consistent with the topics covered during the intervention, which presented diseases associated with different types of microorganisms. "

▼ **Figure 8.** Pre-questionnaire drawing from S5 and post-questionnaire drawing from S10.

PreQ (S5)

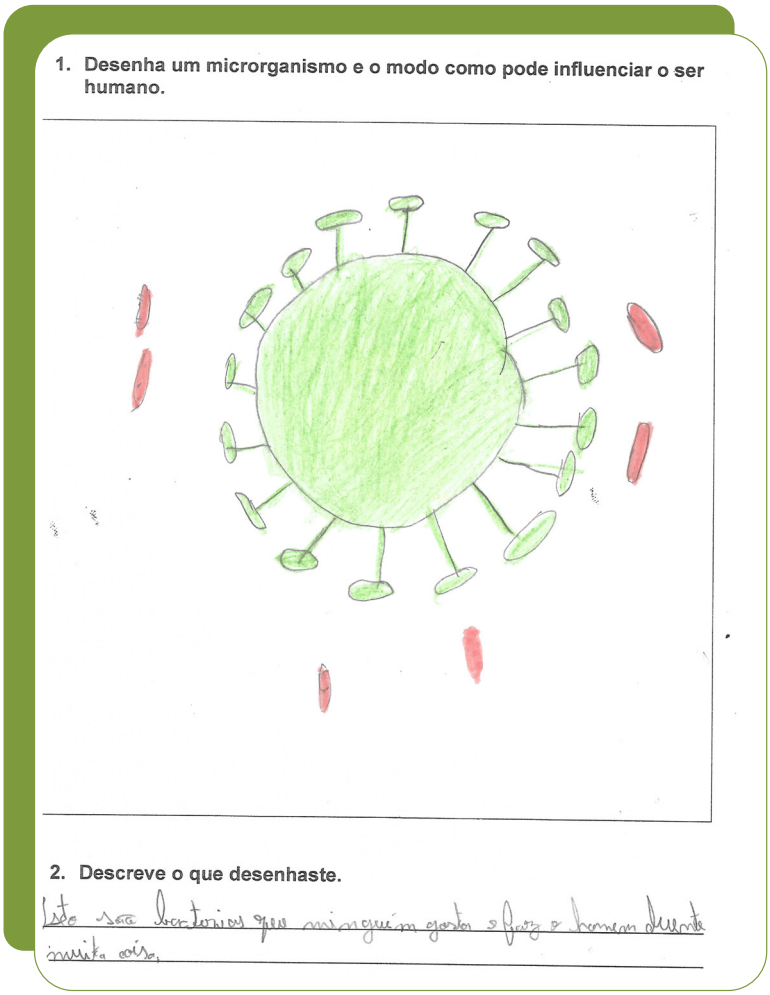


PostQ (S10)



As in the previous category, student 7 (S7) recognised the infection caused by bacteria in the post-questionnaire, describing their drawing as: *'bacteria that nobody likes and make people sick [...]'* (Figure 9).

▼ **Figure 9.** Post-questionnaire drawing from S7.

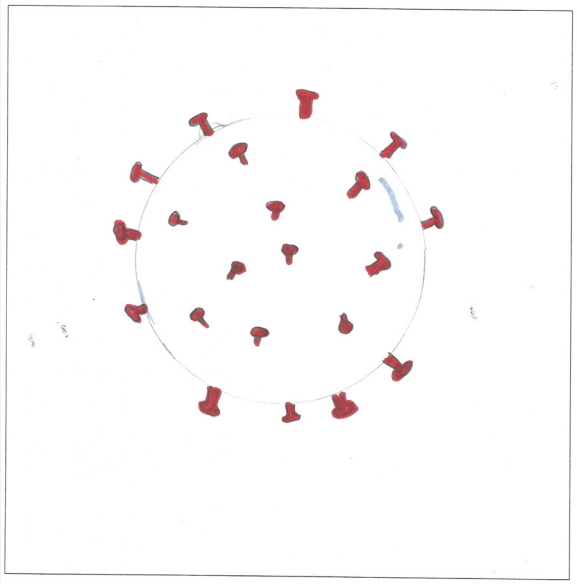


Regarding infectious diseases, nine students specifically identified some caused by microorganisms. Examples include descriptions such as: *'I drew a virus. The virus can cause the flu'* (PostQ, S13; Figure 10) and *'I drew a boy with a fungal infection'* (PostQ, S12; Figure 10). These findings are consistent with the topics covered during the intervention, which presented diseases associated with different types of microorganisms. This change suggests that students learned about specific diseases caused by microorganisms. Notably, the most frequently depicted illness in the illustrations was the 'flu.

▼ **Figure 10.** Post-questionnaire drawings from S13 and S12.

PostQ (S13)

1. Desenha um microrganismo e o modo como pode influenciar o ser humano.



2. Descreve o que desenhaste.

Eu desenhei um virus o virus pode causar uma gripe.

PostQ (S12)

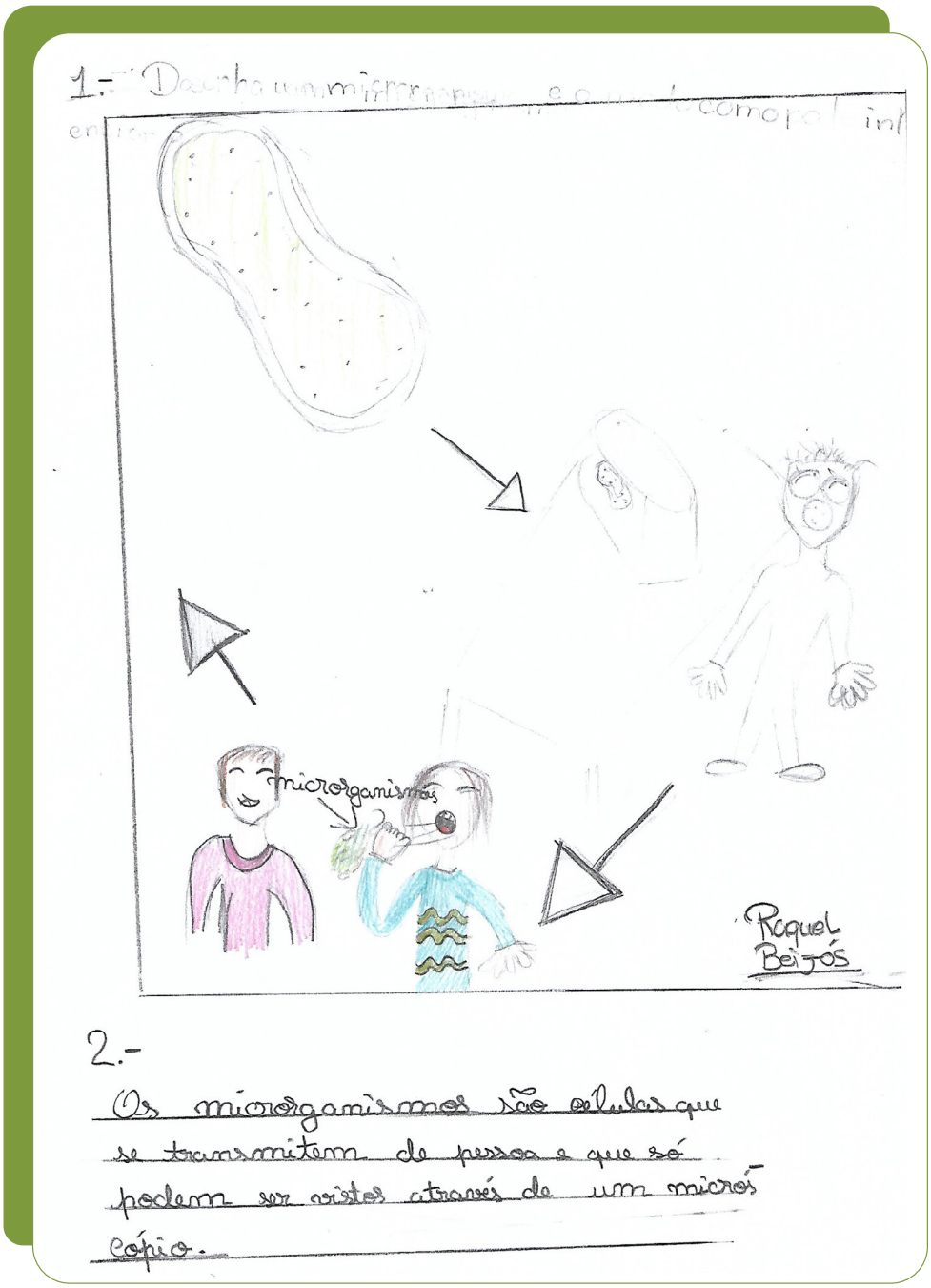
1. Desenha um microrganismo e o modo como pode influenciar o ser humano.

2. Descreve o que desenhaste.

Eu desenhei um menino com micrbe.

Transmission was an action related to microorganisms that was rarely represented. However, student 16 (S16) noted this in their drawing on the post-questionnaire, acknowledging that microorganisms are transmitted through droplets from one person to another (Figure 11).

▼ **Figure 11.** Post-questionnaire drawing from S16.

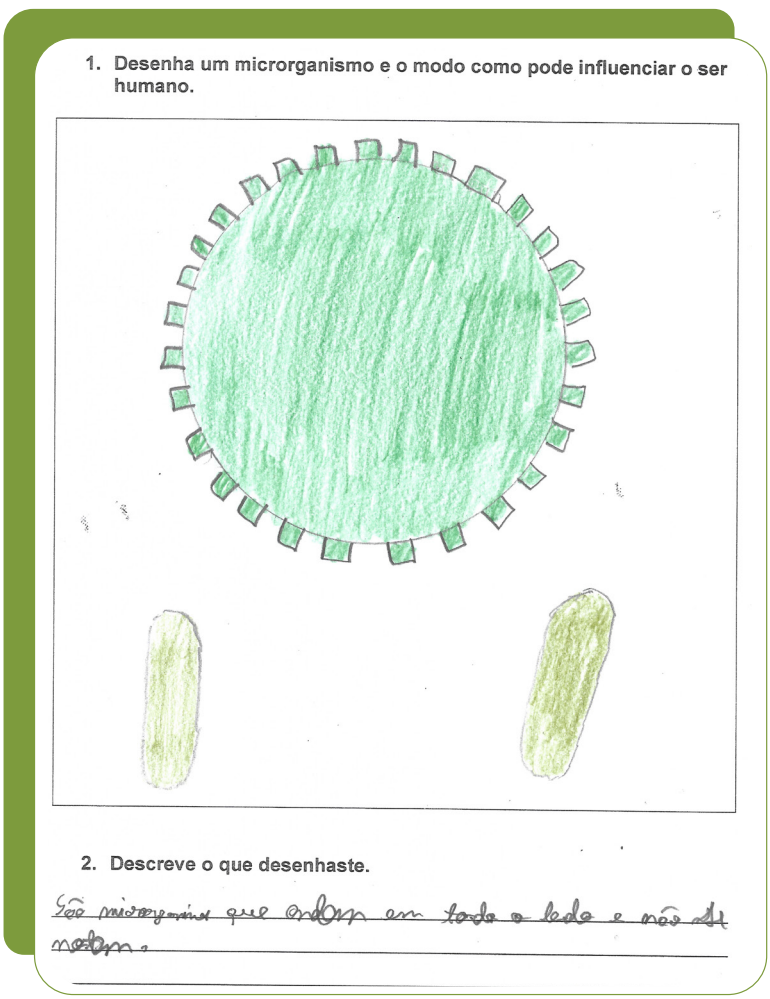


The sub-category 'General beneficial effects' was noted only in the post-questionnaire drawings, likely due to the intervention that emphasised the positive actions of microorganisms. Additionally, the role of bacteria in aiding human digestion was also represented in the post-questionnaire. This concept was expressed in the drawing by student 14 (S14), who mentioned: *'[...] a benefit is that it helps us digest'* (PostQ; Figure 7). This understanding may have emerged from the intervention, which highlighted microorganisms' beneficial effects on digestion.

Representations of the location of microorganisms

The location of microorganisms was depicted in various drawings, both in the human body and elsewhere. Their presence in the human body was primarily noted in the pre-questionnaire. Results regarding the location of microorganisms in the human body were less pronounced in the post-questionnaire because the intervention aimed to illustrate that these organisms are present in all environments. This approach was adopted due to students primarily associating microorganisms with the human body, leading the intervention to emphasise their presence in various objects and surroundings. In this regard, the sub-category regarding the location of microorganisms in other places emerged, which was identified in the post-questionnaire. One example is the description: *'They are microorganisms that are everywhere and are not noticeable'*(PostQ, S8; Figure 12).

▼ **Figure 12.** Post-questionnaire drawing from S8.



Other representations of microorganisms

The category 'Other representations of microorganisms' included drawings related to 'Instruments used to observe microorganisms' and 'Researchers who study microorganisms,' which were only present in the pre-questionnaire. The absence of occurrences in these sub-categories in the post-questionnaire can be attributed to the practical intervention, which focused on observing microorganisms with the naked eye in colonies rather than through magnifying instruments, and did not emphasise the work of researchers in the field.

Conclusions

Addressing the research question, *'How does an inquiry-based learning intervention affect primary school students' conceptions about microorganisms?',* it was noted that, initially, students had limited and imprecise conceptions regarding the type, action and location of microorganisms. These findings are consistent with those of Ballesteros *et al* (2018) and Ruiz Gallardo and Paños (2018). After intervention, the association of bacteria and viruses with microorganisms increased in the post-questionnaire drawings, revealing a deeper understanding of specific types of microorganisms. There was also a greater understanding of the actions of microorganisms post-intervention, with students depicting more specific diseases caused by them. Additionally, the focus of the representations of microorganisms' actions shifted from being primarily about disease causation to also including their general and specific beneficial effects, such as aiding digestion. While some students initially represented the location of microorganisms on the human body, these occurrences declined after the intervention, likely due to the emphasis placed on the presence of microorganisms on other surfaces and objects.

Implications for practice

As students often have preconceptions that make learning about microorganisms difficult, teachers should adopt strategies that challenge these conceptions. One approach that can be effective involves starting by identifying these ideas and then promoting practical activities that motivate students. The proposed enquiry-based learning intervention, centred on practical experiences, could contribute to improving understanding of the different types of microorganisms and their actions through active participation. By taking samples from surfaces in their everyday lives and observing the growth of colonies in Petri dishes, students can develop concrete knowledge about the environments in which microorganisms thrive.

The take-home message for the science community is that, while practical experiences can improve young students' basic knowledge about microorganisms, it is important to focus on exploring concepts that build a solid and accurate scientific understanding from an early age. For practitioners, this underscores the need to develop age-appropriate, engaging and scientifically sound educational activities that not only increase awareness but also foster curiosity and a more accurate perception of microorganisms and their importance in the world. This can help to establish a stronger foundation for more advanced scientific understanding of microbiology and related scientific concepts.

Limitations of the research

The study involved a small sample of 19 students from a single 4th-grade class in a Portuguese public school, which limits the generalisability of the findings. The lack of a control group makes it difficult to attribute any observed changes solely to the enquiry-based intervention, as other external factors could have influenced the results, although still providing valuable pedagogical insights. The assessments were only conducted immediately before and after the intervention, so long-term retention and conceptual understanding were not evaluated.

Future research

Future research with larger, more diverse samples and control groups is suggested to strengthen the validity of similar studies. Incorporating aspects of the Nature of Science (NoS) could further enrich and deepen the research.

Safety note

Reasonable care has been taken to ensure that articles in this journal do not suggest practices that might be dangerous. However, ASE has not tested the activities suggested and can therefore give no guarantee of safety. For further advice on health and safety matters in primary science education, see *Be safe! Health and safety in school science and technology for teachers of 3- to 12-year-olds* (4th edition, ASE, 2011), or contact CLEAPSS (or SSERC in Scotland).

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