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Microbes Go to School: Using Microbiology and Service-Learning to Increase Science Awareness and Fostering the Relationship Between Universities and the General Public

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Microbiology is an essential element of our everyday lives. This is not only the consequence of the importance of some pathogenic microorganisms, but also due to their positive and important role in processes related to human health, food production or waste recycling, to cite a few. However, the relevance of microbiology for the well-being of humankind and the planet still needs to reach beyond academic circles. Many current matters of urgency, such as environmental pollution or climate change, could partly be tackled by using green and sustainable solutions derived from microbial biotechnologies. Nevertheless, the wider public still attributes a negative connotation to microbes such as fungi and bacteria. The aim of this study was to implement service-learning as a pedagogical approach to increase scientific and microbiology literacy in society. Service-learning is a teaching and learning strategy that integrates community service and civic responsibility, fostering the dissemination of scientific knowledge. This approach is used to communicate about pressing societal issues surrounding microbes (antibiotic resistance, natural resources recycling, human microbiota, and food production among others) to an audience of pupils attending public schools. The activity of service-learning is proposed in the final year of the biology bachelor curriculum. Its purpose is to allow university students to develop and practice their lay communication skills as a key competence to be acquired during their university education. In the activity, the students developed their own concept and material for the activity and delivered it to pupils at primary and secondary school levels (pupils aged 6–15 years old). The message is also expected to be disseminated beyond the participants, when the students and pupils share their experience with family and friends. With this pedagogical approach, we intend to raise awareness regarding about the importance of microbiology and its dual roles as harmful and beneficial for humans. We also wish to increase the connection between primary, secondary and tertiary educational institutions. Finally, we want to highlight the importance of having a new generation of communication savvy professionals in biology.

Keywords: microbiology, service-learning, lay communication, antibiotic resistance, human microbiome, games

INTRODUCTION: BACKGROUND AND RATIONALE FOR THE EDUCATIONAL ACTIVITY INNOVATION

In spite of the overall positive role of microorganisms on health and well-being of humans and the environment, the general public often has a negative perception of the role of microbes in their everyday life. This is chiefly the consequence of the strong historical link made between microorganisms and diseases, which is bound to be reinforced as a consequence of the on-going pandemic. There is a clear need to change this negative perception, as microorganisms are not only essential for sustaining life on Earth, but also because of their incredible potential to be used for the benefit of humankind (e.g., pharmacologically active substances, bioremediation, soil fertility). This knowledge must reach beyond the scientific community to have an impact on society in a more direct way. Leading scientists in the field also identified this urgent need to increase awareness of microbiological science in society (Timmis et al., 2019). For this to happen, microbiology should be included in the current curriculum taught at obligatory schools, so that it becomes part of the general knowledge of future generations.

Along with the negative perception of microorganisms, an overall lack of scientific literacy can have important consequences for society. Having a scientifically literate citizenry is essential for making informed decisions ranging from an individual's daily life to developing sound public policy (Donovan and Schmitt, 2014). Moreover, our failure to create and maintain a link between education at school and academic research is sometimes considered as one of the reasons behind the dropping numbers of school pupils engaging in pursuing a career in science, technology, engineering, and mathematics (STEM) disciplines. Another emerging aspect of this barrier between academia and society is science skepticism and the rise of varied conspiracy theories (Van Der Linden, 2015). In response, many countries have developed specific initiatives to promote scientific literacy. One of the tools that can be effective at promoting the connection between science and society is service-learning (Felten and Clayton, 2011). Service-learning is a teaching and learning strategy that integrates community service with civic responsibility, fostering the dissemination of scientific knowledge (Soska et al., 2010). More specifically, service-learning can be defined as "*a course-based, credit-bearing educational experience in which students 1) participate in an organized service activity that meets identified community needs and 2) reflect on the activity in such a way as to gain further understanding of course content, a broader appreciation of the discipline and an enhanced sense of personal values and civic responsibility*" (Bringle et al., 2006; Felten and Clayton, 2011). Accordingly, as service-learning involves both students and the general community, it is an effective tool to connect science and society, in which the three concerned parties, i.e. scientific community, society, and students, all gain from the approach. Indeed, the idea behind service-learning is that the interaction between acquiring knowledge and skills and the development of a practical activity is key to learning, which is an essential aspect of academic studies (Ehrlich, 1996; Felten and Clayton, 2011).

Service-learning projects are diverse and vary depending on the local context, the targeted objectives, and the academic field in which it takes place. Such projects could integrate graduate as well as undergraduate students and the dedicated times could range from short-term modules to whole semester activities or even multiyear projects (Felten and Clayton, 2011). To maximize its effectiveness, service-learning must be used to directly communicate about societal issues in which both the scientific community and the target population have a common ground of interest. For this, microbiology offers a myriad of topics: food production or food spoilage, organic matter recycling, wastewater treatment, microbiome research and personalized medicine; all are just but a few examples of topics that can be used to this end. In this contribution, we present a case-study of undergraduate university students engaged during a whole semester activity as microbiology communicators to pupils at schools (6–15 years old) to help bridge the gap between scientific research and knowledge dissemination beyond the academic community. In our case, the activities were organized around societal issues that illustrate the two opposite sides of microbiology ("dark"-harmful side versus "bright"-beneficial side). We chose this analogy to the popular Star Wars Universe as a mean to reach the non-scientific audience (both children and adults) with easy-to-grasp examples. On the one hand, for the "dark side", the students mainly communicated about antibiotic resistance, which usually reflects the negative and problematic impacts of microbes by associating microbiology with diseases. On the other hand, the "bright side" was discussed through the discovery of bioactive compounds in nature, food production, and the role of the human microbiota on health, among others. All of the latter aimed at highlighting the positive role of microbes and their biotechnological potential.

Using antibiotic resistance as the basis for the development of teaching activities addresses one of the most pressing societal issues of our times. Indeed, antibiotic resistance has been recognized as a key research and policy area not only in Switzerland, but also worldwide (Shrivastava et al., 2018). It has been recognized that part of the problem stems from the inadequate use of antibiotics, and thus, users must be better informed on the appropriate use and limits of antibiotics. However, the measures designed to address this problem usually do not consider the pivotal role that universities can play in educating a new generation of professionals with the ability to better disseminate this message to the general population. Considering only antibiotic resistance for the service-learning activities could lead to further reinforce the association of microorganisms to diseases. Therefore, explaining the role of microorganisms for the discovery of new antimicrobial compounds also offers an opportunity to change the negative perception of the public. This allows to emphasize the role of the microbial resource not only as the origin of the problem (antibiotic resistance), but also as a potential solution (antimicrobials discovery). This shift in perception will ultimately allow us to appreciate that a large majority of microbes are beneficial to humans. The beneficial role

of microorganisms can further be strengthened by the selection of other issues in modern societies, like the challenge of food production to support the constant increasing worldwide population, natural resources recycling, soil bioremediation, or the study of human microbiota and its impact on human health.

The overall objective of our approach was to promote the dialogue between universities and society, by contributing to the development of teaching tools and materials for the dissemination at schools of scientific knowledge about pressing societal issues involving microbes. To reach this goal, we used the concept of service-learning (teaching tool) as part of the active training of new scientists at university level (bachelor level). Service-learning was used to teach school pupils (target public), which will constitute the entry gate for dissemination of scientific knowledge about antibiotic resistance and microbial diseases (the "dark side") and the roles of microbes in food production and human health (the "bright side"). At the same time, service-learning was used to teach university students how to transfer knowledge and communicate about microbiology to a non-scientific public. This represents an important soft skill for their future careers.

PEDAGOGICAL FRAMEWORK(S), PEDAGOGICAL PRINCIPLES, COMPETENCIES/STANDARDS UNDERLYING THE EDUCATIONAL ACTIVITY

Innovation in science education in Switzerland possesses unique challenges given the structure of the school system (regional responsibility at the level of each canton), as well as the multilingual nature of the country. Literacy in microbiology is rather neglected in the current curricula, as compared to other topics in biology. Therefore, in order to foster literacy in microbiology, we have developed an innovative teaching framework that includes the concept of service-learning where third-year bachelor university students deliver teaching activities at schools. This results in material and activities to discover microbiology with playful activities that are tailored for specific school levels. Service-learning allows university students to become more engaged with their local communities and to learn skills in communication and teaching. Service-learning is a modality of teaching that is considered an active learning strategy, as it requires the participants to first master the knowledge to disseminate, to then develop the class material and communicate about it. This level of engagement is highly beneficial to improve their learning capabilities and to develop their communication skills. Indeed, service-learning has been found to be positively related to students performance in STEM disciplines (Freeman et al., 2014). Moreover, this teaching approach also has a positive effect on the receiving communities (i.e. school pupils, but also their relatives), as it promotes dissemination of scientific knowledge to the society, and promotes careers in science (Donovan and Schmitt, 2014).

In order to provide the students with a sound background knowledge on the topics selected within the program and to help them to develop the tools required for the effective implementation of the service-learning activity, the preparatory lectures and practical training in microbiology of second-year bachelor students were restructured. This included partnering with the Tiny Earth Initiative, a global initiative that proposes the crowdsourcing (or even student-sourcing) of antibiotic discovery through the screening of bioactive compounds produced by soil microorganisms in the classroom (https://tinyearth.wisc.edu). The aim of this initiative is to introduce university students in biology to the field of microbiology by following the discovery journey of Fleming and other pioneers in the field of antibiotic research. In our case and given the emphasis of our research portfolio on environmental microbiology (including both bacteria and fungi), specific activities were developed for the second-year biology curriculum. These activities allowed to explore in parallel not only the issue of antibiotic resistance and antibiotic production, but also to expand the interest of our students in microbiology beyond human health. For this, we consider the beneficial use of microorganisms for plant growth promotion and protection against pests through biocontrol. In this way, third-year students participating in the service-learning activity have the knowledge and experience required to develop the scientific aspects of their activities.

METHODS: LEARNING ENVIRONMENT (SETTING, STUDENTS, FACULTY); LEARNING OBJECTIVES; PEDAGOGICAL FORMAT

Participants

The service-learning teaching module consists in 28 h of work in class + 28 h of personal work, equivalent to three credits in the European Credit Transfer and Accumulation System (ECTS). This course is offered during the last (sixth) semester of the bachelor in biology from the university of Neuchâtel (Switzerland) as an optional activity, which ensures the interest of the participants. At this crucial stage of their academic training, students are expected not only to be able to integrate the concepts learnt during their education, but they are also deciding about their future career paths, including specializing into teaching.

Pedagogical Format

The service-learning course was divided into five consecutives sections:

1. Selection of specific scientific topics within the societal issues already identified and choice of the target population (4 h): an initial presentation by the trainers is used to guide the students to narrow down the specific scientific topics to be developed.

2. Presentation of the planned activities among peers as well as to university trainers and schoolteachers (4 h): this allows discussing the complexity of the activity to be proposed and gives the participants the opportunity to share and develop their ideas together. This step helps the students to adjust their activity so that the knowledge they want to transfer is both scientifically sound and adjusted to pupil's age and background knowledge.
3. Preparation of the final activities (8 h): finalizing the teaching material.
4. Service-learning (10 h): actual work with pupils.
5. Final presentation (2 h): feedback among participants.

Learning Objectives

In terms of learning objectives, after taking the service-learning class, the students should be able to:

1) communicate a scientific message in a clear and concise way;
2) apply the knowledge acquired during the theoretical lectures in the development of the activities;
3) explain and illustrate biological phenomena in a simple way;
4) communicate with a non-academic public (e.g., avoid jargon, use of simple words and illustrative language);
5) develop a "playful" activity without missing scientific rigor;
6) evaluate knowledge transmission;
7) develop critical thinking in science;
8) work effectively in a group;
9) communicate with schoolteachers and pupils; and
10) plan and execute the activities.

Qualitative Data

To evaluate whether these objectives were attained and to grade each student individually, a combination of different types of assessments was used. Those consisted of:

1. The creation of an information leaflet (group work; 30% of the final grade); design of a 2-page leaflet summarizing the activity targeted at informing schoolteachers about the program. The evaluation was based on the ability of the students to explain the principles of service-learning in an easy-to-grasp way and to indicate the goal of their activities in a few words.
2. The implementation of an approach to evaluate the pupils following their activity (group work; 30% of the final grade); this aimed at ensuring that the activity developed and delivered by the students effectively allowed the transfer of knowledge during the service-learning. The format was free, but it had to be adapted to the age of the pupils.
3. Written statement (group work; 20% of the final grade); a short description of their activity (20 lines max.), in order to answer the following question: "How does your activity allow to achieve the transfer of knowledge to school pupils?". This assignment created a self-assessment and personal description of their activity and indicated indirectly their ability to work as a team as well as to assess whether the scientific content they wanted to transfer was clear to the students.
4. Personal written statement (individual work; 10% of the final grade); each student was asked to provide a short text about their personal experience within the service-learning activity. Two guiding questions were provided for this: "What was your main motivation to undertake this optional course?" and "How did this module contribute to your personal development?".
5. Feedback from the schoolteachers (10% of the final grade); the teachers were also asked to qualitatively evaluate the students' attitude, both overall and during their intervention in the classroom. The following questions were provided to guide them:
   - How was the communication with the students? Did the students consider your suggestions during the preparation and delivery of the activity?
   - How did the students communicate with the pupils? Were their communication efforts adequate to explain a scientific concept?
   - Were the scientific concepts presented pertinent to the age and background of the pupils?
   - How were the students organised overall (e.g., time management, readiness, preparation)?
   - Were the "playful" aspects of the activity suitable to the school system pedagogy and to the scientific objectives?

Data Analysis

To analyse the data provided by the students, pupils, and teachers, we proceeded as following:

Information leaflet (not Presented in This Study)

The quality of the leaflet was assessed by considering the following criteria:

- The description of the activity is complete, concise and accessible to a non-scientific public.
- The essential information is all present (e.g., contact information, partnership).
- The general layout is attractive.

Evaluation of the Pupils

The evaluations targeting the pupils were analysed according to pupils' age. The assessment was based on the level of information retained by the pupils, as compared to the content of the activity provided by the students.

Written Statement

The written descriptions of the activities were compiled and all identifying information removed. The first analysis of the text focused on the clarity of the descriptions provided by the students. Then, in a second stage, the category of the activity (e.g., creative, game), scientific content, and target audience (age of pupils), were determined.

Personal Written Statement

The information was also compiled and all identifying information removed. After an initial reading to assess the level of general understanding, several common themes highlighted by the students were identified. Those covered the development of personal and/or transversal skills and corresponded to "science communication", "teaching",

TABLE 1 | Service-learning activities proposed in 2020. For each activity, the category, scientific topic, target audience (standard school level according to harmonized -HarmoS- educational level defined by the « Conférence suisse des directeurs cantonaux de l'instruction publique (CDIP) »), and a brief description of the activity are provided.

Category	Scientific topic	Target audience (age bracket)	Description
Creative and experimental	Microbes in our body	2H (5–6 years old)	Crafting of "microbes" and place them in a sketch of the human body during the activities (**Figures 1A,B**). Perform a scientific experiment (grow mould on bread) to assess the impact of hand sanitation (**Figure 1C**)
Discovery and experimental	Finding microbes in the environment (our bodies and elsewhere)	7H (10–11 years old)	A cartoon was used to introduce a scientific quest to find microorganisms in different environments. This was combined with performing a "safe" at home isolation and observation experiment
Gaming	Characterizing different microbial groups (bacteria, fungi and viruses)	8H (11–12 years old)	A board game with daily activities to discover different groups of microbes and their specific features (**Figure 1D**). Field observations of microorganisms, drawings and other activities were included as part of the daily activities

"relationships and teamwork", "ability to adjust to unexpected events" and "creativity".

Feedback From the Schoolteachers

Two types of information were extracted from the feedback: 1) teachers' perception of the service-learning project in general and 2) specific feedback for the students individually. This second information was an additional criterion to grade the students individually at the end of the course. A summary of the teachers answers is presented in this study.

RESULTS TO DATE/ASSESSMENT

Academic Year 2019–2020

The service-learning course was proposed to last year bachelor students for the first-time during spring semester 2020. Ten students participated to the class. Three groups of three or four students prepared activities for three primary school classrooms (school levels 2, 7 and 8H; aged from 6 to 12 years old; **Table 1**) located in the Canton of Neuchâtel, Switzerland. The students introduced the topic of microbiology, with a highlight on its dual sides ("dark" versus "bright side"). The activities developed by the students were categorized depending on their content (**Table 1**; **Figure 1**). Given that the activities were created and conducted throughout the first lockdown in Switzerland due to the Covid-19 pandemic (March to June 2020), all the activities were adapted to an online format. For this, some students prepared informative videos accompanying their activities. "Safe" and easy-to-perform experiments, along with guiding documents, were then delivered to the pupils' homes to complement the activities.

Academic Year 2020–2021

During spring semester 2021, thirteen students selected the service-learning course; they were subsequently divided into six groups of two to three students. The groups prepared activities for pupils aged from 6 to 12 years old (school levels 3H–8H in the HarmoS system) in six primary school classrooms (**Table 2**) distributed in three schools located in the Canton of Neuchâtel, Switzerland. In 2021, the students also introduced the dual role of microbiology, through games, sports and creative activities (**Figure 2**). At this point, the sanitary conditions related to the Covid-19 pandemic allowed for frontal activities with the pupils, as well as for a visit to the university to use the classrooms and the scientific equipment available in the laboratories. In addition to this, some pupils went outside to observe microorganisms and their manifestation in the natural environment and to collect samples. In the lab, they observed these samples using stereoscopes and microscopes. Several groups also isolated microorganisms on agar-based media from environmental or daily-life samples. The approaches are all routinely used by most microbiologists. Such a practical approach had many pedagogical and teaching benefits. Indeed, most of the students noticed a positive effect on pupils' concentration and on the acquired knowledge when they were actively taking part to the activities. In addition, the observation of microorganisms in the natural environment, or from daily-life objects through isolation, helped pupils to realize that microbes are everywhere and not only linked to diseases and hospitals. Finally, visiting facilities at the university and using scientific routine material such as lab-coats, Petri dishes and pipettes, clearly created a scientific interest in these young children and may trigger their motivation to go to a higher education level such as university.

DISCUSSION ON THE PRACTICAL IMPLICATIONS, OBJECTIVES AND LESSONS LEARNED

The preparation of teaching material was a key component of the service-learning class. By offering the university students the possibility to actively participate from the design to the preparation and realization of their specific activities and material, the activity becomes their own and their investment greatly exceeds what they normally do for a traditional assessment. An important aspect is that this material requires the input and feedback of the schoolteachers, who are therefore essential for guiding the participants through the program to effectively reach the pupils and boost their interest. This reciprocal collaboration is one of the key elements in service-learning (Felten and Clayton, 2011). On the long term, the

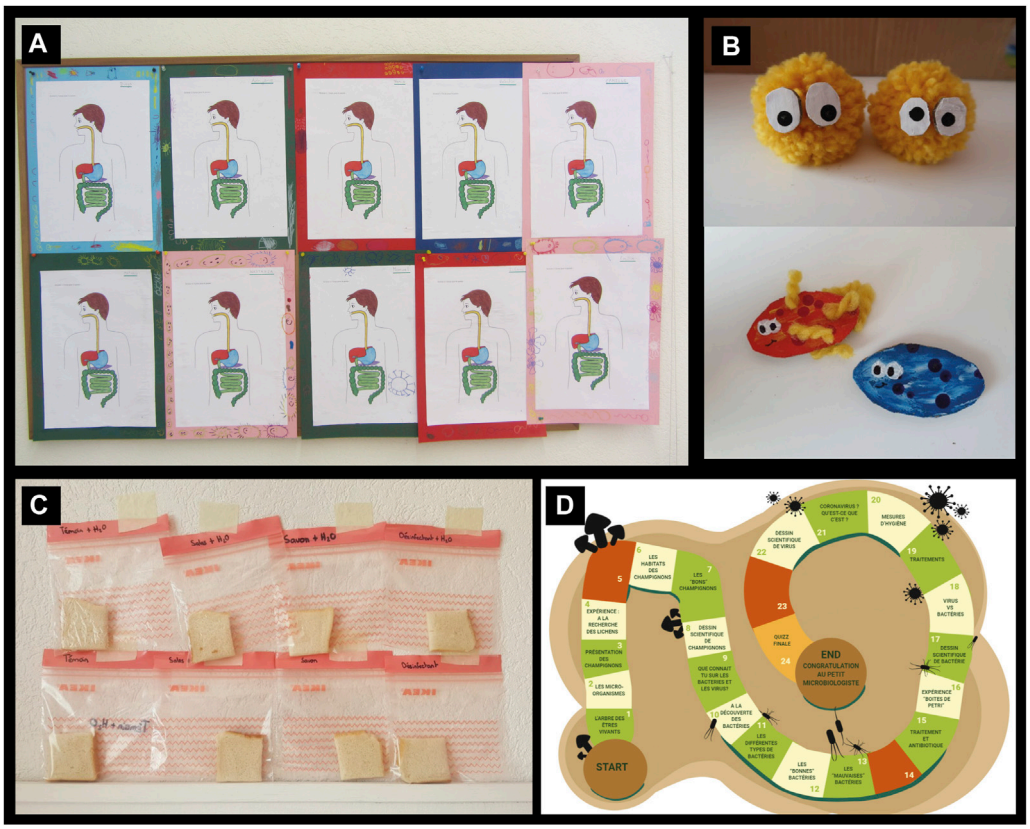

FIGURE 1 | Examples of the material created by the students in 2020 to develop their activities. Sketches of the human bodies coloured by the pupils **(A)**. In those sketches the children had to place the microbes they had crafted **(B)** to illustrate where they expected to find microorganisms in the human body. The children conducted a scientific experiment to assess the impact of mould on a piece of bread **(C)**. Illustration of the board game with daily activities around microbiology **(D)**.

TABLE 2 | Service-learning activities proposed in 2021. For each activity, the category, scientific topic, target audience (standard school level according to harmonized -HarmoS- educational level defined by the « Conférence suisse des directeurs cantonaux de l'instruction publique (CDIP) »), and a brief description of the activity are provided.

Category	Scientific topic	Target audience (age bracket)	Description
Creative and experimental	Microbes and antibiotic resistance	3H (6–7 years old)	Creation of a story about microbes, crafting of a microbe and creation of a fishing game to illustrate antibiotic resistance. Sampling in a pond and in soil to perform microscopic observations in the laboratory
Creative	Microbes, hygiene and food production	4H (7–8 years old)	Use famous story characters for children to introduce "bad" and "good" microbes (**Figure 2A**). Baking bread to illustrate the usefulness of microbes
Gaming and experimental	Environmental microbiology and link between microbiota and alimentation	6H (9–10 years old)	Board game about prevention of diseases through food habits and a healthy microbiota. Outdoors sampling and isolation of microorganisms. Microscopic observation in the laboratory
Gaming and experimental	Antibiotic resistance and development of novel treatments	7H/4H (10–11/ 7–8 years old)	Hospital board game with the aim to cure all sick patients (**Figure 2B**). Text with gaps to complete theoretical explanations. Laboratory experiment using antagonistic microorganisms and antibiotic disks
Gaming, artistic and experimental	Diversity of microorganisms	7H (10–11 years old)	Battle card game inspired from Pokemon to illustrate the diversity of microbes and their impact on humans and the environment (**Figure 2C**). Pixel art to familiarise pupils with microorganisms' shape. Microscopic observation
Sport, creative and experimental	Scientific method and environmental microbiology	8H (11–12 years old)	Board game with physical activities and orienteering race to illustrate the roles of microbes in sport (**Figure 2D**). Mind map to summarize concepts. Isolation of microbes through filtration of beverages in the laboratory

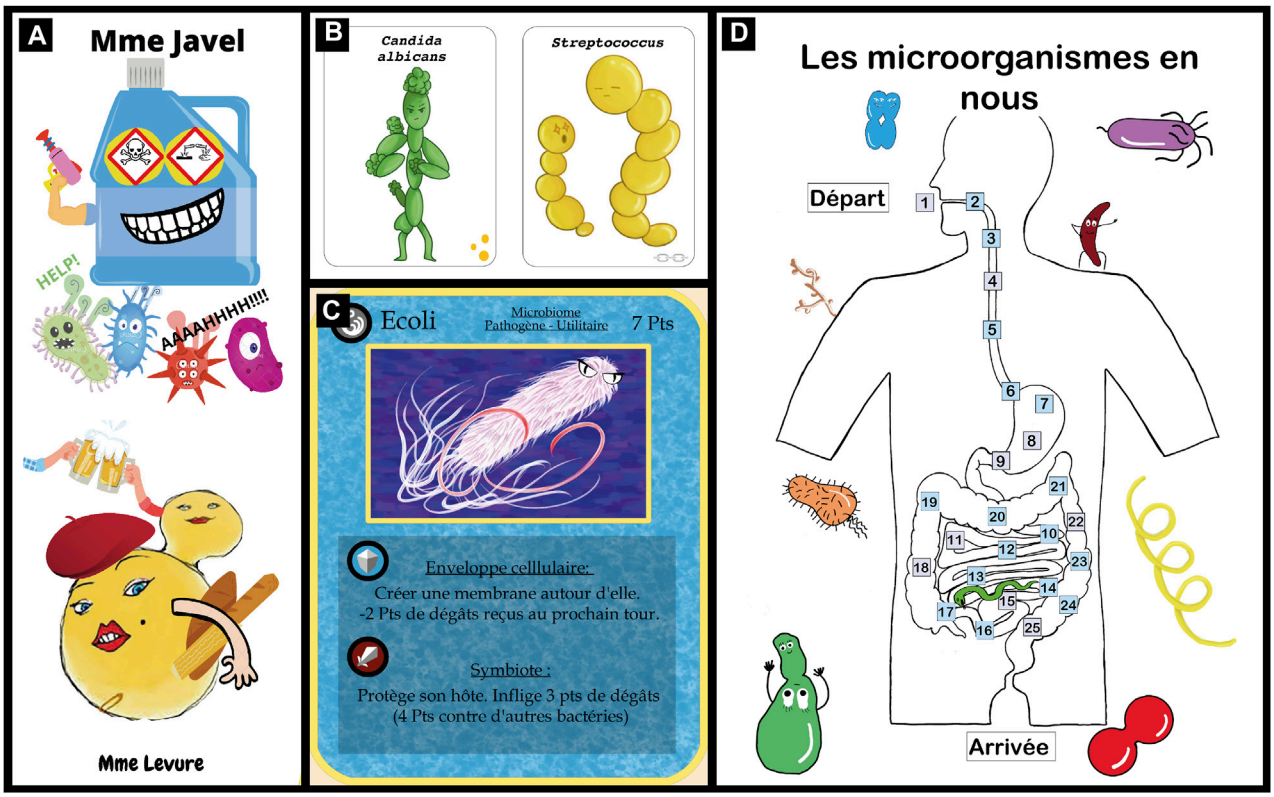

FIGURE 2 | Examples of the material created by the students in 2021 to develop their activities **(A)** Mr.-Mrs. comic characters (originally from kids books written and illustrated by Roger Hargreaves) designed here by the students to introduce the topic of microbiology **(B)** Card illustrating microorganisms that can be responsible of diseases **(C)** Card to play a battle Pokemon-like game with some "attack" and "defence" points unique to each microbe **(D)** Board game with physical challenges and questions about microbes.

material created by the students will be integrated in an electronic live repository containing presentations, document files, images, and videos. The content will constantly be updated with new examples of the different activities and some of them will be available to be used by other teachers and future participants to the program, which will allow to increase the scope of the activities beyond the target populations. Moreover, all the generated teaching material is accessible to other schoolteachers and proposed in English and three Swiss national languages (German, French, and Italian; https://unine.ch/lamun) to allow expanding this initiative beyond the Canton of Neuchâtel, in which French is the first language.

Beyond the Transfer of Knowledge–How Service-Learning Develops Personal Skills of University Students

The service-learning activity appeared as a useful tool to develop academic knowledge, civic learning and therefore, to connect academia and students with society and to spread knowledge. Beside this, the service-learning class also helped university students to develop personal and transversal skills (Eyler et al., 2001; Felten and Clayton, 2011). The latter were numerous and represented an important reason for students to sign up for this class and were identified by the participants as an asset at the end of the activity, as part of their self-assessment. These skills are presented below.

Science Communication

The students were all unanimous about the existence of a gap between scientists and society (e.g., "the scientific world tends, in my opinion, to remain compartmentalized within itself"). They also agreed that such a gap causes issues, such as "a lot of misunderstanding between the political world, the scientific world and the citizens" or promotes "skepticism from some people toward elitist and closed circles of which science is a part". In their mind, scientific popularization and transmission of knowledge is key to building a bridge between these two worlds, but at the same time, it is not an easy undertaking and requires training; "science communication is an integral part of biology and science in general as it allows to break the barrier between scientific/university community and the general public". The service-learning activity gave the students the opportunity to practice lay communication, which would both serve society ("to put science back in its place: in the hands of all"), and their personal career and projects ("the ability of making science popular is, in my eyes, useful in several circumstances, from working for a popularization journal to giving conferences about your research topic to non-specialists").

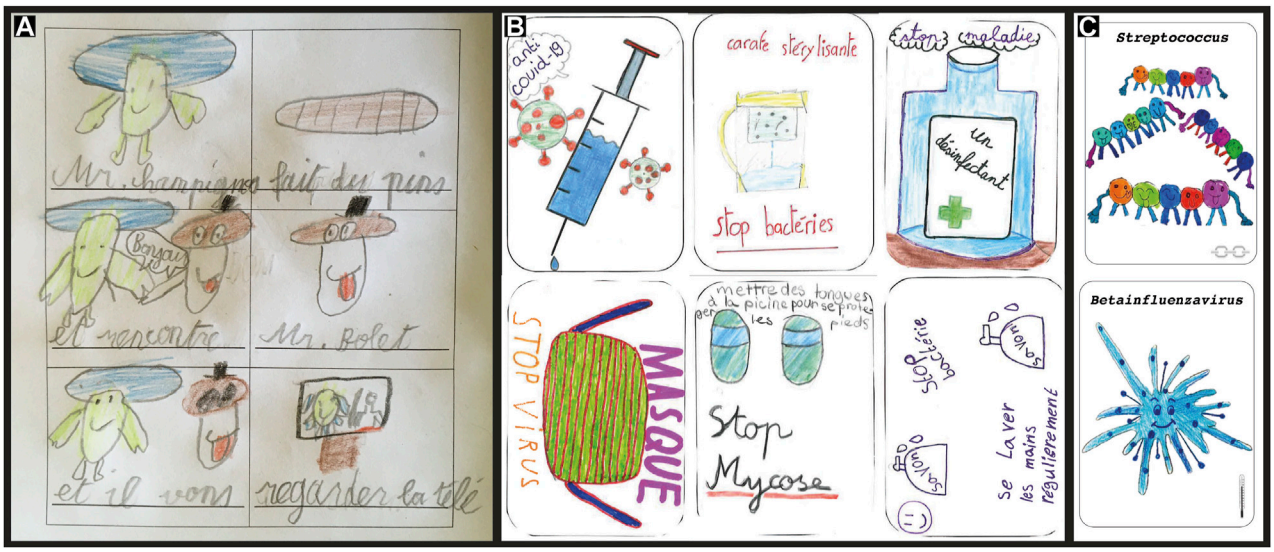

FIGURE 3 | Evaluation methods. For the 6 to 8 years old pupils, the children completed a small storyline with drawings and key words to illustrate that we use yeast to make bread **(A)**. In the evaluation method used for 9 to 11 years old pupils, the children could create their own bonus game card. Depending on the game, the pupils drew cards representing ways to be protected against microorganisms **(B)** or designed their own microorganisms **(C)**.

Teaching

Most of the enrolled students want to become teachers in the future and this was one of the main motivations to take part in the optional service-learning course; "my motivation to take this course was my ambition to work as a teacher in natural science later", "this course represents an opportunity to link teaching and science, two domains that are part of my interests and motivate me". The students largely acknowledged that participating in the service-learning activity allowed them to be confronted with challenges linked with teaching; "I was able to dive into the process behind the preparation of a lesson. It surprised me how time-consuming this task is", "I was not prepared for the need to explain biology using simplified terms, and to give simple but correct answers to questions in the interaction with kids. This definitely represents an experience that could be useful for my future career as a biology teacher.". Overall, students acquired new skills important for teaching, and more importantly, this experience empowered them; "a revelation, becoming a teacher is no more a simple objective, it is my main goal!", "step by step, I have found confidence in what I was teaching and saying", "the feedback from the children was encouraging and creates trust, making me think that I am on the right path for my future career".

Relationships and Teamwork

Beyond the objectives of teaching and scientific popularization, service-learning also aimed to connect people. Teamwork type skills (communication and patience) are crucial transversal skills useful for most careers. The service-learning activity was built to favor the exchanges between students, children, schoolteachers and all the other stakeholders involved in the project. This concept of teamwork was perceived as beneficial; "working in pairs of two was a bonus and I also appreciated the exchanges with the other students about the activity developed". The service-learning did not only benefit the children participating in the activities, but also to the students themselves as they learned and received a lot from the younger pupils; "not only a contributory act, but a reciprocal sharing I have learned a lot from the children, through their pleasantly surprising curiosity and motivation", "a pleasure to see the wonder in the eyes of all the kids when they were looking into the microscopes". At the end of the course, the importance of sharing science was even more present in the minds of the participants; "my principal interest was to share what I learned with kids in a manner that in turn will encourage them to share with their own family and friends", "I really want to keep this concept of a continuous exchange process".

Ability to Adjust to Unexpected Events

Even if the students prepared their activity ahead and planned it over the different sessions, it seems obvious that when working with young pupils, sometimes an activity can last longer than expected or could even be cancelled; "The best prepared lesson can actually happen in a way you have not intended". Therefore, the students had to be flexible and re-adapt their activities to the moment; "The main skill I acquired during this course is the ability to adapt to the situation, no matter how it evolves". The capacity to adapt is definitely an important skill in science. For example, when developing a research project where things do not develop as expected.

Creativity

According to conventional wisdom, creativity is oftentimes associated with artistic domains. Nonetheless, this skill could be valuable for scientists as well. Indeed, having well designed slides for a presentation or an attractive poster helps to convince a target audience about the importance of the research. Despite this, creativity is often neglected and traditional science courses at the university do not usually include such skills; "developing our creativity is undoubtedly beneficial as

being inventive is a considerable quality for a scientist. Unfortunately, I feel that we tend to make little use of this skill in our everyday life as undergraduate students". Creativity is particularly important when working with a young audience. Through the service-learning course, the students were able to develop their creativity by generating their own activity and material. Overall, this call for creativity was approved and praised by the students; "I immediately jumped on the occasion to link my passion for drawings", "having the opportunity to freely express my creativity was priceless".

Feedback–From the Pupils Side

All the pupils attending the activities enjoyed the activities and were eager to find out about the next session offered by the university students. Interestingly, in one class considered as difficult to handle by their schoolteacher, all pupils were able to concentrate and listen quietly for a full period of teaching by the students. This highlights that non-formal, or out-of-the-box, teaching may be a way to foster interests in otherwise non-studious pupils. Beyond this positive feeling, the most impressive and encouraging fact was the indirect feedback provided in the form of the evaluation forms that the pupils had to complete at the end of the service-learning activity. Even the teachers themselves were amazed about the quantity of complex scientific words and concepts the pupils retained all along the activity. The evaluation format was different depending on the age of the pupils. For the younger ones (6–8 years old), the evaluation was mainly based on drawings and oral discussions. For example, during the last sessions, some pupils had to draw their own microbes and a small storyline about what they have learnt during the service-learning activity (**Figure 3A**). This feedback showed that thanks to service-learning, even at a young age, pupils remembered that microorganisms are not only linked to disease, but that they can also be beneficial for humans and for the environment. The students that conducted games with pupils aged 9 to 11 years old evaluated them through the creation of bonus cards to be included in the board or card game they created. The pupils mostly drew cards representing ways to be protected against microorganisms and this highlights that the game proposed was efficient to show pupils that hygiene is important to cohabit with microorganisms (**Figures 3B,C**). Lastly, for older pupils (11 to 12 years old), the evaluation consisted in a multiple-choice quiz. Even though this quiz addressed complex scientific concepts, most of the pupils succeeded, showing that service-learning is an efficient pedagogic approach to transfer knowledge.

Feedback–From Schoolteachers

The schoolteachers that took part in the project also enjoyed this experience. They agreed that the university students did a great work by preparing activities that were well adapted to the pupils. The communication with the students was smooth and their suggestions were always considered. Overall, the feedback from the teachers supports the fact that service-learning is a beneficial teaching strategy and could be easily integrated into the classic schooling program. This is even more true for pupils with learning difficulties, as a different pedagogic method brought in by external teachers can help them to reconnect with the school system.

Conclusion: Putting the Service-Learning Activity Into Perspective

The data and information presented in this case study show that the students enrolled in the service-learning module benefited from this activity on multiple aspects. As shown by previous studies, the service-learning activity exposed students to new people and experiences that potentially lead them to consider a career path (Jones and Abes, 2004; Fitch, 2005). In our case, this is well illustrated by the fact that after the course, many of the students confirmed their desire to become schoolteacher. This desire to transfer knowledge to a younger generation is also in agreement with a previous study claiming that service-learning contributes to enhanced civic engagement (Pascarella and Terenzini, 2005). In addition, our study clearly highlighted that service-learning has a positive effect on personal development, as shown in previous studies in the field (Eyler et al., 2001). In conclusion, the results obtained demonstrate that service-learning is an efficient tool to disseminate microbiology knowledge beyond the academic world and to connect science and society. More concretely, this tool allowed the connection between university students and school pupils using microbiology as common ground (Astin et al., 2000).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

MF, AS, AB, SB, and PJ contributed to the conception and design of the study. MA, LH, GH, YGF, AP, MP, and CV performed the activities. MF, AS, and SB organized the activities database. MF, and PJ wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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