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BiOutils: an interface to connect university laboratories with microbiology classes in schools

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One sentence summary: This perspective article describes an innovative science communication platform, BiOutils, fully integrated in a microbiology laboratory; the platform provides microbiology experiments that can be performed in classroom environments.

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ABSTRACT

The contribution of microbiology to the scientific advances of modern experimental biology has very often made the difference. Despite this, its role as an independent discipline has slowly started to fade away. This situation has been worsening due to (i) a marginal role of microbiology in academic curricula and (ii) a low or misplaced interest by the public at large towards this field of study. In order to counter this phenomenon, microbiology researchers and passionate scientists have made several efforts to engage and inform the broad public and academic policymakers about the importance of microbiology as an independent discipline. One of the approaches used in this direction is to support the teaching of microbiology in schools. BiOutils, a science communication platform based within a microbiology lab, has been committed to this goal since its creation in 2007. In this article, we describe how the platform is able to work in synergy with school teachers, providing engaging activities that can be performed in schools' classrooms. Our aim is to provide a perspective on how every microbiology lab with little costs and efforts can support the teaching of a discipline that will remain independent thanks to the fascination that they will be able to transmit.

Keywords: microbiology; education; classroom activities; communication platform; science teaching

INTRODUCTION

The scientific discipline that studies the microbial world is called microbiology. At the dawn of this field of study, its members, at the time universally addressed as bacteriologists, were some of the most important pioneers of experimental biology (Bennett and Karr 1999). It is thanks to this group of enthusiastic scientists that microbiology is nowadays recognized as the cornerstone of most of the techniques used in modern molecular biology. But does microbiology still exist as an independent discipline today?

The initial bloom of microbiological research saw the development of some greatly diversified techniques, going from the isolation and monoculture of bacterial strains to the work performed in sterile conditions. It is during this fertile period that the simple prokaryotic organism *Escherichia coli* became the well-known rock star of modern research in molecular biology (Blount 2015). Furthermore, the characterization of several bacterial enzymes (e.g. restriction enzymes, *Taq* polymerase) sets the basis for essential lab techniques such as molecular cloning. Thanks to these innovations, most of the actual discoveries of modern

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molecular biology have been achieved (Bennett and Karr 1999). Still nowadays breakthrough improvements of modern lab techniques keep on arising thanks to the definition and adaptation of bacterial mechanisms. A good example is the recent characterization of the 'clustered regularly interspaced short palindromic repeats' acting as an immune system for bacteria and archaea (Horvath and Barrangou 2010). This discovery allowed a huge leap forward for the practice of eukaryotic genome editing (Cong et al. 2013). It is thus clear that, due to the leading role of microbiology in developing experimental techniques, molecular biology has been very much relying on microbiological knowledge since its birth in the early 1960s and it will continue to do so as well in its future (Bennett and Karr 1999; Blount 2015).

However, since microbiology has been more and more considered as an ancillary discipline of modern molecular biology, it slowly started to blend with it. This has brought microbiology to the point of running the risk of losing its identity as an independent scientific discipline (Bennett and Karr 1999). Furthermore, the public at large ignores the crucial role played by the microbial world for the development of animals' biology and for the sustainability of the ecological systems where they belong (McFall-Ngai et al. 2013). On the contrary, the interest for microbiology is usually low or misplaced, being often only associated with nasty diseases or dangerous contaminants. Altogether, this may contribute to the decrease in the number of students who decide to engage their studies/careers in a fascinating discipline like microbiology.

One of the ways to restore the interest of future generations in microbiology, and thus, establishing again its status as an independent discipline, may be improving microbiology teaching in schools (Redfern, Burdass and Verran 2013). Among the different scientific disciplines taught in schools, microbiology has been traditionally used as an engaging hands-on science activity. However, many teachers are nowadays experiencing obstacles that prevent them from proposing microbiology school activities during their classes. Some of these obstacles can either be theoretical (e.g. uncertainty for the results' output, lack of sufficient background and fast pace of the advancements of modern experimental techniques) or technical (e.g. financial resources, biological samples storage, experimental material, microbiological strains handling and biological hazardous waste disposal). In either way, fewer experiments and practical activities focused on microbiology are performed in schools than what could be the case (Redfern, Burdass and Verran 2013). In order to tackle these gaps, microbiology researchers from different academic entities have made several efforts to make microbiology more accessible and usable in the context of school classrooms (Redfern, Burdass and Verran 2015; Robertson 2015).

With a view to providing an example of good practices in disseminating microbiology education in schools, we will report hereafter an innovative approach to support the teaching of microbiology in schools. Furthermore, we will describe some of the classroom kits proposed by our platform and highlight how, after eight years of activity, such protocols have been able to break down the barriers between teachers and the delivery of microbiology in classrooms. Finally, data obtained from a survey developed and designed with the Training and Evaluation Division of the University of Geneva (Enquête sur BiOutils, Secteur Formation et Evaluation, Université de Genève) will evidence the diffusion of the proposed activities and how much such an initiative has been enthusiastically adopted, with an increasing demand, by school teachers in Geneva.

METHODS

BiOutils, a science communication platform from Switzerland

At the University of Geneva (UNIGE), Switzerland, several platforms of science communication for schools and the broad public have been flourishing over the past years. Such platforms cover a broad range of scientific fields (e.g. biology, physics, chemistry, mathematics and astronomy) offering spaces and materials so that hands-on practical activities can be performed outside the classrooms, under the guidance and supervision of university mediators (e.g. PhD students, postDocs) (Renner 2009; Perret 2011, 2012).

Among these platforms, BiOutils (from the contraction of the two words *Biology* and *Outils* that in French means tools) is committed to supporting the teaching of modern experimental biology. The platform offers several classroom protocols that are spanning different fields of modern biology (e.g. protein analysis, ecology, molecular cloning, plant physiology and evolution), with a special emphasis given to microbiology experiments. This is consistent with the fact that it was founded back in 2007 by researchers in microbiology. Importantly, compared to the other UNIGE platforms, BiOutils carries out its role with a different philosophy, its aim being that of fully integrating the teacher in the concept to be transmitted rather than substituting the teacher. The experiments and activities are not performed at the platform itself, but directly in the school environment, as an integral part of the courses provided by the schools' teachers. Thus, teachers themselves illustrate and follow-up the experiments, benefitting of the support and know-how of the BiOutils team. To this end, every experimental activity proposed by the platform is carefully developed in synergy with the curricula of school biology classes. This is made possible thanks to regular meetings that are taking place between schools' representatives (i.e. teacher themselves or their representatives) and BiOutils members. Teachers' requests are thus collected and protocols proposed according to their needs and to the specific curriculum. Notably, this approach makes both the role of the researcher and that of the teacher equally relevant in order to design the most constructive learning set-up for students. Once the curricular needs and the teacher's expectations are defined, a first draft of the activity is developed by the BiOutils staff and, after being trial and tested in the laboratory, it is validated by the educational environment (i.e. teachers). To this end, the activity is proposed to a small number of beta testers (i.e. normally two to three school classrooms) and all the feedback coming from students and teachers is thoroughly collected. Then, according to the comments gathered, the activity is optimized and defined so that it can fit the teacher needs (e.g. time frames, student's age, educational content and experimental manipulations). Importantly, after its launch, the activity will be further developed by the platform according to the comments and suggestions received by the teachers who have used the protocol.

For each activity, the protocol, the pedagogical material and the activity outline are uploaded on the platform's website (<http://www.bioutils.ch/>) so that the material needed for the activity can be directly booked from the activity section webpage. Once the activity has been booked, teachers may pass by the laboratory (i.e. headquarters of the platform) and pick up all the material necessary to perform the experiment in their classrooms. Importantly, most of the material (e.g. petri dishes, PCR machines and micropipettes) is provided by the platform. This enables teachers to take advantage of essential tools that

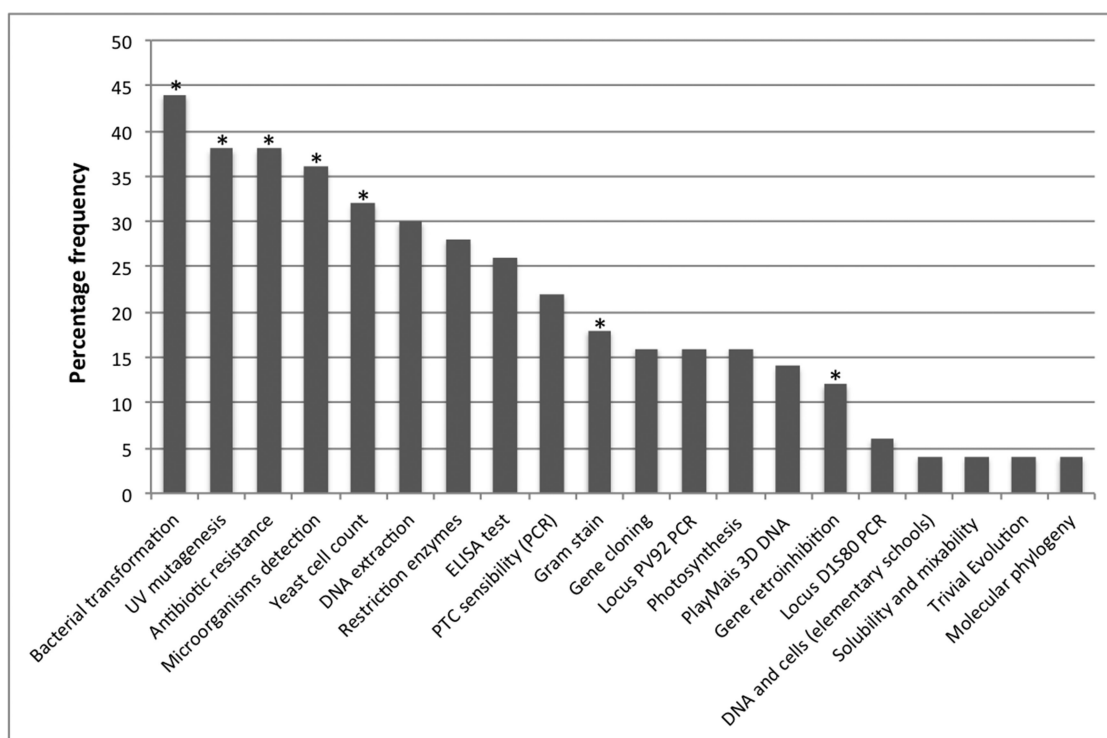


Figure 1. Percentage frequency of the distribution of BiOutils experiences. The output was obtained in response to the question: ‘Which activities have you proposed in your classroom?’ posed to teachers using BiOutils services ($n = 50$). Asterisks represent the activities focusing on microbiology. UV mutagenesis experience is a cross-curricular experience bridging microbiological physiology (i.e. yeast phenotypes) with the risks related to the over exposure to sunrays in humans (i.e. skin cancer development) (<http://www.bioutils.ch>). These results have been collected by the Formation and Evaluation Division of the University of Geneva.

cannot be bought by schools’ institutions due to unaffordable prices and/or because of the limited amount needed (e.g. enzymes). Once the activity is completed, the teacher will bring back the reusable material (e.g. PCR machines, micropipettes) and the used consumables (e.g. petri dishes, centrifuge tubes) that will be disposed of by the BiOutils team. Notably, whereas protocols are freely available on the BiOutils website and the use of the material is free of charge, the only reimbursement that is requested from teachers is that of consumables (e.g. centrifuge tubes, pipettes’ tips, petri dishes and enzymes). Since the consumables provided are the same that are used for research purposes (therefore bought in large amounts), the cost of the reimbursement is (i) constant, (ii) low and (iii) very often affordable by schools’ institution.

One of the most innovative features of BiOutils is the fact that the platform is fully integrated in a laboratory of microbiological research (Dieppoiss *et al.* 2012; Marguerettaz *et al.* 2014). Importantly, this privileged position allows BiOutils to provide its services on the basis of a continuous flux of interactions with other entities of the university. As a matter of fact, many activities are the result of inspiring exchanges between scientists coming from different disciplines. For example, two new activities that will be released during the coming academic year i.e. water microorganisms analysis and microorganisms photosynthetic pigments visualization, have been developed with the support of the chemistry department (water analysis, photosynthetic pigments) and the plant biology department (photosynthetic pigments). Remarkably, this interdisciplinary approach allows for a broader spectrum of learning objectives that can be proposed by teachers during their teaching modules.

RESULTS

Bringing microbiology to the classrooms

At present BiOutils offers more than 20 different protocols for engaging activities on modern experimental biology (Fig. 1; see also <http://www.bioutils.ch>). Among these activities seven are focused on microbiology experiments and are some of the most requested protocols (Fig. 1). Hereby we will describe two of these activities i.e. bacterial transformation and yeast cell counting plus a service that is highly requested by teachers i.e. microorganisms distribution. As it is for all the BiOutils’ experiences, the aim of each of them is to support and promote the teaching of modern biology in schools (Caine *et al.* 2015). The learning objective of each activity will be illustrated case by case within the description of the educational approach.

Yeast cell counting

One of the first experiments proposed by BiOutils is an activity that brings the focus on the microscopic nature of yeast (*Saccharomyces cerevisiae*). This aspect can be illustrated by making an estimation of the living cells that are present in a cube of baker’s yeast, available at most grocery’s stores. With this activity, it is possible to approach several different teaching modules that range from the study of unicellular forms of life to the use of big number formulas (i.e. comparison between the number of *S. cerevisiae* cells present in a cube and the number of humans populating earth). Furthermore, students apply the concept of working in sterile conditions in order to obtain *S. cerevisiae* single colonies on the petri dishes provided, becoming also acquainted with the idea of colony generation and of serial dilution. As for all BiOutils experiments, the complete material and equipment needed to perform the experiment (e.g. petri dishes, pipettes, tube racks)

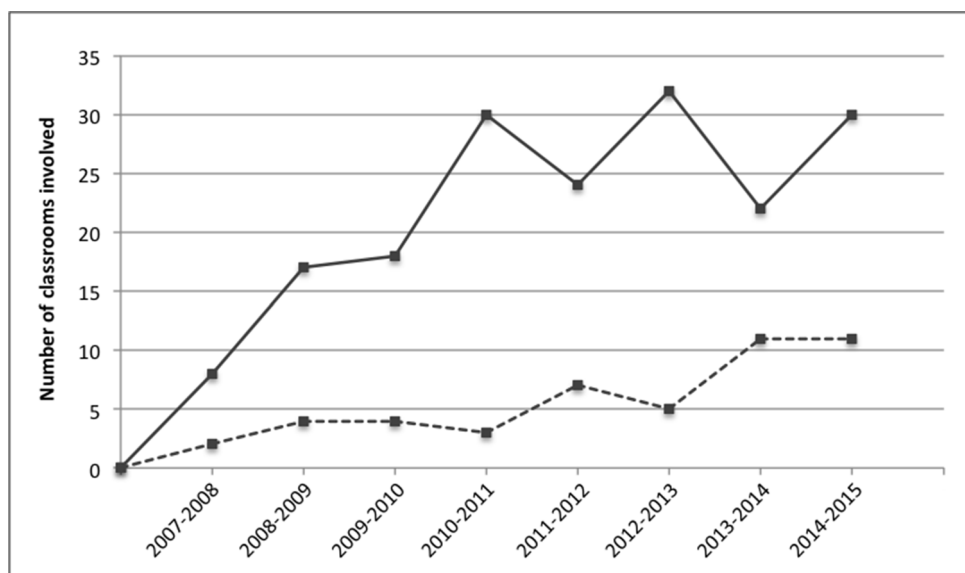


Figure 2. Distribution of experimental kits between 2007 and 2015. The continuous line represents the pattern of distribution of the bacterial transformation kit. The spotted line represents the distribution of the yeast cell count kit. Data sets represent the numbers of kits that have been distributed during the past academic years. These numbers do not account for the maximum number of kits that can be proposed, which, according to our experience, we estimate to be at least double than the data reported.

is provided and teachers can take advantage of a simple trial-and-tested protocol. Since its introduction in 2007, this experiment has been increasingly used by school teachers in Geneva reaching the past year a diffusion among 11 school classrooms that proposed the kit within their biology curricula. This allowed more than 200 students to be directly familiarized with the activity's concepts (Fig. 2). Importantly, the Department of Public Education (Département de l'Instruction Publique, DIP) of Geneva has officially recognized this experiment as a fundamental tool for teachers' good practice to introduce students to the scientific approach. Due to that and due to its interdisciplinary features (e.g. big numbers, powers of 10, serial dilutions, exponential growth), this particular activity is also used by physics and mathematics teachers.

Bacterial transformation

This is a classical experiment, normally proposed in microbiology hands-on classes. The importance of such an activity relies on the remarkable discoveries made by Griffith (1928), and subsequently by Avery, MacLeod and McCarty (1944) which led to the groundbreaking (for that times) hypothesis that '(...) a nucleic acid of the deoxyribose type is the fundamental unit of the transforming principle (...) (Avery, MacLeod and McCarty 1944). As a matter of fact, the bacterial transformation activity gives teachers the possibility to stress the role of microbiology as one of the most important milestones towards the development of modern molecular biology. Furthermore, it offers the basis for a deep critical discussion on bacterial physiology and genetic plasticity (e.g. acquired antibiotic resistance). However, due to different obstacles, this kind of experiment is rarely proposed by teachers. The major limit is the cost of the material needed to perform the experiment, starting from the biological material (e.g. competent cells) to the consumables (e.g. antibiotics, media, petri dishes). Moreover, despite being a simple laboratory technique, there is a considerable amount of know-how needed to perform the experience in a classroom environment. The activity proposed by BiOutils overcomes most of these obstacles, offering, among all the material needed, com-

petent cells, plasmids and selective plates. Importantly, within this activity, the pedagogical inputs are tailored to address different topics both of microbiology (e.g. antibiotic resistance) and of modern molecular biology (e.g. transgenic organism). Furthermore, by providing a plasmid that expresses a lux operon from *Vibrio harveyi*, the students are able to appreciate the result of the bacterial transformation, observing the acquired bioluminescence of *E. coli*. Like for the yeast cell counting activity, the bacterial transformation activity has been proposed since the launch of BiOutils, becoming its most requested activity (Figs 1 and 2).

Microorganisms' distribution

Since its first steps, BiOutils has always offered to teachers the possibility to observe under the microscope different non-pathogenic bacterial strains. Such a support has been proposed in order to overcome the difficulty for teachers to maintain biological strains in the school environment due to the lack of the right conditions (e.g. incubators, media replacement, light cycles). Importantly, some microscopic organisms offer the possibility to experience first-hand the amazement felt by van Leeuwenhoek back in the 17th century when he firstly observed tiny 'animalcules' moving around in different water samples (Robertson 2015). In order to let students experience such amazement, a microorganisms' distribution was introduced by BiOutils in 2009. Since then, one month per year, the platform is committed to providing several visually engaging microorganisms as for example the fascinating *Volvox globator*, the spirally shaped *Arthrospira platensis* (Spirulina) or the predator *Paramecium caudatum* living on bacteria as a food source. The amazing biological architecture and behavior of the organisms involved makes this kind of activity very much appreciated by students so that a high amount of material is distributed every year (more than 2000 students reached in 2014-15 academic year, Fig. 3). The high demand for this service since the first year of its introduction reflects a strong need of teachers for this kind of activity (Fig. 3).

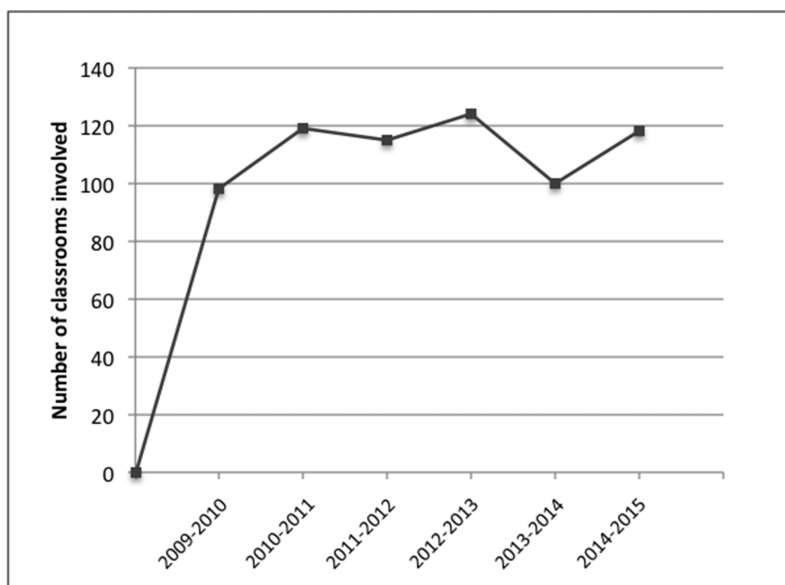


Figure 3. Distribution of microorganisms kits between 2009 and 2015. The continuous line represents the amount of classrooms that performed the protist analysis.

CONCLUSIONS AND DISCUSSION

Even though it mainly addresses the single city of Geneva, the experience of BiOutils shows, to our knowledge for the first time, how an academic science communication platform based in a microbiology research laboratory can operate on the long run (it

will soon celebrate its 10 years of activity) in tight collaboration with school institutions. Thanks to this approach, an increasing number of schools have taken advantage of BiOutils protocols and nowadays 100% of the secondary schools of Geneva refer to BiOutils for their practical activities (BiOutils activity report 2013–14). Such a method has been further confirmed by a recent

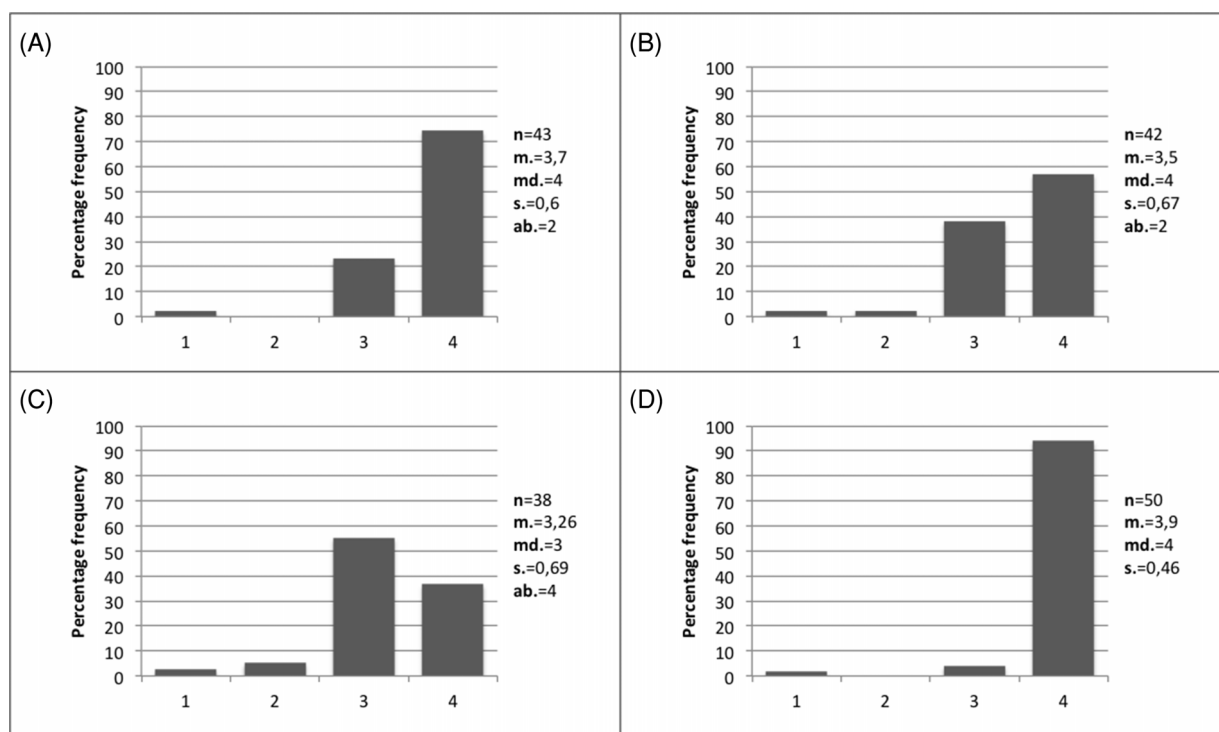


Figure 4. Results of the replies collected by the Formation and Evaluation Division of the University of Geneva. 1–4 numbers represent the gradient of answers from 'totally disagree' (1) to 'totally agree' (4). Percentages represent the answers relative frequency. 'n' stands for number of teachers who answered to the question, 'm.' for the replies average, 'md.' stands for median, 's.' reports the standard deviation and 'ab.' reports the abstention to the specific answer. The graph represents the results to the following questions: (A) 'Does the BiOutils classroom experience increase the interest of students for the topic?': 1: 2,3%; 2: 0%; 3: 23,3%; 4: 74,4%. (B) 'Does the BiOutils classroom experience make the understanding of the topic easier?': 1: 2,4%; 2: 2,4%; 3: 38,1%; 4: 57,1%. (C) 'Is the number of experiences proposed by BiOutils sufficient for your needs?': 1: 2,6%; 2: 5,3%; 3: 55,3%; 4: 36,8%. (D) 'Do you think that it is important that a structure like BiOutils, fully integrated in a research laboratory, should be maintained and developed further?': 1: 2%; 2: 0%; 3: 4%; 4: 94%.

survey that has been sent to teachers who had made use of BiOutils' services (Enquête sur BiOutils, Secteur Formation et Evaluation, Université de Genève). The results were impressive and acknowledged the importance of such an interface within the academic environment. Teachers confirmed that the proposed experiences increase the interest of students for the topic and that they make it easier for students to approach the learning objectives (Fig. 4A and B). Furthermore, despite the consistent amount of activities proposed, it seems that there is a further need of such protocols (Fig. 4C). Consistently, the 94% of teachers interviewed believes in the importance of the existence (and its further development) of such a platform integrated in a scientific laboratory (Fig. 4D). As a matter of fact, BiOutils represents an interface between researchers and schools teachers, acting as a real gateway towards academia. Due to its simple and efficient method, the platform is able to develop activities tailored to the needs of teachers. For example, this year the platform has launched its most recent activity, a bacteriophage protocol, expressly requested by teachers and developed in synergy with them.

The financing of the platform is provided by a certain number of means and ways. At the beginning equipment can be collected from the University laboratories, or purchased with funds obtained from local foundations. Once the platform has a certain size and throughput, salary support from the University is required, in order not to harm the research activities of the hosting laboratory. Finally, in our case we obtained in the past generous support from a foundation to continuously develop new experiments. As it is set up, the consumables are in charge of the schools, ensuring that the teachers are really interested, and leaving to the platform fixed costs and further developments.

Notably, the activities that we have reported can be proposed and supported by every microbiology research lab with very little effort. Consistently, this year and for the first time, a new platform of BiOutils has been opened by another microbiology lab in the Italian speaking part of Switzerland (i.e. BiOutils Ticino). We believe that thanks to similar commitments by academic researchers, more platforms could become steadily integrated with the academic substrate. In order to be successful, the role played by researchers is of the uttermost importance. In fact, the interdisciplinary approach of researchers both on the side of research and education will play a crucial role in creating a bridge between the academic world and school institutions (Handelsman 2003; Anderson et al. 2011). This method can succeed in boosting the fascination for microbiology in students and thus inspire a future generation of microbiologist to pursue the path of a discipline that will remain, thanks to them, independent.

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