

# **Educating in antimicrobial resistance awareness: adaptation of the *Small World Initiative* program to service-learning**

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## ABSTRACT

The Small World Initiative (SWI) is a consolidated and successful education program rooted in the USA that tackles the antibiotic crisis by a crowdsourcing strategy. Based on active learning, it challenges young students to discover novel bioactive-producing microorganisms from environmental soil samples. Besides its pedagogical efficiency to impart Microbiology contents in academic curricula, SWI promotes vocations on research and development in Experimental Sciences and, at the same time, disseminates the antibiotic awareness guidelines of the World Health Organization (WHO). We have adapted the SWI program to the Spanish academic environment by a pioneering hierarchic strategy based on service-learning that involves two education levels (higher education and high school) with different degrees of responsibility. Along the academic year, 23 SWI teams each consisting of 3-7 undergraduate students led by one faculty member have coordinated off-campus programs in 22 local high schools, involving 597 secondary/high school students as researchers. Post-survey-based evaluation of the program reveals a satisfactory achievement of goals: acquiring scientific abilities and general or personal competencies by university students, as well as promoting academic decisions to inspire vocations for science- and technology-oriented degrees in younger students, and successfully communicating scientific culture in antimicrobial resistance to a young stratum of society.

## Introduction

The lack of new classes of antibiotics in the market and the quick development of resistance to our current therapeutic arsenal by clinically relevant bacteria have led us these days to the so-called “antibiotic crisis” (Courvalin, 2016; Friedman *et al.*, 2016; Piddock, 2012). The facts are that only 8 of the 33 antibiotics that are currently in clinical trials can be considered novel in terms of structure or mechanism of action, and none of such drugs have been released to the market in the last three decades, while the list of worrying multi-drug resistant bacteria considered a serious challenge to human health globally keeps on growing (Leung *et al.*, 2011; WHO, 2014). Among these, major threats are posed by extended spectrum beta-lactamase and carbapenemase-producing *Enterobacteriaceae*, *Acinetobacter baumannii* and *Pseudomonas aeruginosa* in hospital environments, or multi-/extremely-drug resistant *Mycobacterium tuberculosis* in the community. Infections that were not fastidious to treat at the turn of the century, such as gonorrhoea, *Helicobacter*-related peptic ulcer,

typhoid fever and dysentery are now concerned as serious threats and have been added to this list (WHO, 2017).

Although in developed countries the use of antibiotics in the clinics and community health care services is now controlled by efficient antibiotic stewardship policies, massive use of antibiotics in animal production is still a problem in several countries in spite of bans (Lakshmi *et al.*, 2017; Cameron & McAllister, 2016). Inappropriate practices in the past have already led to selection of resistant bacterial clones in multiple environmental niches related to human activity (Cantón & Morosini, 2011). The current scene has led to pessimistic reports announcing for the mid-21st century a post-antibiotic era in which common infections might be untreatable (O'Neill, 2014).

In the latest years, warnings on the antibiotic crisis from health authorities, led by the World Health Organization (WHO), have triggered serious programs on antibiotic awareness, social education and incentives to promote research and public health policies to tackle this overwhelming challenge. The present situation calls for a holistic One Health perspective, which involves approaching the problem from different angles, summoning diverse expertise profiles, ranging from clinicians, veterinarians, environmentalists and epidemiologists to experts in education and communication (Collignon, 2013).

The Small World Initiative (SWI) is a successful education program based on crowdsourcing, which is consolidated in the USA. It was conceived by Prof. Jo Handelsman and coworkers with a double aim: to promote vocations in young students for research and development in Biomedical Sciences and to disseminate the public health problem posed by the antibiotic crisis following the WHO guidelines. SWI is based on active learning, using hands-on approaches that involve students in real discovery of novel bioactivities.

SWI follows the same experimental line that led pharmaceutical companies in the second half of the 20<sup>th</sup> century to the development of most antibiotics now available. Companies have largely abandoned this approach due to low yields of hits and a non-sustainable investment/profit ratio, as the development of a new antibiotic is as costly as that of other drugs, but its return on investment in the market is considerably lower. Crowdsourcing involving a large, ever-extending community, as proposed by SWI, should enhance the likeliness of success while providing an exceptionally valuable toolkit for Microbiology education. Guided by faculty members, SWI students design their own experiments, collect and analyze the samples, isolate soil microorganisms and assay their ability to produce antagonistic effects on tester bacteria that are safe

relatives of clinically relevant multi-drug resistant pathogens. Students are often further involved in characterizing the positive isolates and presenting their results in congresses and symposia, even participating as authors in research articles (DeLuca *et al.*, 2017; Davis *et al.*, 2017; Caruso *et al.*, 2016).

After its initial success in the USA, SWI has been implemented in 14 other countries. We present here our results on a pilot experience to introduce SWI in Spain during the 2016-17 academic year, orchestrated from the largest public university in Madrid and the Spanish Microbiology Society (Sociedad Española de Microbiología –SEM). As an innovative contribution to the SWI tactics, we proposed in SWI@Spain a “symbiotic” integration of two educational levels by merging SWI with service-learning methodology.

Service-learning is grounded on active learning, but scholarship activities must directly impact in the community, providing tangible benefits to the society. Thus, in service-learning, training activities are focused to solve real problems outside the university campus, bringing academic activity closer to the actual demands of society (Stewart & Wubben, 2014; Bringle & Hatcher, 1996). Beyond active learning, the success of these strategies relies on their demand for real-time professional decision-making and their teamwork-promoting nature, as well as in the emotional component provided by the physical interaction with the actual subjects of the action. Service-learning has been applied to diverse contexts related to Biomedical Sciences, mostly in the health care environment, but also in the field of microbiology (reviewed by Webb, 2017).

Applied to SWI, the goals of the intervention in society by service-learning from the University involve disseminating the major health problem of antibiotic awareness and inspiring vocations for Science, Technology, Engineering and Mathematics (STEM) in young students. Unlike the situation in the USA, in Spain and other European countries the decision to follow a science- and technology-oriented path is made during high school, as curricula in Higher Education Degrees are not openly flexible. Thus, the goal of inspiring STEM vocations would not be achieved in Spain if first year university students (“freshmen”) were preferentially targeted, as approached by SWI in the USA educational environment. However, this is a priority goal in Spain, as ingress into STEM Degrees has fallen roughly from 30 to 25% in Spanish universities from 2009 to 2015. Thus, adapting SWI to service-learning would provide benefits to both university students that would greatly promote their skills in Microbiology and present them with real responsibilities on managing a research project; and to secondary/high school students that would be motivated toward STEM-related Degrees in their future

academic decisions. Our results illustrate that implementing SWI on high school from the university by service-learning largely fulfills these goals.

## **Materials and methods**

The complete development of a service-learning project implies (1) detecting a necessity in the community, (2) planning the activity to attend this need, (3) carrying out the activities, (4) evaluation and reflection, and (5) assessment and celebration.

To adapt the USA SWI program to an educational service-learning project for undergraduate students the activities programmed should be linked to specific learning objectives related to their curricula at the university. Table 1 summarizes the expected learning outcomes and the main project activities associated. Detailed description of these activities is given in points 2 and 3 of this section.

### 1. Identifying community needs

Awareness of the global antibiotic resistance problem and inspiration for STEM vocations, the general goals of SWI, were identified as priority needs of the community. In the case of the Spanish SWI program, as compared to the initiative in the USA, reaching STEM students earlier in the educational pipeline, prior to committing to a Degree, was a key factor.

### 2. Planning and preparation

*Organizing faculty members as SWIPs.* Following the scheme of the original SWI program in the USA, faculty members were prepared as *SWI Partner Instructors* (SWIPs) at Complutense University. Funding was obtained from the university through an Innovative-Teaching Call while some laboratory instruments and infrastructure were provided by faculties.

*Recruiting university students and community partners.* Microbiology faculty members explained the SWI program to undergraduate students and volunteers were organized into groups. A total of 112 undergraduate and 9 master students were recruited as

volunteers to participate in the initiative. A requisite for inclusion was to have passed basic microbiology lab classes. Undergraduates were from Degrees in Pharmacy (n=68), Biology (n=18), Biochemistry (n=13), or Veterinary (n=13) and master students from the “Microbiology and Parasitology: Research & Development” (n=7) or “Experts in Secondary and High School Education in Science” (n=4) programs. High school partners were invited to participate by faculty members from personal or professional contacts.

*Training of undergraduate students as SWITAs.* Volunteering undergraduate students, collectively termed SWITAs (*Small World Initiative Teaching Assistants*), received special lab training during three consecutive days in three 2 h sessions. In these sessions they collected, weighed and processed soil samples, resuspended 1 g of soil in sterile water, plated dilutions, selected colonies, performed antibiotic assays and interpreted them (Hernandez *et al.*, 2015). Also, during these training sessions faculty members explained and debated with the SWITAs the aims of the project, as well as technical questions, including biosafety, instructions for sterilizing material, choice of appropriate culture media, recording and analysing the results, etc.

### 3. Action

*Team work strategies at the university.* Twenty-three SWI teams were established, each consisting of one faculty member (SWIPI) and 3 to 7 undergraduate/master students (SWITAs). Each team was commissioned to implement the SWI program in a particular hosting secondary or high school (Fig. 1A). Among the 121 trained SWITAs 119 were eventually included in one of such teams and two quit the project after the training. SWI team members were encouraged to use the project’s social networks (Facebook™ open group SWI@Spain and Twitter™ account @SWISpain) to disseminate their activities. SWI teams met at the university research labs on a periodical basis to discuss the logistics of SWI actions, to prepare and sterilize material and culture media, to analyze the experimental results and to design data recording sheets and survey forms.

#### *Planification of explanatory lessons*

Through individual or group tutoring sessions at the university preceding visits to high schools, the SWIPI trained the teaching abilities of SWITAs. Each member of the team was in charge of communicating to younger students at high school the appropriate knowledge on a particular topic: scientific method, data recording and sampling, basic

biology of prokaryotes, mechanisms of action of antibiotics and resistance, biosafety and good laboratory practice, epidemiology of resistance transmission and the One Health concept. With this aim, SWITAs prepared their own talks with/or without MS Powerpoint™ presentations as teaching material. Further continuous training for each team or individual student was monitored by each faculty member by specific tutoring sessions.

*Activities in education centers.* Twenty-two secondary/high schools in the region of Madrid were arranged to host SWI, involving a total of 597 students that mostly worked in couples, eventually processing over 250 soil samples of diverse origins and isolating over 5,000 microorganisms. SWITAs were responsible for (i) organizing and managing an operative Microbiology research lab at the host centres; (ii) compliance with biosafety level 1 in which soil samples could be processed and rigorously analysed; and (iii) communicating the problem of antimicrobial resistance (AMR) and the guidelines for the proper use of these drugs. The calendar of SWI activities in hosting high schools was developed in five 2 h-sessions distributed in three to five weeks. In each of these five sessions the SWI teams carried from the university labs all the necessary equipment (sterile fungible, toothpicks and swabs, automatic pipettes, gloves and lab coats, sterile water and culture media) to the schools. After each session all material was taken back to university labs for incubation and disposal or recycling in biosafety containers.

Although each team was encouraged to innovate, the methodological basics are illustrated in Fig 1B:

In session 1, SWITAs explained to the teenage students basic microbiological concepts, the AMR challenges, the aims of the project and their responsibilities as researchers, as well as notions on data recording and the scientific method. Sampling kits, consisting of a ziplock bag containing a sterile scraper, a pair of gloves, a sterile polypropylene tube and a sampling data recording sheet, were delivered and indications on how to collect the sample given.

In session 2, the SWI team gave instructions to weigh 1 g of sample, suspend it in 10 mL of sterile water, prepare serial dilutions and plate 0.1 mL of the 1:100 to 1:100,000 dilutions in 10% trypticase soy agar (TSA, Conda, Spain) supplemented with 25 mg/L cycloheximide (Sigma-Aldrich) to prevent proliferation of fungi.

In session 3, SWITAs provided explanations on microbial diversity and differential colony morphology and axenic culture, helping younger researchers pick and patch 16-25 colonies onto a new TSA “mother” plate with the help of a grid.

In session 4, SWITAs introduced concepts on multi-drug resistant microorganisms of the ESKAPE group (*Enterococcus faecium*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, and *Enterobacter* species), and provided calibrated suspensions of safe relatives and sterile swabs for the students to spread a lawn on brain heart agar (BHA, Conda, Spain) Petri dishes. At least one Gram-positive (usually *Staphylococcus epidermidis* ATCC 14990) or one Gram-negative (*Escherichia coli* ATCC 11775, *Acinetobacter baylyi* ATCC 33305 or *Enterobacter aerogenes* ATCC 51697) were assayed per couple of students. All grown microorganisms from the mother grid plate were individually replicated by high school students under the supervision of the SWITAs on these plates using sterile toothpicks. A *Pseudomonas entomophila* strain IA-2 (F. Navarro-García, unpublished) was included in the assays as a positive control for antagonism, as it produces inhibition haloes on tester bacteria.

In the fifth and last visit, results were recorded and discussed. Back at the university labs, bacterial isolates able to produce inhibition haloes were selected and re-streaked for further analysis by SWITAs to perform as a follow-up of the service-learning experience.

#### *Attending to scientific meetings*

SWITAs were encouraged to present the results of the SWI service-learning experience to different congresses. Supervised by SWIPs, oral or poster presentations were prepared individually or in groups.

#### 4. Evaluation and reflection

*Surveys and statistics.* Assessment of the activities at both education levels were performed by post-surveys. To assess the impact of the complex service-learning experience on undergraduate students, an 18-page interactive Adobe pdf survey file including 40 groups of questions was made available to SWITAs at the end of the semester. Most groups of questions (22) were designed as structured questions including one to thirteen sub-questions to be answered by ticking on a Likert response bipolar scale (e. g. strongly disagree < disagree < neutral < agree < strongly agree).



The survey included also 6 dichotomous questions (yes/no or true/false) and 12 blank spaces for free redaction upon specific enquiries. This survey was based on the USA SWI Undergraduate Research Student Self-Assessment document (URSSA, SWI, USA), and was handed to undergraduate students post-experience. The URSSA was translated into Spanish and freely adapted to specifically evaluate aspects of the service-learning approach. The adaptation involved multiple changes, including specific questions on their appreciation of the value of the service-learning approach and their satisfaction with the various stages and actors of the project, in addition to the ones related to direct learning outcomes present in the original survey.

To evaluate the service at high schools of the SWI program, on the fifth visit of SWI teams, students and teachers were handed a brief survey that was filled on a voluntary basis. A Likert-scale was used, containing 11 questions related to the influence of the program on the attitude of students toward experimental sciences as an option for future Degree studies, as well as their perception of AMR awareness. They were also asked to write down the aspects of the experience that they considered “the worst” and “the best”. Given that subjects involved were under 18 years old, all activities and data collection were approved by both the School Council (equivalent to IRB in the USA), as well as by their parents via a signed statement.

*Group discussion and analysis.* Each group of university students together with their SWIPI had formal or informal meetings to discuss the development of the activities, personal and group benefits, as well as the difficulties encountered. Proposals were forwarded for correcting the identified pitfalls and reinforcing strengths.

## 5. Final celebration

A closing event was organized at the university in order to bring together all the project participants, university SWIPIs and SWITAs, plus high school students and their teachers. Divulcation lectures by recognized experts on both antibiotic discovery and service-learning methodology were organized and diplomas and prizes were given to SWITAs and school teachers in a join-together festive afternoon.

## Results and Discussion

### *Assessment of the service-learning strategy on undergraduate students*

Surveys on SWITAs were delivered post-experience and probed the benefits of the experience on acquiring skills and competences, perception and learning on AMR, usefulness of the service-learning approach, and impact of the project on future curricular decisions and their attitude toward a research-oriented career. Due to the extension of the survey (over 40 groups of questions in total), a set of salient results is shown in Figure 2, whereas the whole dataset can be consulted at the accompanying Supplementary material. Importantly, 98.5% of the students (all but one) judged that service-learning was more efficient for their own formation than the classic pedagogical techniques prevailing in our academic environment, mostly involving lectures and programmed lab training (see Fig. 2A). An extract of selected points related to the student's impressions on acquisition of skills and abilities through the program are summarized in Fig. 2B. These data reveal that their involvement in SWI was very illustrative to them for their perception of the relevance of research and their own ability and self-assurance to participate in a research project. Some scientific abilities were highlighted as considerably promoted by the experience, such as comprehension of the basis of investigation (83.3%), understanding scientific and safety protocols (80%) or analysis and discussion of scientific data (63%). SWITAs frequently claimed (95%) that the project seemed to potentiate their abilities to work in a team more than individual development (in agreement, "interaction with their team colleagues" was the item with a highest score in the global evaluation of the "satisfaction with the project" section of the survey, summarized in Fig. 2C). As a benefit of interaction with lower education levels, their ability to communicate science (92.6%), answer questions on a scientific basis and solve problems (78.4%), were highly promoted by the experience. Better learning by teaching others and improvement of their skills for public speaking were benefits commonly acknowledged by the university students, as was also concluded in a service-learning experience of health education conducted by undergraduates in a community health fair (Cain, 2013).

One out of four (24.24%) of the enquired undergraduates participated in scientific meetings where they presented the results of the service-learning experience at the high schools (Universidad Complutense Congress for Undergraduate students on Health Sciences, 2017 FEMS Congress, European Congress for Biology Students SymbioSE and SWI Symposium-ASM Microbe 2017) and 7.69% were awarded a prize in these events. These activities promoted the acquisition by the students of

competences on elaborating scientific documents, communicating scientific results or oral public presentation.

Globally, according to their answers, 91.08% were either satisfied (36.03%) or very satisfied (55.05%) with the project (Fig. 2B). Of the 68 SWITAs who participated in the survey, 87.88% had never participated in an innovation project and none had participated in service-learning experiences, although 21.54% had joined volunteering programs. When asked whether they would recommend the experience to other colleagues, all students (100%) answered positively. As shown in Fig. 2B, around 98% of the SWITAs considered that the program had boosted their interest in the field of Microbiology and their scientific vocation, which they positively valued for their professional development. As a benefit of interaction with lower education levels, their ability to communicate science was highly promoted by the experience, as repeatedly stated by SWITAs in the free redaction boxes included in the survey enquiring them for concrete benefits (data not shown).

As for the impact of the approach in future academic decisions for the undergraduate students, the experience did positively inspire in different degrees the possibilities of orienting their curricula toward research, or enrol in Master Degree programs, hospital internships or PhD studies (see data in Fig 2D). It may seem paradoxical that the professional opportunity that was less successfully promoted by the project was high school education (only 26.32% of the students declared to have awakened some degree of interest). This is likely due to the fact that such a vocation is uncommon in students that have started a STEM Degree in the Spanish academic environment. Actually, in our particular context, we may interpret this modest but unexpected increase in interest in teaching as an achievement of the service-learning strategy.

When asked whether service-learning should be introduced as a routine approach in their curricula and in which proportion, 16.66% answered that all credits, compulsory or elective, should be based on service-learning, 38.84% stated that half of them, 36.36% that one third, and 12.12% clicked on the option that only credits corresponding to elective subjects. No students chose the “none” option (see Supplementary Data). These results show to what degree the students appreciate the benefits of active learning and positively value their introduction in academic curricula. Nevertheless, as discussed previously (Farr, 2010, Stewart and Wubben, 2014), full implementation of service-learning methodologies for all students in one or several courses would be challenging, requiring adaptation of academic programs, sustainable funding and faculty support. As an alternative to this, in our pilot experience the participating

students either received an extra mark in their Microbiology courses or they were allowed to replace credits (2 ECTS) for another subject of their Degree or Master.

### *SWI assessment on pre-university students*

A total of 204 post-surveys were collected and analysed at high schools and the results are shown in Fig. 3. The planned service of our project (inspiration for STEM vocations and awareness about antibiotic resistance problem) was successfully fulfilled.

Remarkably, 81.37% of the students considered that participating in SWI enhanced their interest in scientific research (rating 4-5 points in both items, green colour in Fig. 3) and 87.25% claimed that it did improve their competencies in science. Regarding AMR awareness, 75.98% reckoned (4-5 points) that SWI provided them with deeper knowledge of the problem and 87.74% claimed to have improved their consciousness on the proper use of antibiotics. Most students, on a 1-5 scale, globally evaluated the project with 5 (52.94%) or 4 (39.21%). Moreover, 91.17% would recommend other colleagues participating in the program (score 5; 96.57% adding up those who scored 4 this item).

Similar service-learning projects involving microbiology undergraduates and high school students have been reported (reviewed in Webb, 2014). As in our experience, young pupils agreed that they had learned more about microbial diversity and antibiotic activity and resistance than they did in a traditional format. Additionally, all the school teachers were enthusiastic and grateful for the experience and requested to participate in following editions. A similar impact was described in other projects involving undergraduates and younger learners in which the teachers evaluated the methodology: 91 % of them considered worthwhile the effort and time and 100% said they would participate again (Abrahmsen, 2004).

On their free redaction on the best and worst features of the experience, high school students often cited as best: “participating in a real research project”, “direct contact with the SWITAs” and as the worst “the nasty smell of the cultures” and, most commonly, the frustration of failing to obtain positive hits in their particular antibiosis assay. This is also reflected in the low rating of the statement “Your results can contribute to scientific advances” in the survey (Fig. 3). The students interpreted this personally, manifesting their individual failure in finding antibiotic producers, rather than in the light of the value of joining hands to achieve a collective goal. This remarks the importance of communicating to students that they should be ready for failure as well

as for success when hypotheses are scientifically tested. Through the overall project, the ratio of preliminary halo-producing isolates was 1 suspect hit per 37 tested, meaning that in an average group of 24 students in 12 couples, testing 20 microorganisms per couple only one out of two couples would likely find a putative producer in a best case scenario. Hits should be presented as valuable collective findings, stressing the cooperative nature of the crowdsourcing strategy and anticipating that individual success in this sort of screen is a rare event.

### *Recollection and final celebration*

Of note, beyond learning and service goals of the project, SWIPs, SWITAs, high school students and teachers spontaneously spread SWI activities in social networks (SWI@Spain and schools Facebook and Twitter accounts, SWI@Spain blog), local papers, university and school webpages, or communication events. A very encouraging event was the performance of final celebration acts either individually at the schools or globally at the university with the participation of students from all high schools involved in the project.

When implemented in high schools, the get-together recollection act was of great pedagogical value, according to the appreciation of university and school teachers, visibly reinforcing the links between students of both levels. Thus, we decided to recommend including this recollection and communication challenge in the working schedule for future SWI service-learning interventions, and to make undergraduate students responsible for this activity, thus adding a new learning objective for them.

Finally, an all-actors “closure celebration” at the end of the service-learning activities is an occasion for new feedback among all the participants and an opportunity to recognize and acknowledge the work, appreciate the service and share the learning. Nicely, one of the “best-liked things” expressed by the school students was “meeting their SWITAs again”. Several groups of students spontaneously brought posters on their research to be exhibited at the hall by the gates of the conference room where the act was held. This will be encouraged in the future, as combining this “closing ceremony” with a symposium for SWI students should enhance its value in education. The title of the pilot SWI@Spain closing event, “Teaching the emotion of discovery: digging up future antibiotics” was indeed illustrative of the satisfaction of all participants with this experience.

## Conclusions

The adaptation of SWI to service-learning by integrating different education levels greatly potentiates its intrinsic value as an active learning-based strategy. Fully implication of undergraduate students on a service action was the key element for acquiring or reinforcing general or specific competencies and skills, which are more difficult to achieve with traditional teaching methods. For them, SWI combines the benefits of the program on their perception of research as a perspective for their own professional development with the communication experience and social responsibility of taking the program out of the campus and closer to society. For secondary/high school students, it brings a University-led international research project into their schools, starting a spark for scientific vocations that is lit by those who are the age of their older brothers and sisters, creating a unique creative environment for research. For both secondary/high school teachers and university members, it is an encouraging and valuable methodology to successfully train students and to engage academia and community. Thus, this is an excellent strategy from an academic point of view, but also successful for disseminating critical scientific ways of thinking, in particular on AMR awareness. The success of the pilot experience here described has prompted us to extend the initiative to other 20 universities around Spain in the frame of a SWI@Spain network that operates through the 2017-18 academic year, as well as to potentiate the dissemination to society by involving the students on the organization of AMR awareness symposia at high schools open to their communities.

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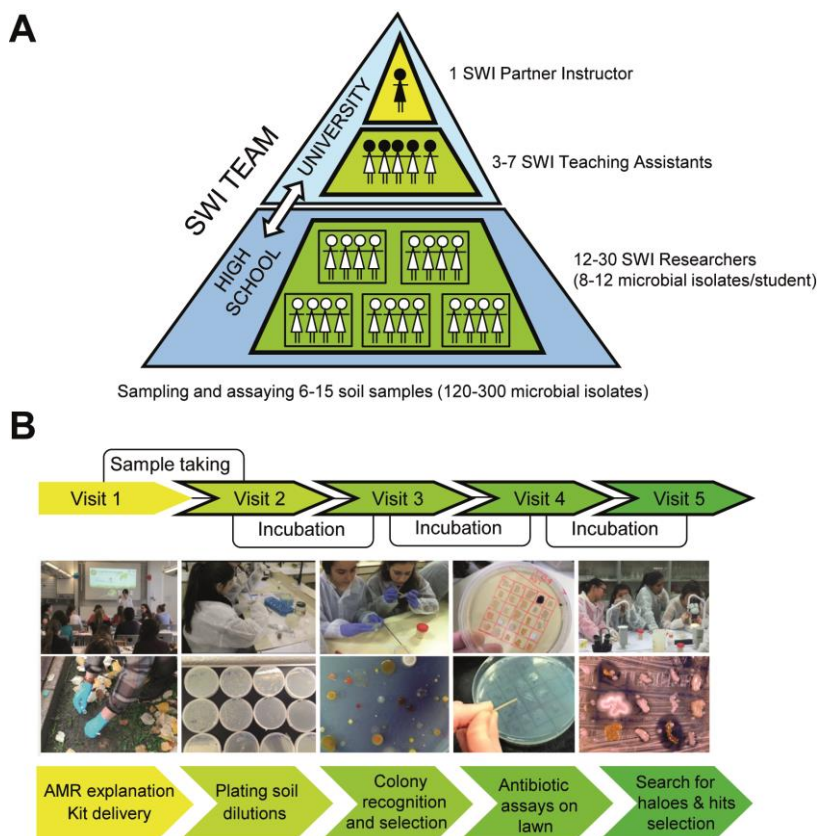
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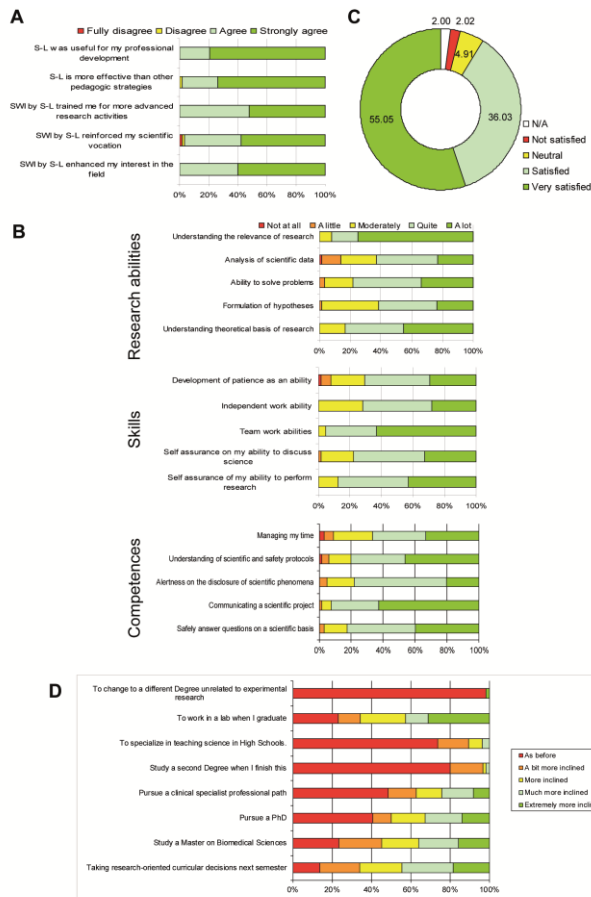
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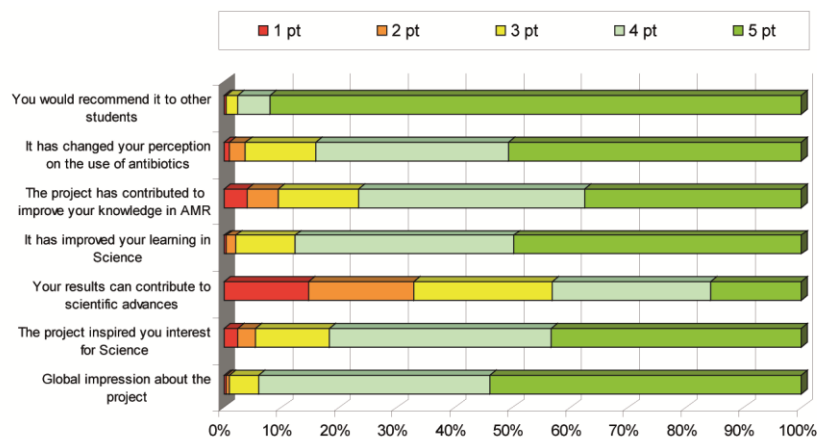


**Fig. 1. A. Hierarchic scheme of SWI implementation by Service-Learning.** One University SWI Team is led by a single SWIPI, responsible of the tuition of 3-7 Undergrads (SWITAs). In turn, when the team moved outside the campus onto a high school, each SWITA was in charge of 4 to 6 SWI young researchers in average. This hierarchy amplifies 5-fold on each step the operative ability of the team, while sharing and balancing responsibilities in the management and supervision of research. **B. Flowchart of the activities operated by SWI teams in secondary/high schools.** A chronological timeline of the five visits of the SWI team off-campus to its assigned secondary or high school and the main tasks carried on at each stage is shown. Sample taking was performed individually by the students through the weekend and incubations were done at the University labs. See Materials and Methods for details.



**Fig. 2. Summary of selected survey results on undergraduate students involved in the service-learning SWI experience.** **A.** General appreciation by the students of the contribution of SWI by service-learning (S-L) on particular formative aspects, as indicated in the legends. **B.** Answers of the students to selected items in the survey related to their acquisition of abilities, skills and competences during SWI by service-learning. Original full texts for questions were: rate the profits attained by your SWI experience in the following topics. Research abilities (upper graph): 1. Understand the relevance of research in my learning topics; 2. Analyzing scientific data; 3. Solving problems; 4. Formulating hypotheses that can be experimentally addressed; 5. Understanding the theoretical basis of a research project. Skills (middle graph): 1. Development of patience with the times demanded by experimental research; 2. Ability to work independently; 3. Ability to work collaboratively with other team members; 4. Self-reliance when discussing scientific topics with my classmates; 5. Confidence in my abilities to contribute to scientific discovery. Competences (lower graph): 1. Managing efficiently my time; 2. Understanding laboratory and biosafety protocols; 3. Alertness on

the disclosure of scientific phenomena; 4. Communicating scientific concepts; 5. Answer questions providing scientific arguments. **C.** Degree of satisfaction. Data are the average from 12 individual questions, related to particular aspects of the programme (organization and coordination of the project, relations with colleagues and faculty, suitability of equipment, safety, institutional support and availability of information). **D.** Evaluation of SWI impact on future career or academic decisions in SWITA students. The graph records the answers of the students to the question 'after the SWI by service-learning experience, how much more inclined are you to...'. All data are expressed in percentages, showing the preference of students for each answer (n=67). "Degree" refers to Bachelor Degree.



**Fig. 3 Summary of survey results on secondary/high school students.** Summary of data from 204 surveys collected from high schools. The percentage of each given score is indicated for each item. In the score ranking, 1 is the lowest and 5 the highest appreciation for each item. Full questions for the aspects summarized in the figure were the following (in order): 1. Would you recommend participation in this project to other colleagues or schools?; 2. This experience has changed your perception about the use of antibiotics; 3. Your participation in SWI has provided you with a better knowledge on the challenge posed by antibiotic resistance; 4. This project has improved your scientific skills; 5. You believe that your own results can contribute to scientific advance; 6. Your participation in the project has awakened in you interest or curiosity for Science; 7. Reflect your global opinion on the SWI project.

**Table 1.** Learning objectives of SWI by service-learning on undergraduate students related to the project activities programmed.

<b>Learning objectives</b>	<b>Main project activities linked</b>
<b>Research competencies and skills</b>	
Understanding the creative nature of research	All
Basis of antibiotic resistance and adequate actions to control it	-SWITAs training course -Preparation of the explanatory sessions for high schools
Understand the basis of a research project, scientific documents and protocols	-SWITAs training course -Preparation of sessions at high schools
Formulate hypotheses and develop experimental work, manage biosafety rules	-SWITAs training course -Sessions at high schools
Rigorously perform data collection, processing and analysis	- SWITAs training course - Group tutorials with SWIPI
Discuss and communicate science to different audiences	-Explanatory sessions at the high schools -Debate with other SWITAs, SWIPI, and high school teachers and students -Participation in scientific conferences
Answer questions with scientific arguments	- Debate with other SWITAs, SWIPI, and high school teachers and students -Participation in scientific conferences
Elaborate scientific documents	Participation in scientific conferences or divulgation events
<b>General competences and personal or social abilities</b>	
Self-organization and independent work	-Coordination of team activities -Preparation of explanatory sessions for high schools
Play roles and assume responsibilities	-Coordination of team activities
Collaborative work in team	All

Oral expositions in public	-Explanatory sessions for high schools -Oral presentations in congress
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