Design of a Science, Technology, Engineering, Art and Math (STEAM) program based on digital fabrication and Do-It-Yourself (DIY) philosophy focusing on health and humanitarian response in low income schools in Perú

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Abstract

The present paper shows the design of a Science, Technology, Engineering, Art and Mathematics (STEAM), which incorporate digital fabrication and Do-It-Yourself philosophy to make possible an effective scientific experience in public schools from vulnerable areas. This low cost STEAM education program is oriented to health and humanitarian response and has been designed based on the context of areas where the El Niño–Southern Oscillation event caused damage last year (2017). This novel program is called "H2STEAM" and is focused on the teacher training method to ensure the sustainability of its implementation. We believe that a humanitarian and health-oriented educational program will give students and teacher's knowledge and positive attitude to confront any challenge in their community, making possible an impact through collaboration toward climate change and social displacement.

1 Introduction

Currently, three million of Peruvians do not have access to safe water, while five millions do not access to improved sanitation [1], these facts become critic when El Niño–Southern Oscillation (ENSO) phenomenon take place, more severely in the Northern Perú. ENSO is a cyclic phenomenon and reaches Perú at December, currently it has been difficult to detect it in advance because of its anomalies. Local governments still have problems to implement prevention plans and the response to the environmental crisis is not efficient. Some of the ENSO effects are floods, mudslide, drought, in fact the climate changes. In addition, we have health risk related to this climate changes, such as vector-borne diseases, water-borne diseases, diarrhoeal diseases, as well, as social impacts such as evacuations of people, poor settle of emergency camps and deactivation of local economic structures. Carapongo is a county of one the most populated district in Lima, capital of Perú, which suffered in 2017 floods. The anomalous ENSO in this region caused the displacement of 200 families in emergency camps. Local schools were acting as donation centers for months and students were out from classrooms, most of them without the realization of the real cause of the disaster.

In this context, we develop a Science, Technology, Engineering, Art and Math (STEAM) program for teachers to improve the education in order to prevent health crisis and promote efficient response based

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on the Do-It-Yourself (DIY) philosophy and powered by digital fabrication. We believe that future generations with knowledge, technical and engineering skills will confront their challenges with more efficacy.

1.1 Do-It-Yourself (DIY) philosophy

The exploration and explanation of events through the scientific method is the core of the science development; for this purpose, expensive lab equipments and strict protocols are generally used in order to ensure standardization. However, it is difficult to replicate in low-income schools and poor communities. Since the 1990s, the DIY philosophy has been increasingly incorporated into digital technology, giving the opportunity to democratize knowledge, science, and technology to a broad population with multiple backgrounds. Nowadays, the scientific community is open to this DIY movement, and promotes school programs such as the iGEM (International Genetically Engineered Machine) competition.

1.2 STEM, STEAM programs

STEM is a well-known acronym for an educational program based on science, technology, engineering, and mathematics. The addition of the “A” corresponds to art, but what does the A stand for in STEAM? Several authors refer “A” to include the humanities in a way to teach empathy, ethics and citizenship. STEAM programs arise in a context to improve and put in value the interdisciplinarity, creativity, authentic or real-world learning, and project-centered thinking [2].

Selected programs in US are; Atoms & Molecules Workshops and DNA Workshops organized by MIT (Edgerton Center), USC Viterbi STEM Educational Outreach Program organized by University of Southern California (Viterbi School of Engineering), CAPSULE organized by Northeastern University and the Museum of Science, ASM teachers Camp organized by University of Illinois at Urbana-Campaign. Among STEAM programs, the SUCCEED (The Summer Center for Climate, Energy, and Environmental Decision-Making) is related to our H2STEAM program. It is a free summer program organized by Carnegie Mellon University, which its main goal is to improve the decision making for students entering 10th grade and K12 teachers. It consists of two sections: a five day workshop with approximately 20 students entering 10th grade, and a two day workshop with approximately 10 math and science educators. SUCCEED offers a variety of activities that include conventional classes, laboratory activities, field trips (e.g., thermal and nuclear power plants, a battery manufacturing facility), and other hands-on activities related to energy and climate change. Finally, teachers are able to prepare a better curriculum to be used in class [3].

Despite all STEAM programs available, it is important for developing countries to design their own program taking in consideration the concerns of public school administrators (infrastructure, resources and teachers skills). In Perú, in remote areas, teachers do not use computers to manage their class, and the infrastructure is precarious. Generally, low-income students present chronic anemia, tuberculosis, and are under the risk to contract malaria, dengue and other endemic diseases because of the precarious infrastructure and weak social structure in which they are involve. To overcome particular challenges of poor communities, we develop a suitable STEAM program to prevent health risks with education, technology and engineering skills based on the understanding of our social and environmental vulnerability. This program is called H2STEAM and its purpose is to strengthen the capacities of creativity, innovation, teamwork and resilience in low-income children and adolescents. To accomplish this, a new methodology for teaching science and technology at low cost is transferred to teachers of public schools. The program has three main objectives. The first is getting teachers master H2STEAM methodology, the second is getting teachers to implementH2STEAM workshops at school, and finally to influence on the importance of teaching science and technology in innovative ways. This program ensures that any schools in vulnerable areas can replicate it.

2 Methodology

There is a strong global tendency to include in the school curricula an approach of engineering and design, because they are considered fundamental for future work [4]. In this way engineering, design and prototyping skills like "digital fabrication", mainly 3D printing technology and DIY electronics, are taught as transversal subjects as an enabler across the curriculum.

Our methodology is based on problem-based learning and convergence education [8] in a way to be economically affordable for any schools in vulnerable areas. For this reason all the H2STEAM workshops are inspired by the DIY philosophy. The workshops are presented to students in a very reflexive way to develop empathy to communities in difficult circumstances through the multidisciplinary working team. Figure 1 shows a scheme of the H2STEAM program, all workshops pass through a DIY and low cost version powered by digital fabrication. All the program has a health orientation applied into a context of a vulnerable community in order to help them to generate a humanitarian response to face their local challenges.

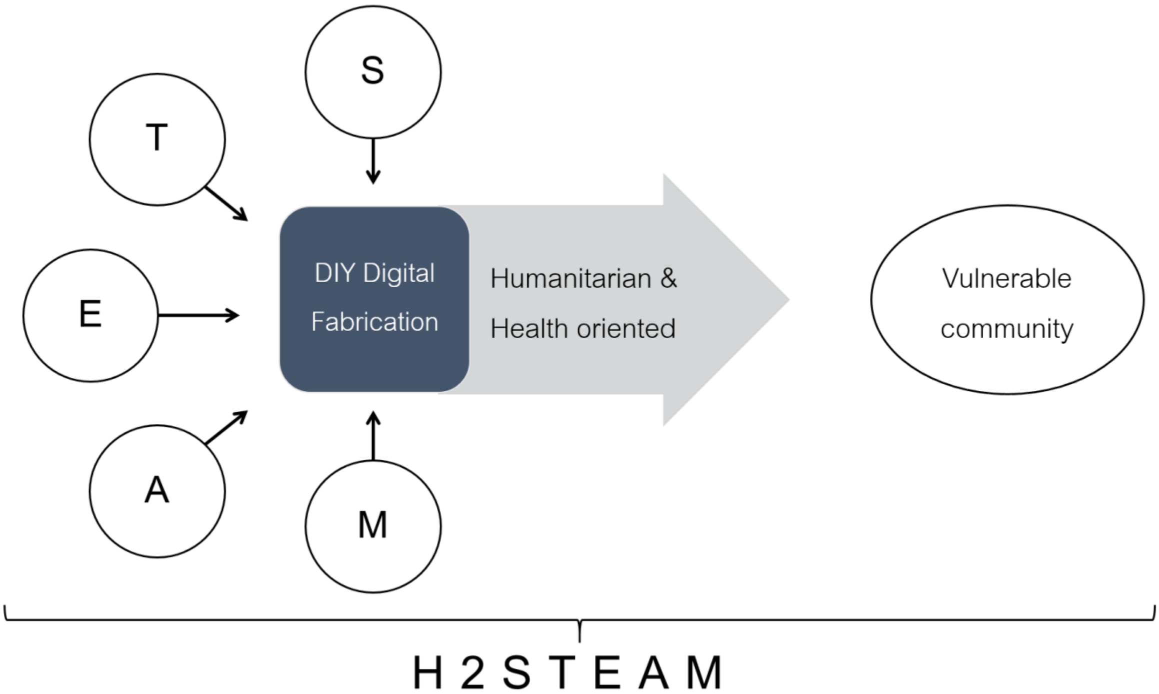

Figure 1: Scheme of H2STEAM program. Science (S), Technology (T), Engineering (E), Art (A), Mathematics (M).

The methodological approach consists in digital manufacturing trainings in which the participants learn 3D design and printing to build the laboratory equipments. And four science workshops in which participants will learn how to use their own designed lab equipment. All H2STEAM workshops will be oriented to local health risk (malaria). Figure 2 shows the methodology flowchart and Table 1 shows the H2STEAM workshops outcomes and goals.

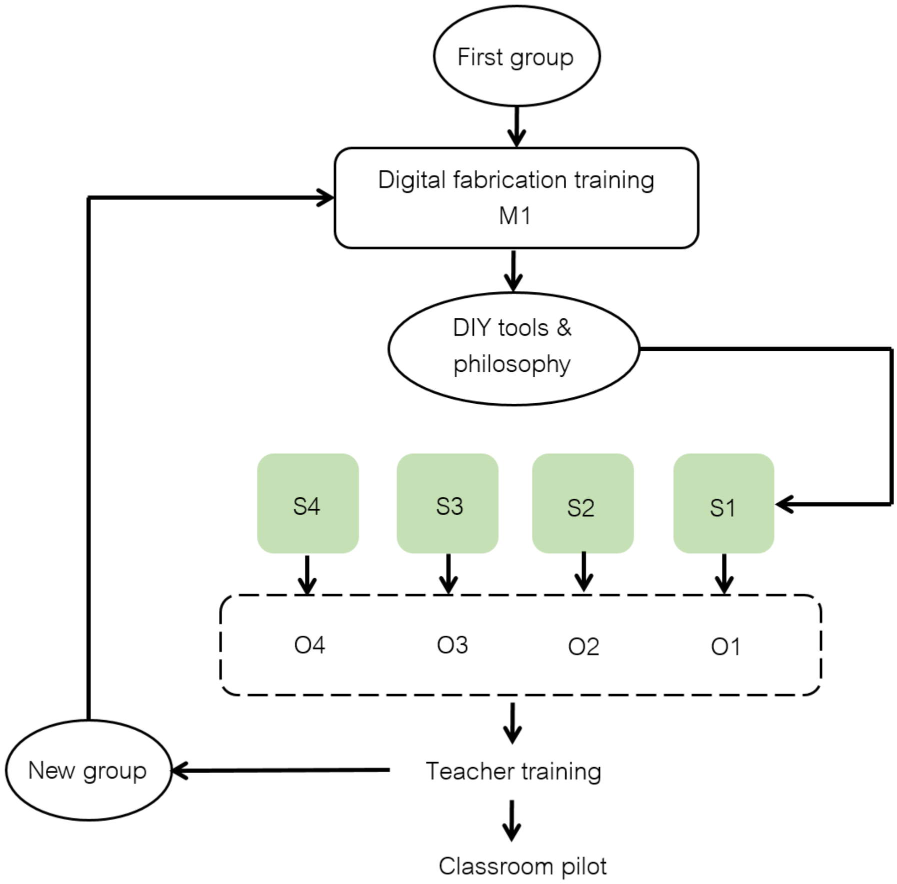

Figure 2: Methodology flowchart. Two types of workshops, maker (M1) and science (S1-4). Outcomes of the H2STEAM workshops are denoted as O1-4

Table 1. Summary of the workshops of the H2STEAM program.

	Workshop	Outcome	Goal
M1	Digital Fabrication	*Build DIY Tools & Equipment*	Introduce participant to 3D printing and basic electronics
S1	BioToys: mosquitoes as vectors of diseases	*Design and print the four stages of mosquito*	Understand the malaria transmission and identify its vector
S2	Microwords in our hands	*Petri dishes with samples of bacteria growing*	Understand the micro environment from surroundings
S3	How to glow the gene – luciferase case	*An interactive prototype of a biomimetic firefly*	Understand the bioluminescent and its application
S4	Learning phage technology with little bots	*An interactive prototype of bacteriophage - bacteria*	Understand the action of bacteriophage and its role in bioengineering

3 Results and discussion

The chosen public school to test the H2STEAM program is José Faustino Sanchez Carrion in Carapongo, which is located on the right bank of the Rimac river (Figure 3).Rimac river is one of the three main rivers of Lima. Carapongo had been and agronomical zone, but recent years because of the high demographic pressure of the city it has been occupied by rural immigration. There is scarcity of drinking water and sanitation, most of the families use aquifers and artisanal septic tank in order to get water and sanitation.

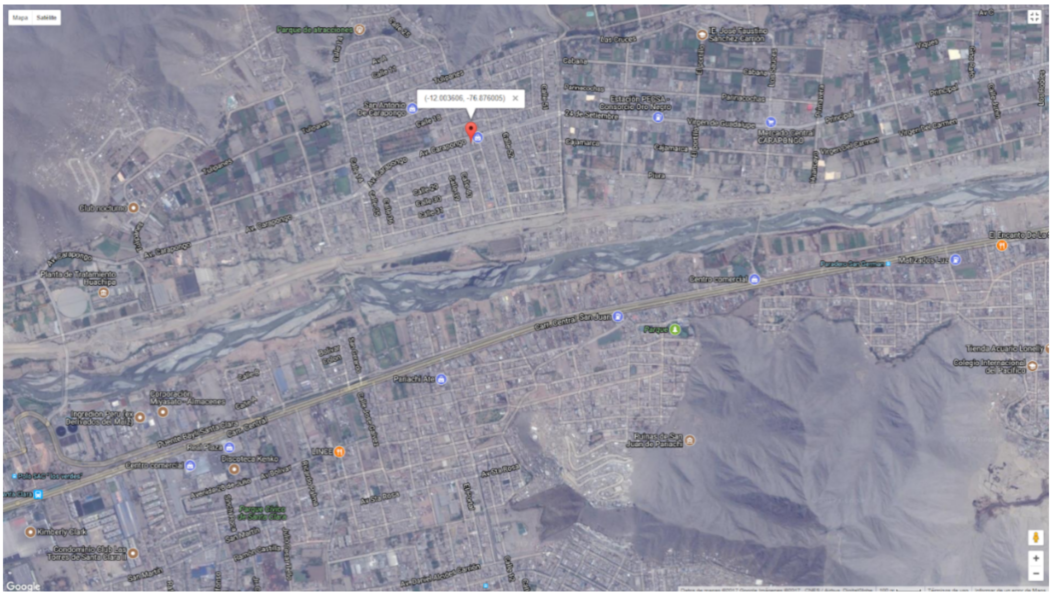

Figure 3. Satellite image of the area in which H2STEAM program takes place. The chosen school has the following coordinates: Lat -11.9894986 and Long -76.8681846.

In agreement with the administrator of the school, we select five science teachers to start the primary test. We design the H2STEAM program based on the teacher experiences through the workshops. The H2STEAM program consists in six days workshops (three hours each)in the same school science classrooms. The integration of the workshops are based on the resolution of a health problem, through the understanding of the problem and assessments of several biotechnology tools. They are project-based workshops, and students participate actively in teams. There are two types of workshops: maker and science. The concepts and the logic sequence of the workshops were under several cycles of internal evaluations. The edited workshops and their principal characteristics are:

3.1 Maker Workshops

Digital Fabrication (Technology / Engineering). In two sessions participants are able to construct their own lab equipment such as incubator, microscope, magnetic shaker and micropipette. We develop lab equipment using digital technology and basic electronic skills. These instruments will be used in the following science workshops, and students will be able to replicate them in time when they needed to extend the experience to the entire students. We deliver engineering and coding skills into science context. In this way, the 3D printing technology and DIY electronics are taught as transversal subjects as an enabler across the curriculum.

3.2 Science Workshops

Four workshops are developed in the way to introduce students to biotechnology in order to understand their applications to solve health issue. We center our attention to malaria because Perú has endemic cases and outbreaks arise during ENSO events (Figure 4). The chosen challenge is how to control the development of the malaria parasite, *Plasmodium falciparum,* in the mosquito midgut lumen [5].

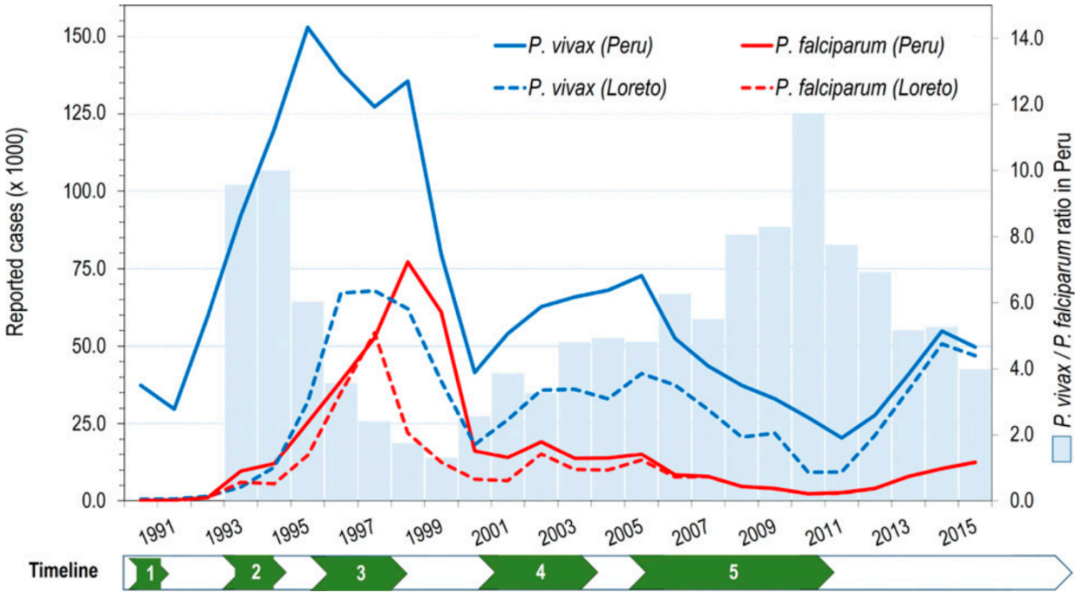

Figure 4. Annual reported cases by *Plasmodium* species in Perú and Loreto: 1990–2015. Information on annual malaria cases was obtained from the Regional Health Directorate of Loreto. Numbers in the timeline point out important events that influenced malaria incidence: 1) first report of *Plasmodium falciparum* in Loreto (1990); 2) first reports of chloroquine resistance (CQR) in *P. falciparum* (after 1994); 3) very strong El Niño Southern Oscillation (ENSO) phenomenon (1996–1998); 4) implementation of new antimalarial treatment policy for *P. falciparum* and *Plasmodium vivax* malaria (2001–2004); and 5) Global Fund-PAMAFRO project (2005–2010) [6].

Figure 5 shows the sequential of concepts delivered through the four science workshops. At the end, students will be able to understand the malaria transmission by mosquitoes and several biotechnology techniques which led to implement ideal solutions to overcome the health risk such as phage technology, engineered symbiotic bacteria and luciferase-labeled bacteria.

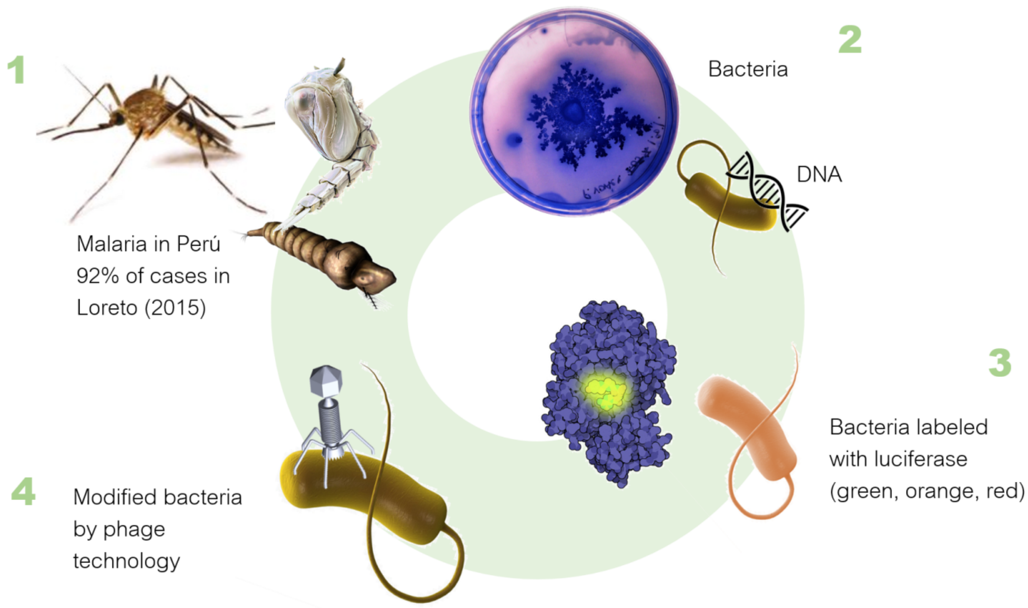

Figure 5. Integrated theme of the H2STEAM workshops. Workshops are BioToys: mosquitoes as vectors of diseases – Malaria case (1), Microworlds in our hands (2), How to glow bacteria: luciferin case (3),Learning phage technology with little bots (4).

3.2.1 BioToys

Mosquitoes as vectors of diseases – Malaria case (Science / Art).The main theme of this workshop is the *Anopheles* mosquito live cycle and the interaction of mosquito with pathogen parasites – Malaria case. The information will be delivered based on gamification. Students will model each stage of the mosquito cycle by groups and learn how to identify two types of mosquitoes based on their morphology differences (Figure 6 and Table 2). We use the digital fabrication to teach how infected female *Anopheles* mosquitoes transmit malaria. The design of mosquito will be modular, so we can use it as a morphology model to explain transmission of the human malaria parasite through the saliva during feeding.

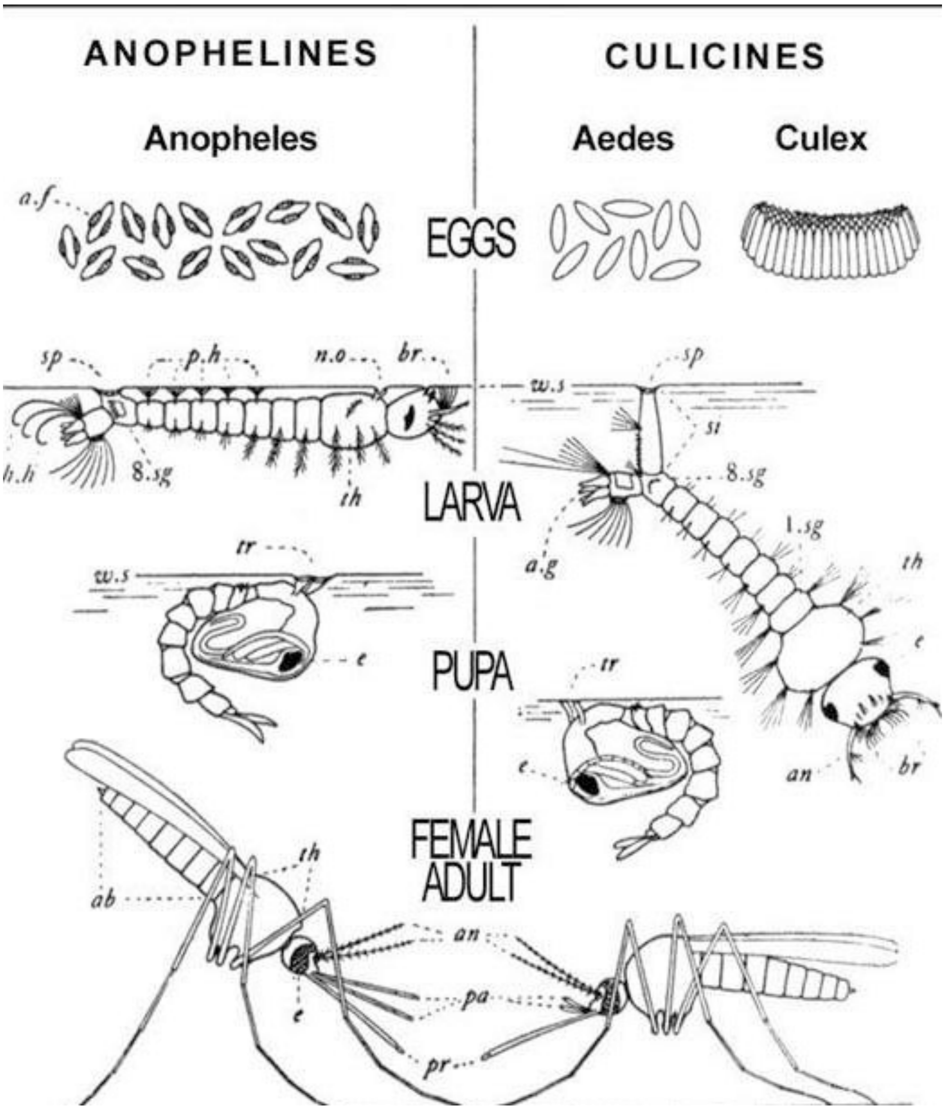

Figure 6. Morphological differences between anophelines and culicines mosquitoes in all their stages: egg, larva, pupa, and adult.

Table 2. Difference between Culex and Anopheles Mosquitoes

Stage	Culex	Anopheles
Egg	Vertically laid in clusters on the surface of the water	Singly and horizontally laid on the surface of the water
	Cigar shaped	Boat shaped
	Does not have lateral air floats.	Have two lateral air floats, helping to float.

	On dirty water	On clean water
Larva	Bottom feeder	Surface feeder
	The respiratory siphon is long	The respiratory siphon is short
	It forms an angle inside water	It remains parallel with water surface
Pupa	Colourless	Green
	The respiratory trumpets are long and narrow	The respiratory trumpets are short and wide
	The abdomen is less bent	The abdomen is more bent
Adult	Body is provided with stouter legs	Body is provided with delicate legs
	Wings are transparent and can fly for long distance	Wings are spotted and cannot fly for long distance
	There is presence of small palpi near proboscis	The proboscis and palpi have same length
	At rest body lies parallel to the surface	At rest body is inclined at an angle of 45º to the surface
	It transmits filarial parasite	It transmits malarial parasite.

3.2.2 Microworlds in our hands (Science)

The goal of the workshop is to understand that we are surrounded by microorganisms and also inside our bodies. In order to corroborate these premises, students take samples on agar plate based on their own curiosity. Finally, participants recognize how bacteria form colonies and how to look at them using the microscope and staining methods. In this science experiment workshop participants test their own assembled lab equipments (magnetic shaker, incubator and microscope). This workshop will bring the idea that it is able to engineer bacteria for our own benefits taking in advantage its reproduction rate, secretion system, and the symbiosis with other organisms. For the malaria control, symbiotic bacteria that naturally live in mosquito midgut are good targets [7]. In this context we will deliver the concept of anti-malaria effectors releasing inside the *Anopheles* mosquito using the secretion system of a particular symbiotic bacterium.

3.2.3 How to glow bacteria - luciferin case (Science)

It is common to use a bioluminescent proteins such as luciferase to label a modified organism. In this workshop students learn how proteins have bioluminescent property and how it is used in assays. They will be able to recognize this property in common examples as fireflies. The notion of bioluminescence is detailing while students build their fireflies bots as a model of study.

3.2.4 Learning phage technology with little bots (Science / Mathematics)

Transformation is a common technique to genetic manipulation in bacteria. It consists in the insertion of a particular gene through the infection of bacteriophages in a bacteria culture. In order to deliver the concept, the participants will create a functional set of phage – bacteria model, in which the genetic information reading is represented by the color changing RGB LED light strip when a sensor recognize the color of an object. This object represents the packed DNA from bacteriophage. The type of phage that participants learn by doing it is T4, which infects *E.coli* bacteria. The bacteria is represented by a domo, which is constructed by the join of two type of triangles (equilateral and isosceles), which dimensions are according to the diameter of the desired domo. All the electronic parts are settled inside the domo in a way that the LEDs on the surface of the prototype will change according to the color of an object when it enter into the domo.

The sustainability of the H2STEAM program in public school is based on the integration of the administrators in the program, we also train teachers not only in H2STEAM but also in the building of their own lab equipments. The DIY philosophy is reinforced through all the workshops to teachers and students. To a better training we offer all the materials and equipment needed to practice and build their devices. The donation of a basic DIY lab equipment set and 3D printer is offered to the school at the successfully end of training program. Figure 7 shows a bunch of photos of the H2STEAM workshops in Jose Faustino Sanchez Carrion School (classroom pilot).

A B

C D

E F

Figure 7. Compilation of photos of the H2STEAM workshops. 3D modeling process on computers (A), 3D printing of a designed object (B), Learning mosquito life cycle (C); 3D printing instructions (D); Bacteria sampling on agar plates (E), Learning phage technology based on bots (F).

Almost all STEAM programs in US are project-based learning model and some of these programs are organized by universities, which solve real-world problems solicited from local industry using the engineering design process. Our program is focused on community problems related to environmental crisis and encourage the integration of academic and technical skills to create possible solutions taking in consideration their own viabilities. In Perú, the schools curricula do not approach environmental and its consequences in human health risk by active learning. The lessons are mainly based on board and using traditional techniques (writing essays, compositions or highlight newspapers). There are STEM schools in Perú, but they are private and strong biased by the university admission examinations. The main focus on these schools are that students enter to universities and there is no room to explore, most of the lessons are from the examination contents and students practice standardized question types. On other hand, through H2STEAM program participants notice how the integration of academic and technical skills come together in a better understanding of a particular problem. They will connect several concepts and by the reinforcement of teamwork students will develop soft skills such as empathy, conflict resolution, and leadership.

4 Conclusions

The implementation of STEAM programs in low income schools is not an easy task even if it is free. Poor school infrastructures and low teacher salaries cause difficult to flourish innovation in class. We develop a program called H2STEAM to improve the way to teach science. This new program is inspired by the DIY philosophy in order to reduce the cost to experiment in class and is oriented to the health risk of the local community. The implementation of H2STEAM program will offer the opportunity to remote area in Perú inspire future generation to take STEM careers in a very responsible way, connected to the vulnerable community.

Acknowledgments

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