Digital Petri Laboratory: How Fab Labs and Interaction Design Can Support Microbiology in Raising Awareness About Antimicrobial Resistance

Matteo Subet, Ginevra Terenghi, Cristina Margarida Corti, Serena Cangiano

Matteo Subet, SUPSI University of Applied Sciences and Arts of Southern Switzerland, Switzerland
matteo.subet@supsi.ch

Ginevra Terenghi, SUPSI University of Applied Sciences and Arts of Southern Switzerland, Switzerland
ginevra.terenghi@supsi.ch

Cristina Margarida Corti, SUPSI University of Applied Sciences and Arts of Southern Switzerland, Switzerland
cristina.corti@supsi.ch

Serena Cangiano, SUPSI University of Applied Sciences and Arts of Southern Switzerland, Switzerland
serena.cangiano@supsi.ch

Abstract

Antimicrobial resistance (AMR) is a growing global health challenge primarily caused by the misuse and overuse of antibiotics. Raising awareness and promoting responsible antibiotic consumption using innovative methods is needed to combat this issue.

The Digital Petri Laboratory (DiPLab) project addresses this need by integrating Fab Labs and interaction design practices to create an open-source, hands-on learning tool for high school students. DiPLab offers a simulated microbiology laboratory experience where students can perform virtual tests to observe bacterial reactions to antibiotics. This interactive experience combines digital and physical elements, enabling students to understand bacterial behaviour and antibiotic responses without the risks associated with real laboratory environments.

DiPLab has proven effective in enhancing student engagement and comprehension of AMR through iterative design and user testing. The project demonstrates the potential of multidisciplinary collaboration in creating tools that raise awareness and make complex scientific topics accessible and engaging.

Future developments will focus on refining the device and expanding its application in educational and community awareness settings, underscoring the importance of innovative and experiential learning in addressing AMR.

Keywords

Antimicrobial resistance, microbiology, open-source device, hands-on learning, engage community

1 Introduction

Alexander Fleming's 1928 discovery of penicillin revolutionised the treatment of bacterial infections. This groundbreaking discovery, called antibiotics, encompasses substances that inhibit or eliminate bacterial growth. Made publicly available in 1945, antibiotics increased life expectancy by eight years, becoming the most widely used medication globally (Microbiology Society, 2015). During his Nobel lecture, Fleming warned about the cautioned use of antibiotics to prevent the development of resistance, which could render them ineffective (Fleming, 1945).

In recent years, particularly following the COVID-19 pandemic, Antimicrobial Resistance (AMR) has emerged as a silent pandemic, garnering global attention (Akram et al., 2023). The World Health Organization defines AMR as the ability of bacteria, viruses, fungi, and parasites to resist antimicrobial medicines (2023). According to Britannica (2024), antimicrobials are chemical agents that inhibit or destroy microorganisms. The most well-known antimicrobials are antibiotics, which are effective solely against bacteria. However, other antimicrobials can also combat viruses, fungi, and parasites.

The increase in antibiotic consumption in humans between 2000 and 2010 is alarming. Of the 36% more prescribed antibiotics, half are declared unnecessary (Van Boeckel al., 2014). Animal-related consumption data paints an even worse picture, with a projected 67% rise between 2010 and 2030 (Laxminarayan et al., 2016). AMR in humans is directly linked to food consumption, contact with antibiotic-treated animals, environmental factors, and globalisation facilitating worldwide transmission (WHO et al., 2016). Projections indicate that AMR could cause 10 million annual deaths by 2050, potentially surpassing cancer as the leading cause of mortality worldwide (Review on Antimicrobial Resistance, 2014).

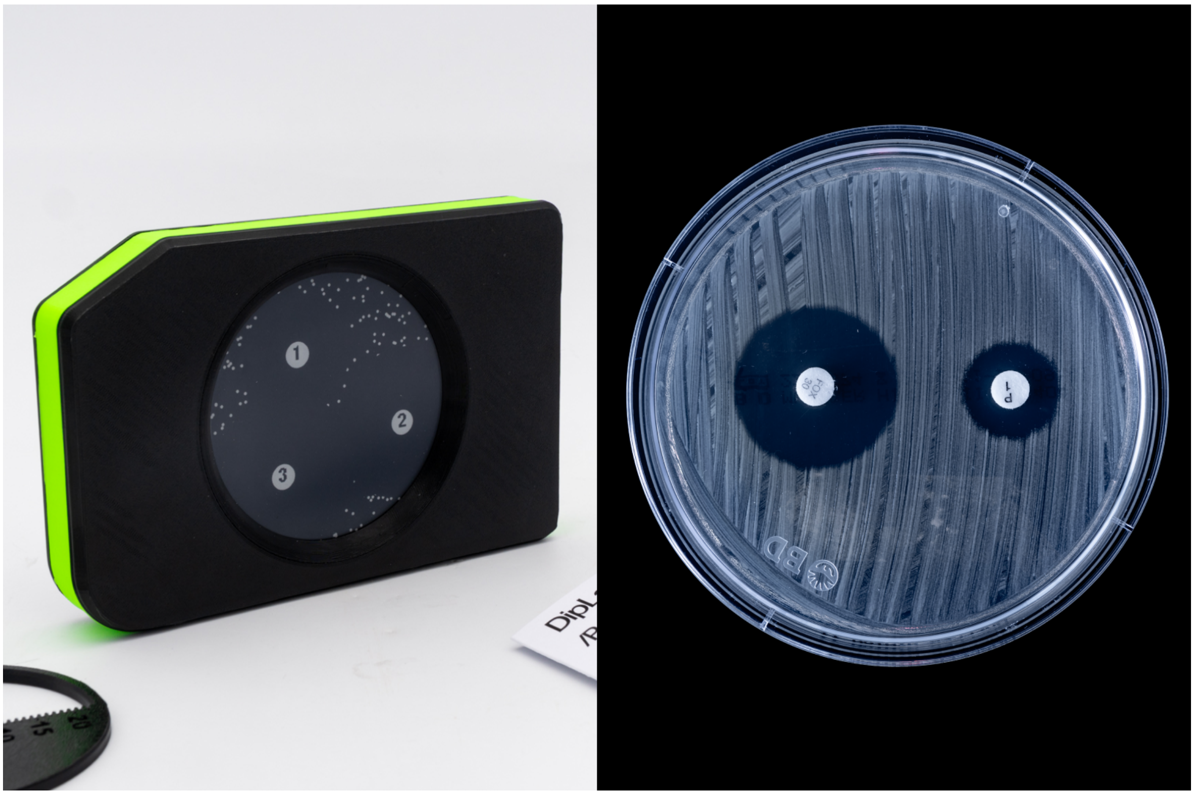
As the World Health Organization, World Intellectual Property Organization, and World Trade Organization (2016) suggest, addressing this silent pandemic requires a multifaceted approach, including stewardship, innovation, and access to information. They emphasise education on the theme as a crucial component alongside antibiotic distribution, prescription, and diagnostic measures. This project focuses on raising awareness of antibiotic usage and the issue of antimicrobial resistance among young citizens to preserve the already-known antibiotics.

This paper explores how Fab Labs can utilise an open-source, multi-modal device to raise AMR awareness among high school students. It provides a comprehensive overview of the project, detailing the design process model for the device and associated workshop, technical aspects of the product, and key findings.

The Digital Petri Laboratory (DiPLab) is an interactive experience that integrates interaction design and microbiology to address the critical issue of AMR. This paper proposes an innovative approach to increasing awareness of complex scientific topics through an interactive activity implementable in Fab Labs worldwide using readily available equipment. While hands-on activities effectively promote awareness, conducting such activities in microbiology laboratories presents challenges due to space constraints, safety protocols, and health-related accessibility issues.

DiPLab tackles these issues by offering a digital product replicating real-life scenarios, allowing the community to engage with the subject matter without the risk of accidental exposure to contaminants in a physical laboratory. Specifically, the platform simulates the process of cultivating bacteria and conducting tests to determine the effectiveness of antibiotics, such as the Kirby-Bauer test. This test, also known as the disc diffusion test, is used in laboratories to assess how well different antibiotics work against bacteria. The presence or absence of a zone of inhibition around the antibiotic disc indicates whether the bacteria are susceptible - or resistant to the tested antibiotic. If the antibiotic kills or inhibits the organism, there will be no growth around the disc. On the other hand, if the antibiotic concentration is insufficient or the antibiotic is ineffective against the bacteria, growth will be observed around the disc.

Figure 1: the DiPLab device and petri dish for conducting the Kirby-Bauer test. Image courtesy of MAKEAWARE CC BY 4.0.



2 Project Framework and Methodology Applied

2.1 Onboarding non-experts on scientific topics and related projects to DiPLab

The development of DiPLab is supported by the SPEARHEAD (Swiss Pandemic & AMR - Health Economy Awareness Detect) project, funded by Innosuisse, the Swiss Innovation Agency. Initiated by the University of Basel, this project involves a consortium of 12 research and industry partners, including the University of Applied Sciences of Southern Switzerland (SUPSI). SPEARHEAD focuses on the critical issue of Antimicrobial Resistance (AMR), with particular emphasis on Urinary Tract Infections (UTIs), one of the most prevalent AMR-related conditions. Within this context, the design suggested a framework for experimenting with diverse practical activities to enhance awareness of AMR (Cangiano et al., forthcoming).

MAKEAWARE, the subproject led by SUPSI, aims to collect patient-led data to provide a more comprehensive understanding of the current AMR situation. The project employs two digital tools to gather narratives related to antibiotic usage and UTIs. An anonymous questionnaire enables participants to generate personalised data pills in circles, displayed on the MAKEAWARE website, which also features a tool for collecting written stories. Additionally, the subproject supports three distinct workshop formats designed to engage citizens in practical exploration of AMR issues.

The first workshop, Visualizing the Resistance, provides citizens access to a real microbiology laboratory, allowing them to observe cultivating bacteria with various antibiotic treatments. Participants completed a questionnaire by utilising actual Petri Dishes and live organisms. Their responses are then correlated to generate inhibition zones, which depict areas where bacteria cannot grow when exposed to antibiotics they are susceptible to. This phenomenon is commonly referred to as "the zone of inhibition." This workshop emphasises adherence to laboratory protocols and safety measures (Terenghi et al., 2024).

The second, Perturbant Fluids, led by Zoe Romano, introduces participants to scientific protocols and tools through the microscopic examination of crystallised tears.

The third workshop is made possible by the DiPLab presented in this contribution. The project, as stated, aims to raise awareness among high-school students on antimicrobial resistance beyond laboratory settings, engaging a broader audience through its accessibility and lack of specialised requirements. The experience, which takes inspiration from the results of the Visualizing the Resistance workshop, is designed to let users experience the Kirby-Bauer test in a digital environment by using a product and their smartphones to create their own fictional laboratory setting.

All these diverse workshop formats aim to increase public awareness and understanding of AMR through hands-on, interactive experiences tailored to different audiences and settings.

2.2 Needs and issues related to laboratory accessibility

Hands-on activities play a crucial role in demonstrating the interactions between antibiotics and bacteria to address the intangible nature of antibiotic resistance and enhance public awareness. The workshop Visualizing the Resistance aims to replicate a standard microbiology laboratory procedure: The Kirby-Bauer test. This procedure is essential for identifying resistant bacteria and determining antibiotic efficacy, as it assesses which antimicrobial agent is most effective in treating a patient's bacterial infection (Hindler & Munro, 2024).

The practical implementation of antibiotic testing involves several components: a petri dish with an agar base serving as a growth medium for bacteria, a specific bacterial to inoculate, and a set of antibiotic discs to test. The World Health Organization (2003) has published comprehensive guidelines detailing the precautions and standards for accessing and operating within a microbiology laboratory that handles antibiotics. These guidelines encompass general safety measures such as hand hygiene protocols. Furthermore, they stipulate access restrictions, prohibiting entry to individuals not trained in laboratory safety protocols and procedures.

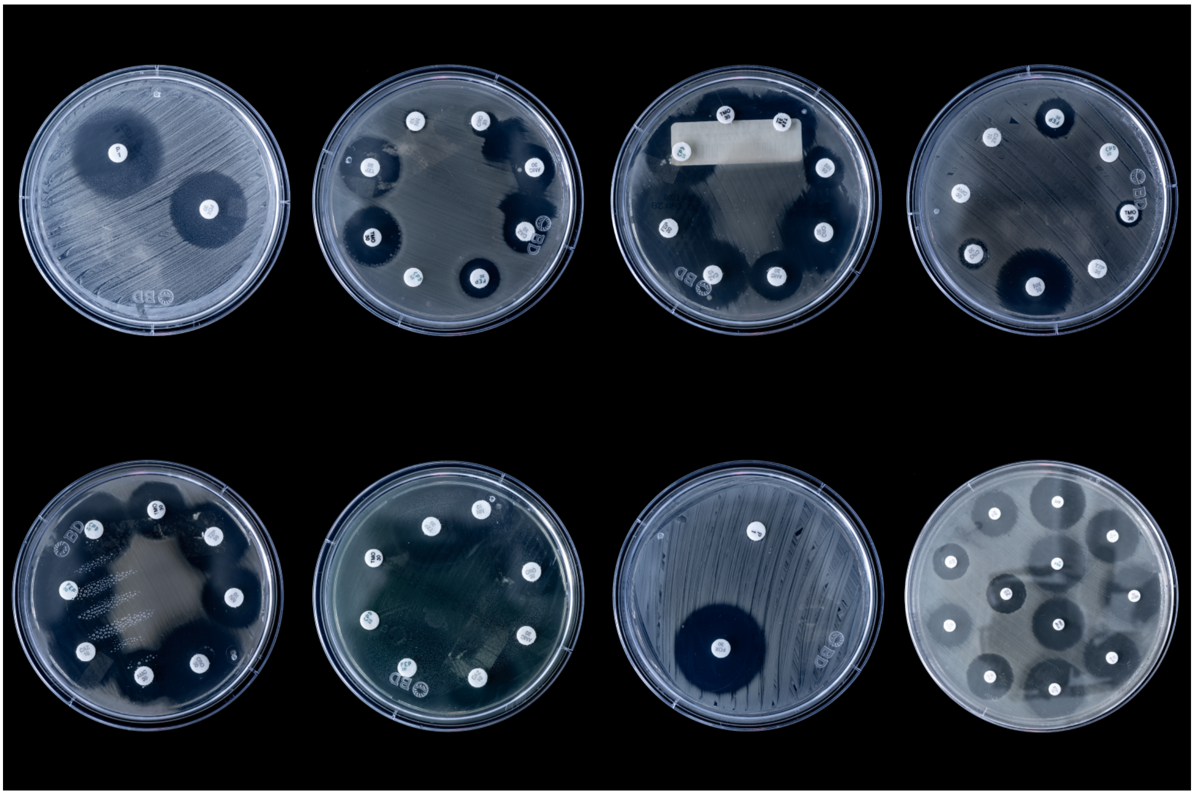
Facilitating workshop participant access to a microbiology laboratory presents significant challenges, requiring multiple preparatory steps and the presence of highly trained laboratory personnel for supervision. The experience gained from the Visualizing the Resistance workshop highlighted several difficulties regarding participant accessibility. Each workshop requires careful attention to safety information, as most participants have no experience in a microbiology laboratory setting. Additionally, restrictions must be implemented for individuals who are unwell or immunocompromised.

Ensuring proper laboratory access also requires attention to participants' dress. All individuals entering the laboratory must wear Personal Protective Equipment (PPE), including a lab coat, gloves, and safety goggles, which must be worn throughout the workshop, with particular vigilance during the direct handling of antibiotics and bacteria.

It is important to note that the materials used in the workshop, including antibiotic discs, bacterial cultures, and agar bases, pose potential risks to handlers. While workshop facilitators strive to minimise these risks, all participants must know the inherent dangers.

Additionally, the Kirby-Bauer test requires a minimum 24-hour incubation period before results can be observed, meaning participants cannot view immediate outcomes but must rely on subsequent imaging. Furthermore, antibiotic testing generates biohazardous waste requiring specialised disposal methods.

Figure 2: different petri dishes with Kirby-Bauer test completed. Image courtesy of MAKEAWARE CC BY 4.0.



2.3 Application of a Design Process Model to raise awareness of AMR

The Digital Petri Laboratory experience development adheres to the Design Thinking methodology proposed by the Interaction Design Foundation (2016), comprising five iterative stages: Empathize, Define, Ideate, Prototype, and Test. This approach was adopted as part of an Interaction Design thesis project, following the process outlined by the Interaction Design Foundation (IxDF).

The selected Design Process Model is iterative and non-linear, placing the user at the centre of problem-solving and innovation through prototypes generated after user testing. This approach aims to create tailored solutions for the target user (IxDF, 2016). The model stages allow for iteration at each step to delve deeper into each phase, even after the testing.

Each phase serves as a crucial source for designers to craft a user-centred project:

- Empathize: The design journey typically begins with a research phase focusing on user needs and problems, which helps designers explore the research framework.
- Define: Insights gathered from the previous stage are analysed and synthesised to converge on a more defined scenario that better represents the current state of human-centred problems and needs.
- Ideate: With the project foundation established, designers can better define project ideas, diverging from traditional solutions for the target user.
- Prototype: This stage is generally divided into different sub-steps, ranging from raw paper prototypes to high-fidelity products. This step often requires multiple iterations with the testing phase to refine the project.
- Test: As the overall model is human-centred, testing the solution developed in the previous stage is fundamental to acquiring a deep understanding of the interaction between users and the designed solution.

Given this theoretical background, the development of the DiPLab experience began with the thesis project "DiPLab – An Interactive Multimodal Experience to Involve Young People in Learning about Antimicrobial Resistance" (Subet, 2023).

The thesis project started with a comprehensive review of projects and literature in interaction design, microbiology, and citizen science. Multiple relevant case studies were identified, helping to better define the current state of the art in these domains.

The mapping of existing projects in similar domains was categorised into three distinct groups:

- Physical kits serve as activities to introduce participants to science-related topics.
- Projects requiring a hands-on approach for users to experiment with the topic.
- Digital experiences where researchers share specific topics using various methods to raise awareness among participants about a particular scientific subject.

This structured approach to research and development ensures a comprehensive understanding of the field and provides a solid foundation for creating the DiPLab experience.

The POST/BIOTICS project (Vidhi, 2016) is a tangible kit designed to enable users to discover new antibiotics using materials from their surroundings with antibacterial properties. This project adopts a citizen-science approach, allowing non-researchers to contribute to scientific research by generating new data. These data are shared in a communal database accessible to microbiologists and scientists working on antibiotic development. The kit includes various test plates and tools for sample collection, which can be read wirelessly using an Android phone and subsequently uploaded to the shared database. POST/BIOTICS is particularly relevant as it allows participants to simulate the role of a scientist while contributing to scientific research.

My First Biolab (Fein, 2020) is another tangible kit that provides a laboratory experience in a box. It enables users to grow living organisms in a school without needing a microbiology laboratory. To comply with safety regulations, the product uses bags containing two layers of polyacrylamide polyethene sealed with a laser-cutting machine to contain living microorganisms. Users interact with the microorganisms only from the outside of the bags. The system is activated via an app, allowing users to analyse data collected by sensors within the box.

Simply Science (https://www.simplyscience.ch/) is a Swiss foundation that encourages young people to engage with technology and scientific topics. The foundation's website features various news articles and experiments that can be conducted at home or school. The experiments are categorised based on the target user's difficulty level, required tools, and prior knowledge. Each experiment has a dedicated webpage detailing the procedure, necessary materials, and expected outcomes. This project is notable for its ability to make scientific topics accessible without requiring prior technical knowledge, thereby promoting a hands-on approach to learning.

Biota Beats (Kim et al., 2020), an experiment created by the MIT Media Lab, aims to disseminate microbiology among participants, specifically the symbiotic relationship between humans and bacteria. The experience involves participants collecting bacteria using a swab, which is then grown in petri dishes. The growth patterns are analysed using an algorithm that converts them into musical beats. This innovative approach allows participants to visualise and understand the diversity of bacteria in different parts of the human body.

From a theoretical perspective, the literature was analysed to understand antimicrobial resistance and its effects better, the role of citizen-science projects in enhancing public knowledge of scientific topics, and the importance of microbiology in our world.

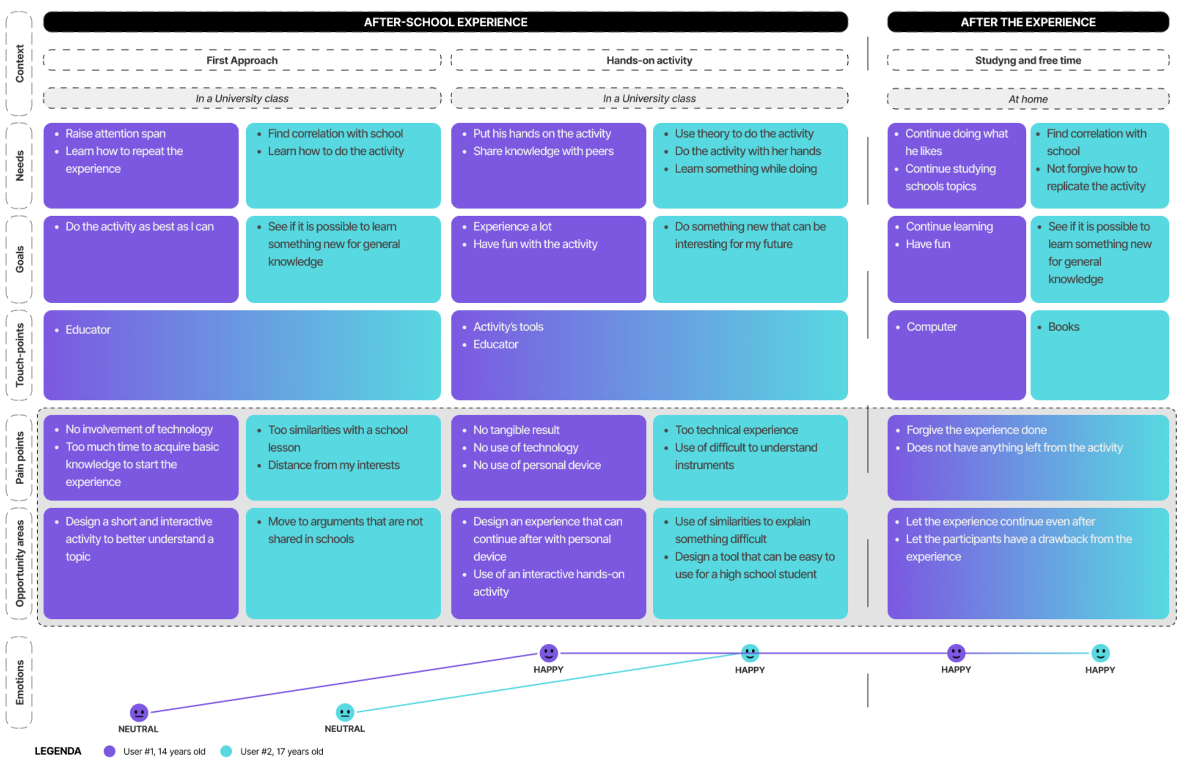
The research highlighted the potential of utilising experiential and STEM activities to disseminate scientific content in non-scientific contexts, such as public events. A significant challenge identified was the difficulty in communicating knowledge in microbiology. As Scavone et al. (2019) suggest, there is a need for more precise and engaging communication methods in microbiology to raise awareness on specific topics such as AMR.

To address these challenges, user research was conducted to understand better the needs of the target audience, specifically teenagers, and to gain insights from experts in science dissemination regarding effective methods for raising awareness without alarming the target users. Teenagers were interviewed to discuss their learning preferences and interactions with scientific topics. The main findings indicated a preference for hands-on activities over traditional theoretical lessons, as practical engagement facilitates a better understanding of complex topics. Additionally, maintaining focus during scientific classes proved challenging for those less interested in the subject matter due to limited attention spans. However, engagement in practical activities significantly increased their focus. Furthermore, there was a high appreciation for digital support and interactive digital tools in learning scientific subjects, as these tools sparked interest and leveraged the technological familiarity of the target audience.

From the disseminators' perspective, simplifying complex scientific topics without compromising accuracy or omitting crucial information was emphasised. Disseminators suggested focusing on fundamental concepts and providing tools for further exploration. Additionally, using real-life examples and emotional engagement was highlighted as an effective method for enhancing information retention. For instance, an interviewed expert shared his way of explaining electromagnetic waves by first discussing how radio works, thereby constructing a joint base of understanding between the experts and students.

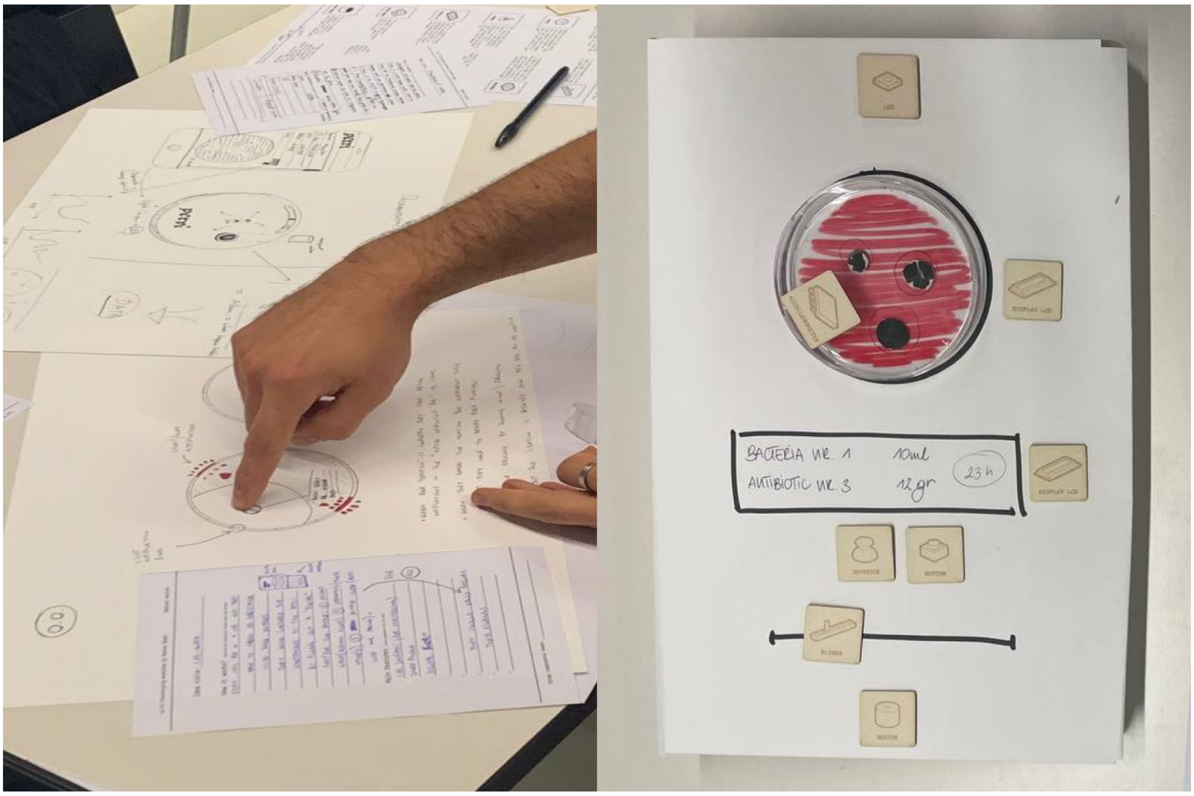
The initial phase outcomes were analysed in the define stage, leading to the development of two user archetypes and a user journey map. The first user target is a student interested in scientific topics but unaware of AMR who prefers experiential learning and short lectures. The second is a less interested student in science but uses interactive tools to study and memorise information for exams. The user journey map analysed each step of a student's school day and after-school experience, focusing on the after-school period as an opportunity for designing short, interactive activities to enhance understanding of scientific topics.

Figure 3: user journey map of an after-school experience. Image courtesy of MAKEAWARE CC BY 4.0.



The concept development phase resulted in the idea of a digital tool simulating a petri dish and laboratory experience of an antimicrobial test. This approach aims to help students better understand bacterial behaviour and antibiotic interactions, providing a more precise comprehension of the main factors in AMR. Following developing an initial cardboard prototype, the project was presented at the Junior Design Research Conference (Subet, 2022). A workshop with design students from various Swiss master's programs allowed to test and validate the experience through the co-design of derivative concepts and prototypes.

Figure 4: workshop at the JDRC at Basel, 2022. Image courtesy of MAKEAWARE CC BY 4.0.



The first interactive prototype was developed based on interviews with experts and students, the analysis of the state of the art and literature and the result of the validation workshop, incorporating an electrical board, buttons, and an accelerometer sensor. User testing with target users was conducted to evaluate and refine the experience. Currently, DiPLab is in its third iteration, having undergone multiple user testing sessions with students, microbiology experts, and science dissemination professionals. Two workshops were conducted with students during the TecDays in Switzerland, further refining the experience.

This iterative process of development, testing, and refinement demonstrates a commitment to creating a user-centred, effective tool for engaging high school students with the complex topic of antimicrobial resistance.

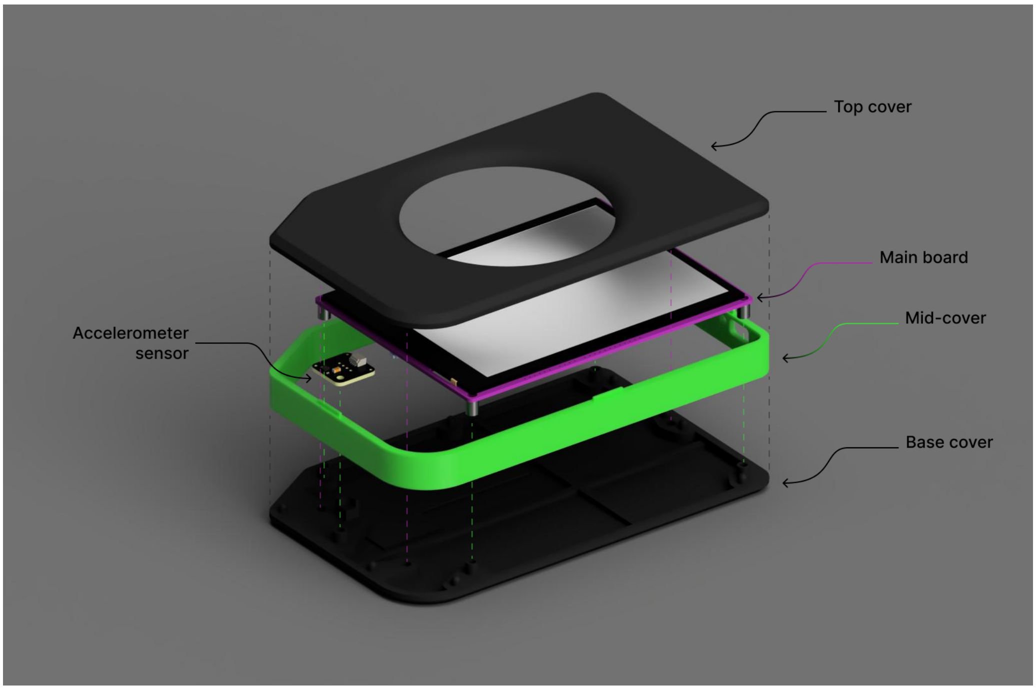
Figure 5: the three versions of DiPLab, the Beta Version (top-left), the first version (bottom-left) and the actual version (right). Image courtesy of MAKEAWARE CC BY 4.0.

3 Development of an Experience to Raise Awareness on AMR

3.1 Multimodal Device to Simulate a Microbiology Laboratory: DiPLab

The device comprises three primary components: the board, the cover, the data, and the software.

Figure 6: the DiPLab 3D model exploded. Image courtesy of MAKEAWARE CC BY 4.0.



The current version of the Digital Petri Laboratory is built around a board designed by Soldered Electronics, specifically the INKPLATE 6 PLUS. This board was selected for two main reasons: the inclusion of the ESP32-WROVER-E microprocessor and the availability of an e-ink display with touchscreen capabilities. The microcontroller is essential because the Digital Petri Laboratory is envisioned as an access point capable of storing the entire application, which can then be shared with a connected smartphone. The Wi-Fi module facilitates both data reception and transmission. Additionally, the microprocessor can efficiently manage the e-ink display and its touchscreen functionality, providing a reasonable response time for user interaction. This touchscreen capability replaces the buttons used in the initial interactive prototypes, enhancing user interaction with the device.

The board is equipped with several other components, including a battery connector for lithium-ion batteries with charging capabilities, an easyC connector linked to the microcontroller's I2C port, a microSD card holder, unused in the current prototype, and a CR2032 battery holder for the real-time clock, also unused.

Figure 7: the electronic board used to develop the actual version. Image courtesy of MAKEAWARE CC BY 4.0.

A crucial component of the prototype is the accelerometer, which is integral to the current design of the experience. This custom-made component connects to the easyC connector without requiring additional soldering, based on a LIS3DH sensor permit to collect data on the device’s movements, allowing interaction with the device. The choice of this board was further justified by its open-source nature, with all hardware details, including gerber files, bill of materials, and pick-and-place files, available on the Soldered GitHub page (Soldered Electronics, 2021).

Figure 8: the custom-made accelerometer board in comparison to half of a Swiss franc. Image courtesy of MAKEAWARE CC BY 4.0.

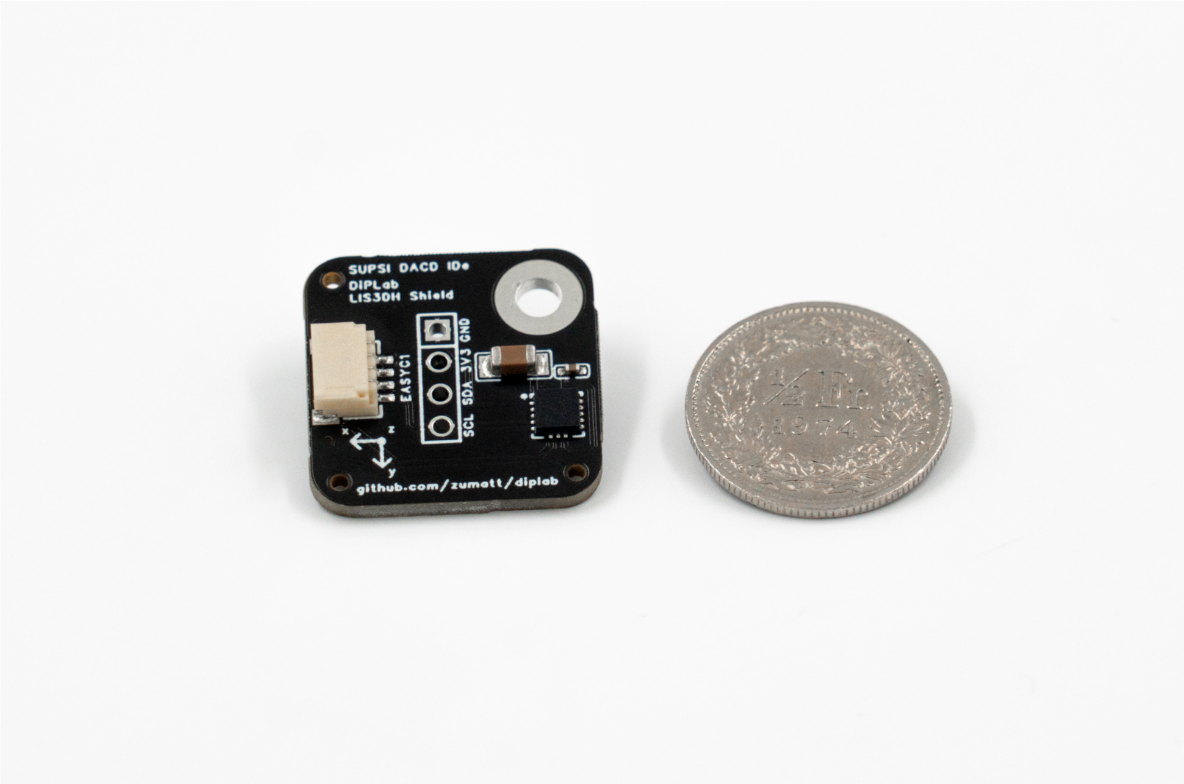
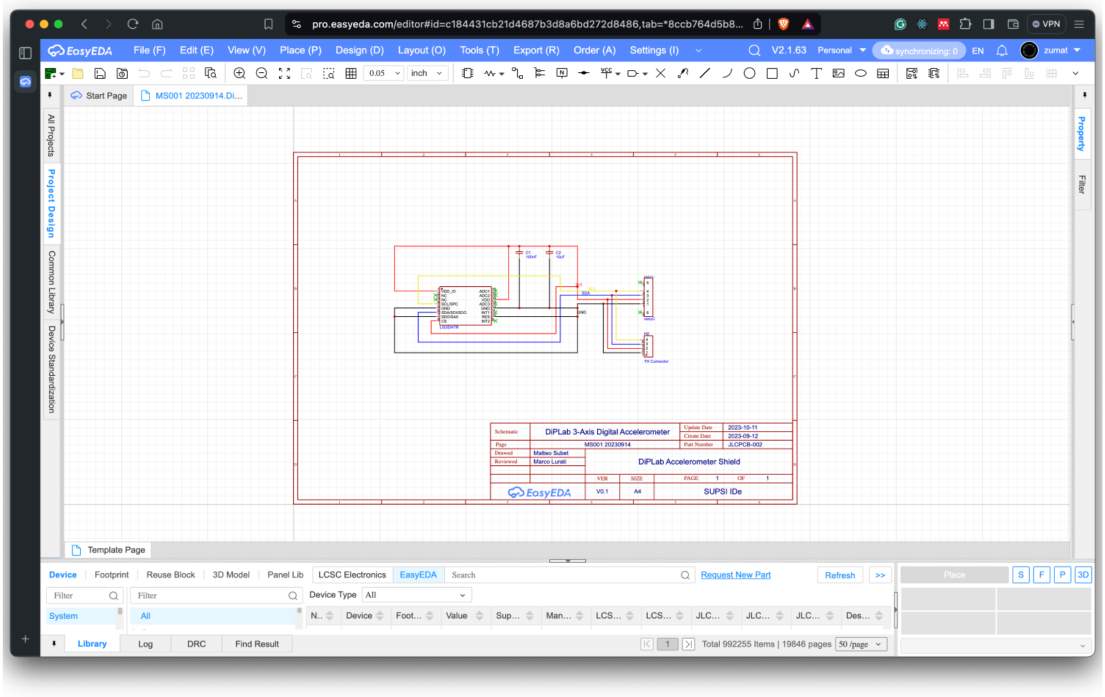


Figure 9: the custom-made accelerometer board schema. Image courtesy of MAKEAWARE CC BY 4.0.



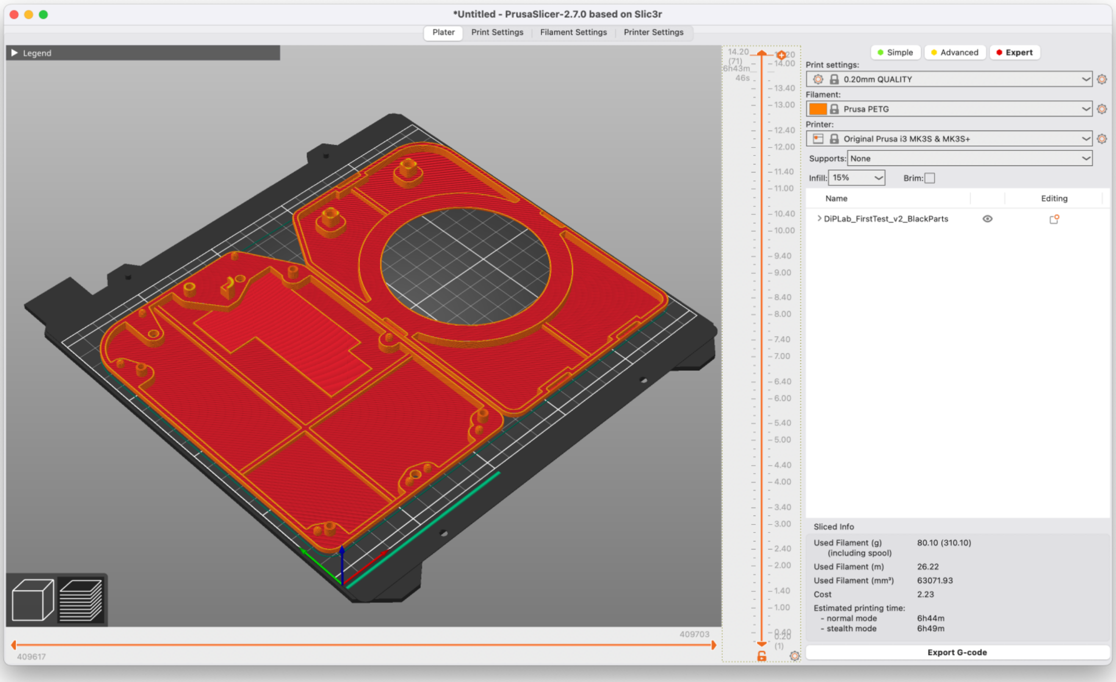
The product design revolves around the board, resulting in two distinct designs that differentiate the product versions. The initial prototype for the thesis project was based on an older, larger PCB design.

When the current version was developed for four different devices, there was the need to buy new boards, and it was discovered that the product had changed in a smaller factor. This facilitated the creation of a new version with various improvements, including enhancements to the product itself. The current product features a 3D-printed case housing the two boards that power the DiPLab, incorporating specific features to enhance user experience and streamline fabrication. The design allows users to view only a portion of the screen, representing a real-size petri dish on the e-ink display. The angled corner ensures participants can use the device from the correct viewing angle without specific instructions.

Figure 10: the first (top) and actual (bottom) version of the DiPLab. Image courtesy of MAKEAWARE CC BY 4.0.

From a fabrication perspective, the object is designed to minimise material usage and printing time. Multiple iterations were conducted to achieve a design that allows a single device to be printed in approximately 7 hours for the top and bottom parts and around 3.5 hours for the mid-cover and coloured parts. The device is split into two parts, enabling the manufacturer to assemble them using super glue at four points, creating a single piece. Three anchor points connect the top to the bottom, where the two boards are secured. The main board is anchored at four points, while the accelerometer board is secured with a single screw and nut. Pins were added to the bottom to facilitate assembly and ensure proper alignment with the top part, reducing assembly time and potential errors. The choice of materials and colours is flexible, allowing customisation based on preference. The current version uses PETG for the top and bottom covers and PLA for the central part, chosen for its superior finish on larger horizontal surfaces, giving the product a more commercial appearance.

Figure 11: the slicing of the DiPLab cover done with PrusaSlicer. Image courtesy of MAKEAWARE CC BY 4.0.



The current version of the Digital Petri Laboratory, available on GitHub (Subet, 2023), is designed based on the workshop experience detailed in the subsequent chapter. The software is entirely written in C++, utilising a modified library for the INKPLATE 6 PLUS to exclude the microSD capabilities. This modification was necessary to accommodate the libraries required to run an access point for hosting the application, which conflicted with the INKPLATE 6 PLUS library. The web app is uploaded in the Electrically Erasable Programmable Read-Only Memory (EEPROM).

The software operates on a code written using state machine logic, with an API enabling precise control of each board component. Communication with the phone is managed via an asynchronous web server and a web socket on two different ports. The first exposes the web pages to the phone, allowing the user to view the application, while the second facilitates user interaction with the webpage, awaiting events. Each event is recorded using a JSON file created by the webpage for each event. Actions on the app trigger feedback on the webpage and send commands to the board.

From the board's perspective, each state includes different drawings on the e-ink display to show the user interface and other actions to enable the interactiveness of the device, such as reading accelerometer values to spread bacteria and using touch capabilities to place antibiotics. The antibiotic value calculation is based on the provided data, with each antibiotic having a resistance value determined by the developer. This value indicates whether the antibiotic is sensitive and determines the size displayed on the screen. These values are calculated directly on the board and then sent to the user's phone.

The bacteria data used in the activity are derived from the annual publication by EUCAST (2024), detailing various antibiotic susceptibility patterns and overall antibiotic responses for the bacterial isolates. This data includes values for sensitive and non-sensitive antibiotics for each bacterium, allowing for an experience that can be updated annually with accurate study data.

3.2 Pilot workshop to raise awareness among teenagers using a digital device

The Digital Petri Laboratory is conceptualised as a multifaceted experience culminating in a workshop designed to raise awareness among teenagers on Antimicrobial Resistance. The workshop format was integrated into the TecDays initiative, a program in Switzerland that offers high school students the opportunity to choose from various workshops and activities (SATW, 2024). The workshop is structured to last 90 minutes and accommodates between eight and twenty participants, divided among four devices. Each device is colour-coded to differentiate it from the others for technical and experiential reasons. Technically, each device generates a unique wireless connection to prevent overlap, while experientially, the colour-coding allows students to work with different bacteria, with each device preloaded with specific data.

Figure 12: four DiPLab devices for the first workshop at TecDays and a device used by the students' group during the activity. Image courtesy of MAKEAWARE CC BY 4.0.

Drawing from the research phase, which identified the students' and experts' needs and preferences, the workshop was designed to connect the experience to real-world scenarios. This was achieved by creating booklets containing four patient stories in a medical folder format. Each folder includes personal information about the patient, such as age, disease, related bacteria, drug allergies, medical history, and a patient code that links the paper records to the digital petri device. Inside the folder is a table for recording data from the device, using a personalised ruler to categorise bacteria as sensitive or resistant to certain antibiotics. The back of the folder features a manifesto and additional information about the project.

Figure 13: the internal part of the patient folder used during the workshop. Image courtesy of MAKEAWARE CC BY 4.0.

The workshop has three main phases: discovery, experience, and assessment. During the discovery phase, the workshop curator introduces the topic of AMR using interactive slides, explains the activities participants will undertake, and provides a quick demonstration of how to use the device. In the experience phase, participants use the devices to simulate an antibiogram test, typically conducted in a laboratory setting. The results of this simulation are used to fill in the data table and determine which antibiotics could potentially treat the patient. The assessment phase involves participants researching the pathology and possible treatments and sharing their findings and perspectives with the other groups.

Figure 14: four students are doing the DiPLab workshop during TecDays. Image courtesy of MAKEAWARE CC BY 4.0.

The workshop is designed to include at least one patient case that is difficult to treat, one with only one treatment option, and another that is treatable, thereby highlighting the challenges of antibiotic usage and the issue of antimicrobial resistance.

The concept aims to provide high school students with a digital tool that simulates a petri dish and the laboratory experience of an antimicrobial test. This approach helps students understand bacterial behaviour and antibiotic interactions, offering a more transparent comprehension of the main factors involved in AMR.

4 Findings

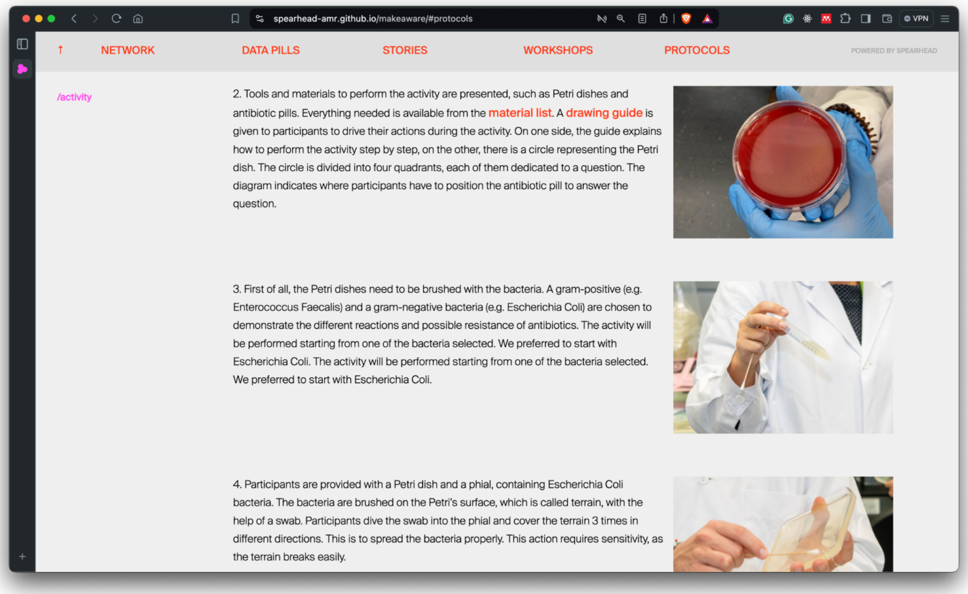
4.1 The importance of multidisciplinarity in raising awareness: the intersection between Microbiology and Interaction Design

Collaboration between designers, particularly interaction designers and microbiologists, is crucial in developing effective awareness campaigns for microbiology-related issues. Interaction designers possess the expertise to communicate complex information through various media, while microbiologists provide the necessary scientific knowledge and validation. This interdisciplinary approach ensures that scientific information is accurately conveyed without distortion while delivering an engaging experience.

The challenge lies in making scientific resources in microbiology accessible to the general public, as these are often difficult to comprehend and may lead to misinformation. To bridge this gap, citizen science has emerged, involving the general public in scientific research activities (Austen et al., 2024). Transdisciplinary approaches in citizen science projects have proven effective in enhancing understanding of complex problems, such as pollution, through practical engagement.

The intersection of Interaction Design and Microbiology offers significant potential for raising awareness of critical issues. Disseminating workshop protocols and procedures to individuals who did not attend the workshop is a valuable contribution to enhancing the accessibility of scientific information. By providing detailed information on how the workshop is conducted, this resource can be found on the project's website (https://spearhead-amr.github.io/makeaware/) and serves as a means to replicate and understand the workshop's processes.

Figure 15: the protocol developed for the workshop Visualizing the Resistance. Image courtesy of MAKEAWARE CC BY 4.0.



Projects developed under this philosophy aim to enable individuals to replicate the experience while understanding the underlying scientific concepts. However, it is essential to note that such initiatives do not replace the role of scientific support. Expert guidance remains essential for a comprehensive understanding of the topic and for ensuring that no crucial information is omitted to simplify complex scientific concepts for public consumption.

This approach aligns with the broader goals of science communication and public engagement in scientific research. By making microbiology more accessible and interactive, these initiatives can increase public awareness and understanding of critical issues such as antimicrobial resistance, potentially leading to more informed decision-making and behaviour at both individual and societal levels.

4.2 Design and development of the device

The current iteration of the DiPLab, developed as a high-fidelity prototype, is based on a commercial product released as open hardware. This dependency on a third-party product introduces potential challenges in terms of long-term availability and consistency, as changes made by the manufacturer could directly impact the device's reproducibility. While most devices can be produced within a FabLab environment, specific electronic components must be sourced externally. The current prototype has an approximate production cost of $150 per unit, excluding the necessary 3D printing equipment and assembly tools.

The time required to manufacture the devices is significant in the production process. Despite efforts to optimise efficiency, the current production timeline remains substantial, particularly when considering the need for multiple units to conduct a workshop effectively. Additionally, the software component requires further refinement to ensure robust functionality across various smartphone platforms.

The product's multimodal nature has demonstrated efficacy in engaging students. However, there is potential to streamline the interface to a single-screen physical device, eliminating the need for a smartphone. Alternatively, retaining the smartphone component could enhance functionality, although the current design limits connectivity to offline capabilities.

Despite these limitations, the current version of DiPLab has proven to be remarkably reliable, having been utilised in numerous sessions with minimal issues. This is particularly true considering its rapid development as a high-fidelity prototype developed by a single person. The use of 3D printing and essential electronic components in its construction has the added benefit of generating interest among students who may not be primarily drawn to microbiology but are intrigued by the technological aspects of the device.

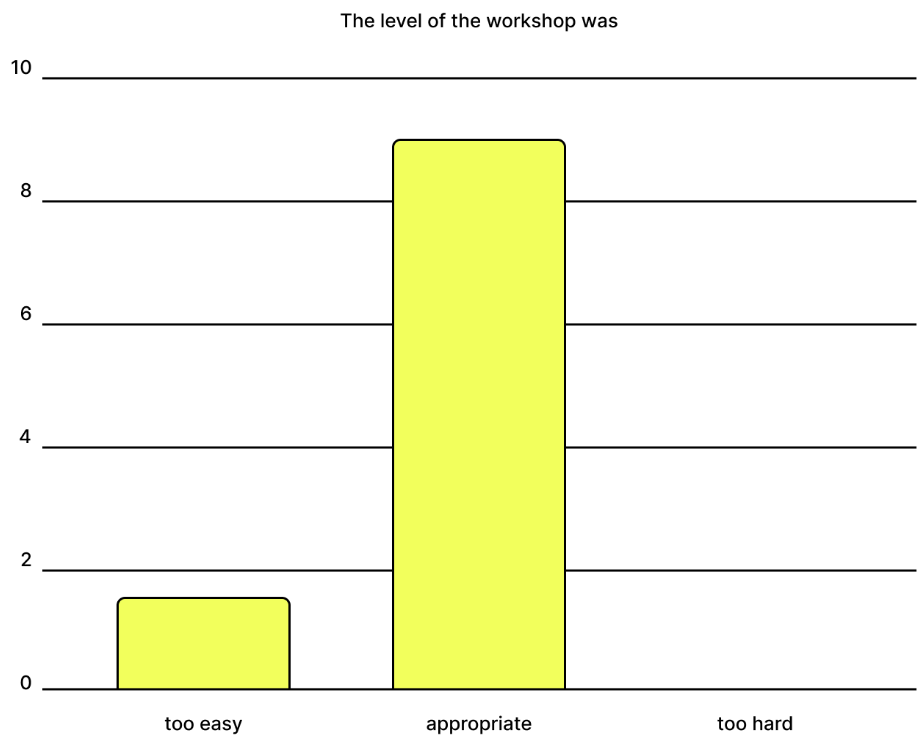
These observations provide valuable insights for future iterations of the DiPLab project, highlighting areas for potential improvement in production efficiency, cost-effectiveness, and expanded functionality. The project's success in engaging students through its technological components suggests potential avenues for broader STEM dissemination applications.

4.3 Workshop experience fostering participation and interaction through technology

The experience has been implemented on five occasions, engaging approximately 50 participants. The overall outcomes have been predominantly positive, with students expressing satisfaction and appreciation for the multi-modal approach to addressing Antimicrobial Resistance. Even participants with prior knowledge of AMR found value in the ability to test antibiotics using digital and physical interfaces.

Figure 16: plot of the answers for the module evaluation from workshops done during the TecDays. Image courtesy of MAKEAWARE CC BY 4.0.

Figure 17: plot of the answers for the level of the workshops done during the TecDays. Image courtesy of MAKEAWARE CC BY 4.0.



The activity has received validation from experts in microbiology and scientific dissemination, garnering positive feedback and suggestions for improvements, which have subsequently been incorporated into the current iteration of the product. Experts have expressed interest in utilising the product as a dedicated didactic tool for teaching laboratory-related topics. The ability to demonstrate antibiotic testing without the necessity of a physical laboratory environment has particularly captured the attention of educators involved in teaching these subjects to first-year students in Microbiology.

Despite these successes, the workshop has encountered specific challenges. The primary difficulty lies in attracting participants when the activity is offered to high school students, as the topic of AMR may not initially appeal to this demographic. However, it has been observed that once engaged, students typically find the activity interesting, and their interest in the broader topic is often sparked by the actions required to perform it. To address this recruitment challenge and maintain the project's objective of community outreach and awareness, a potential strategy involves directly targeting educators within scientific fields as facilitators of the workshop experience. The approach tested has increased student participation. Importantly, this increase in participation has not compromised engagement or attention levels. This is noteworthy, particularly given that interviews with students revealed a relatively low attention span among the target user group.

The workshop's conclusion also presents an area for improvement. The activity transitions to online research on diseases and antibiotics, which may lead to potentially misleading information sources and disconnections from the DiPLab. This final stage presents an opportunity to enhance the connection between the two devices and provide access to a curated, reliable source of information integrated within the DiPLab system.

These findings and observations provide valuable insights for the continued refinement and development of the DiPLab experience.

5 Conclusion and Future Works

The Digital Petri Laboratory is an innovative approach that simulates the Kirby-Bauer test to explore antibiotic resistance. The research highlights its strengths and areas for potential enhancement in achieving awareness-raising objectives as well as educational effectiveness. Combining Interaction Design and Microbiology, this interdisciplinary project yielded promising initial results. Recent evaluations have generated interest in implementing the experience in various settings as a community awareness workshop and an educational support tool.

The Design Thinking methodology (IxDF, 2016) employed throughout the project has proven effective in creating an experience that addresses user needs. This approach, which emphasises continuous iteration and improvement, has informed the development of future iterations based on insights gathered from conducted workshops.

A project limitation is tailoring the experience to meet the specific needs of a well-defined target audience. While the current iteration is broadly designed for high school students, workshop insights have revealed the need for more precise user segmentation. Consequently, future iterations will require a more precise definition of the target audience, with two potential directions emerging: microbiology education with a tool serving as a digital twin of the laboratory environment or community engagement to raise awareness about AMR.

Regardless of the chosen direction, addressing the accessibility challenges associated with traditional microbiology laboratories remains a central focus in the project's development. Efforts will be directed toward refining the multi-modal product to digitalise the real-world experience, thereby mitigating spatial, safety, and accessibility constraints inherent to physical laboratory settings.

Future development of DiPLab will incorporate findings and experiences from the past year to enhance the product and refine the experience. Since the workshop is the primary research focus, redefining the activity is a priority. This refinement will be mainly addressed during the working group at the conference, with results subsequently shared with the community. From a product perspective, the goal is to redesign the board to enhance design freedom and reproducibility, enabling widespread replication without reliance on commercial products.

An additional avenue for exploration is the potential use of the device to expand research on predicting bacterial responses to specific antibiotics through machine learning algorithms trained on available data, such as that from EUCAST (2024). This could enhance the workshop experience by incorporating more antibiotics and categorising results and scientific research to aid new antibiotic development. The feasibility of this approach requires validation from experts in Artificial Intelligence and Microbiology.

The ultimate objective is to develop DiPLab into a fully-fledged product that can be distributed to schools and utilised for workshops or lessons without requiring extensive expertise from the facilitator. This would involve providing educators with concise guidelines on product usage, thereby broadening its accessibility and impact in educational settings.

Acknowledgement

The Digital Petri Laboratory explores the intersection between Fab Labs, Interaction Design, and Microbiology to elevate awareness of Antimicrobial Resistance. This pioneering endeavour was initiated by the University of Applied Sciences and Arts of Southern Switzerland (SUPSI) under the auspices of the SPEARHEAD project, generously funded by Innosuisse. We profoundly thank the SPEARHEAD project for providing the opportunity to conceptualise and present the DiPLab project and workshop. Additionally, we extend our gratitude to Antonella Autuori, research and teaching assistant at the Design Institute at SUPSI, whose invaluable contributions have greatly enriched the design and implementation of the workshops. We want to express our sincere gratefulness to Marco Lurati, scientific collaborator at the Design Institute and FabLab manager at SUPSI. Without his invaluable assistance in the development of the product, the DiPLab would not have been a reality. We also need to extend our appreciation to the laboratory at LaFilanda in Mendrisio who helped us to fabricate the four versions of DiPLab. A debt of gratitude is also owed to the experts in science education and dissemination for their unwavering support throughout the research process, as well as the high school students who were vital participants in the project. In addition, we extend sincere appreciation to the Swiss Academy of Engineering Sciences (SATW) for giving us the privilege of presenting our workshop during the TecDays across Switzerland. Furthermore, profound gratitude is expressed to all the high school students and educators who participated in the pilot workshops, providing indispensable feedback that has been influential in refining and enriching the Digital Petri Laboratory experience.

References

Akram, F., Imtiaz, M., & Haq, I. (2023). Emergent crisis of antibiotic resistance: A silent pandemic threat to 21st century. In Microbial Pathogenesis (Vol. 174, p. 105923). Elsevier BV. https://doi.org/10.1016/j.micpath.2022.105923

Austen, K., Janssen, A., Wittmayer, J. M., & Hölker, F. (2024). The potential of citizen science to transform science: Lessons for a sustainable future. In People and Nature (Vol. 6, Issue 2, pp. 435–445). Wiley. https://doi.org/10.1002/pan3.10614

Britannica, T. Editors of Encyclopaedia (2024, February 26). antimicrobial agent. Encyclopedia Britannica. Retrieved 27 June 2024, from https://www.britannica.com/science/antimicrobial-agent

Cangiano S., Terenghi G., Autuori A., Romano Z., Subet M. & Pham A. (forthcoming). SPEARHEAD-MAKEAWARE!: a design research framework to tackle antibiotic consumption and resistance through creative approaches of data co-creation. In Pfannstiel, M., Kueh, C., Palozzi, G., (eds.), Service Design, Creativity and Innovation in Healthcare. Springer.

European Committee on Antimicrobial Susceptibility Testing - EUCAST (2024, January 1). Clinical breakpoints - breakpoints and guidance. Retrieved 20 June 2024, from https://www.eucast.org/clinical_breakpoints

Fein, Y., Gome, G., Zuckerman, O., & Erel, H. (2020). My first biolab. In Proceedings of the 2020 ACM Interaction Design and Children Conference: Extended Abstracts. IDC ’20: Interaction Design and Children. ACM. https://doi.org/10.1145/3397617.3402040

Fleming, A. (1945, December 11). Penicillin. In World Scientific (Eds.), *Physiology Or Medicine 1942-1962* (pp. 75 – 95). World Scientific.

Nobel Lectures, Physiology or Medicine 1942-1962, Elsevier Publishing Company, Amsterdam, 1964

Hindler, J. F., & Munro, S. (2010). Antimicrobial Susceptibility Testing. In Clinical Microbiology Procedures Handbook. Wiley. https://doi.org/10.1128/9781555817435.ch5

Interaction Design Foundation - IxDF. (2016, May 25). What is Design Thinking (DT)?. Interaction Design Foundation - IxDF. Retrieved 17 June 2024, from https://www.interaction-design.org/literature/topics/design-thinking

Kim, C., Guo, A., Salhotra, G., Sprinkhuizen, S., Shetty, K., & Kong, D. S. (2020). Sonifying Data from the Human Microbiota: Biota Beats. In Computer Music Journal (Vol. 44, Issue 1, pp. 51–70). MIT Press - Journals. https://doi.org/10.1162/comj_a_00552

Laxminarayan, R., Matsoso, P., Pant, S., Brower, C., Røttingen, J.-A., Klugman, K., & Davies, S. (2016). Access to effective antimicrobials: a worldwide challenge. In The Lancet (Vol. 387, Issue 10014, pp. 168–175). Elsevier BV. https://doi.org/10.1016/s0140-6736(15)00474-2

Microbiology Society (2015, July 9). What are antibiotics and how do they work?. Microbiology Society. Retrieved 25 June 2024, from https://microbiologysociety.org/membership/membership-resources/outreach-resources/antibiotics-unearthed/antibiotics-and-antibiotic-resistance/what-are-antibiotics-and-how-do-they-work.html

Review on Antimicrobial Resistance (2014). Antimicrobial resistance: Tackling a crisis for the health and wealth of nations. Chaired by Jim O'Neill. Retrieved 20 June 2024, from https://amr-review.org/sites/default/files/AMR%20Review%20Paper%20-%20Tackling%20a%20crisis%20for%20the%20health%20and%20wealth%20of%20nations_1.pdf

Scavone, P., Carrasco, V., Umpiérrez, A., Morel, M., Arredondo, D., & Amarelle, V. (2019). Microbiology can be comic. In FEMS Microbiology Letters (Vol. 366, Issue 14). Oxford University Press (OUP).

Soldered Electronics (2021). Inkplate-6PLUS-Hardware. Retrieved 20 June 2024, from https://github.com/SolderedElectronics/Inkplate-6PLUS-Hardware

SATW (2024). TecDays. Retrieved 20 June 2024, from https://mint.satw.ch/de/tecdays

Subet, M. (2022, November 17). DiPLab - An Interactive Multimodal Experience to Involve Young People in Antimicrobial Resistance and Antibiotic Usage. Junior Design Research Conference (JDRC), Basel, Switzerland. Zenodo. https://doi.org/10.5281/zenodo.8423407

Subet, M. (2023). DiPLab - An Interactive Multimodal Experience to involve Young People in learning about Antimicrobial Resistance. https://doi.org/10.5281/zenodo.10727626

Subet, M. (2023). zumatt/diplab: DiPLab V1 (Beta). https://doi.org/10.5281/zenodo.10276251

Terenghi, G., Cangiano, S., Autuori, A., Corti, C. M. (2024). Fostering a Patient-led Culture of Care Through Data Physicalization: A Design Approach to Create Awareness and Promote Data Collection on Antimicrobial Resistance. In Proceedings of DRS. DRS2024: Boston. Design Research Society. https://doi.org/10.21606/drs.2024.419

Van Boeckel, T. P., Gandra, S., Ashok, A., Caudron, Q., Grenfell, B. T., Levin, S. A., & Laxminarayan, R. (2014). Global antibiotic consumption 2000 to 2010: an analysis of national pharmaceutical sales data. In The Lancet Infectious Diseases (Vol. 14, Issue 8, pp. 742–750). Elsevier BV. https://doi.org/10.1016/s1473-3099(14)70780-7

Vidhi, M. (2016, February 29). Citizen science can support antibiotic research and education. Retrieved 20 June 2024, from https://medium.com/@vidhimehta/citizen-science-can-support-antibiotic-research-and-education-a7780cb41863

World Health Organization - WHO, World Intellectual Property Organization - WIPO, World Trade Organization - WTO (2016, September 14). Antimicrobial resistance – a global epidemic. Prepared by the Secretariats of WHO, WIPO and WTO. Retrieved 20 June 2024, from https://www.wipo.int/edocs/mdocs/mdocs/en/wipo_who_wto_ip_ge_16/wipo_who_wto_ip_ge_16_inf_2.pdf

World Health Organization - WHO (2023, November 21). Antimicrobial resistance. Retrieved 20 June 2024, from https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance

World Health Organization - WHO (2003, January 1). Manual for the laboratory identification and antimicrobial susceptibility testing of bacterial pathogens of public health importance in the developing world. Retrieved 21 June 2024, from https://www.who.int/publications/i/item/WHO-CDS-CSR-RMD-2003.6 https://doi.org/10.1093/femsle/fnz171