Putting the Lab back into Fab Lab

by

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Submitted to the Program in Media Arts and Sciences, School of Architecture and Planning, in partial fulfillment of the requirements for the degree of

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Abstract:

The fab lab movement has given people around the world access to digital fabrication tools, letting them produce prototypes, products, and even small businesses. Efforts like Fab City have tried to widen that impact to the scale of cities, but top-down engagement with local government has so far struggled to reach the community level. Making, however, is only half of what a local economy needs. To build and trust their own solutions, communities also have to be able to measure and prove them - yet the protocols and tools that assist in assessment remain centralized, proprietary, and often out of reach. This thesis asks what the smallest set of capabilities lets a community evaluate the efficacy of its own hygiene products, and demonstrates that such a lab can be built, operated locally, and governed by the communities it serves, by being developed in unity with an existing fab lab. The work develops through HyTech, a collaboration between the MIT Center for Bits and Atoms, fab lab Peru, fab lab Chile, Indigenous Amazonian communities, and Procter & Gamble, in which low-cost field labs are used to test the efficacy of community hygiene knowledge - from mosquito repellents to hair care. The technical work is paired with a co-creation and alignment methodology and a documented pathway to a benefit-sharing agreement grounded in the Nagoya Protocol and Peru's ABS framework.

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Flying high is easier than flying low

and flying fast is easier than flying slow.

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1 Introduction

I am sitting with Beno Juarez on the river bank of the Amazon River just north of Iquitos. We took a boat from the city that can only be reached by airplanes to reach communities living deep in the forest. When the river gets choppy the boats cannot reach them. One of the elders of the NC Etna Kukama had just taken us to one of their Lupuna Trees, the mother of the forest. We had gone there so that we could discuss our research plans in the presence of the tree. I had watched him, and multiple others in our group, hug the tree and sit with it while contemplating what we had come to ask. "I wanted you to witness this", said Beno, "the act of asking the tree for permission, because none of this research will work if we cannot communicate that the forest is viewed as an active participant in this research. It is not a resource - it is a co-creator." Do not forget this.

The dominant response to inaccessible science has been to make the hardware cost less. ***If it were cheaper, it would already be everywhere.*** It has been a remarkably successful response. Initiatives such as Fab Labs, BioLabs, and Makerspaces have laid the groundwork for this shift, offering inclusive platforms for experimentation, education, and citizen engagement. These environments not only democratize access to technology but also activate community participation in shaping sustainable futures, aligning local action with global knowledge-sharing networks (Gershenfeld, 2007). The gap this thesis addresses is not access to making but access to knowing.

Today scientists require much more complex, intricate, and expensive tools to perform measurements and experiments, and while fab labs and open-source biolabs have worked hard to open up the entry boundary to biology and biotechnology: the instrumentalisation to not just create and experiment but to also be able to investigate the intricacies of their biodiverse environment, and to find low cost solutions for them to be able to perform this across multiple communities at once - and simultaneously give them access to knowledge via developing a cooperation pathway with industry consultation partners. As will be explored in this thesis, there is willingness on both sides. Institutionally, this thesis uses the fab lab as the mediating body that finds and brokers the aligned cases. Fab labs are suited to this role in a way no other institution combines: they are locally rooted, with community relationships that predate any given project; they are globally networked, so external partners can find and reach them; they are procedurally open, so their methods can be audited by all parties; and they hold no commercial stake in the knowledge that passes through them.

Much of the trajectory of this thesis aims towards portable personal laboratories and the possibilities that such can unfold. The trajectory of personal fabrication is habitually compared to the trajectory of personal computing: an expensive institutional machine, redirected two decades later into something a child can own. If biology were easily accessible as an iPad to a 5 year old, how might that change both access to knowledge and understanding of the physical and biological components of fabrication of everyday goods that are needed to keep a community healthy?

Within the scope of this thesis, the *HyTech* case study is used to develop the field lab inventory, the efficacy protocols it enables, and the co-creation and benefit-sharing infrastructure that lets remote communities use both to their own benefit while protecting their ancestral knowledge.

HyTech as a case study has the potential to help shift the public perception of how indigenous communities can not only participate in open-source science but also in collaborations with industry partners while protecting their ancestral plants and wisdom.

I hope that this work will help enable broad-based participation in communities being able to participate in understanding and developing their own products using fab lab adjacent Lab infrastructure.

1.1 Biodiversity

Sustainable materials and sustainable practices play an increasingly vital role in redefining how we engage with matter in both ecological and social contexts. The complexity of global supply chains, consumer behavior, and regulatory environments presents ongoing challenges in reducing the environmental footprint of personal hygiene products. Continued collaboration between industry, governments, and consumers is essential to develop and implement effective solutions that balance hygiene needs with environmental sustainability. In this context, platforms like Materiom - which curate open-source recipes for biomaterials based on locally abundant biomass - demonstrate how decentralized innovation and collaborative knowledge-sharing can support ecological transition (Garmulewicz et al., 2018).

When working with indigenous communities and locally sourced biofabrication, the ecological biodiversity in which this research takes place influences the research and the participants. A large part of this thesis work takes place in Peru among multiple indigenous communities, who consider the forest that they are working with a co-investigator in the work that we are doing. All the recipes and protocols developed in this thesis were done in alignment with the goal of reforestation of the natural landscape in which they are taking place. The aim to understand the efficacy of local plants also helps inform the local communities which plants should be a priority for reforestation in order to support the communities in a more circular way of living, to help relieve them from the dependency on supply chains which bring one-use plastics and polluting chemicals to their forest that they have no way of removing from their environment.

1.2 Motivation: Putting the Lab back into fab lab

Building on the foundations of the FabNetwork and the fab lab infrastructure this research aims to introduce bio-infrastructure to fab lab structures. The fab lab here is viewed as more than just the physical space, as much as the community network and interpersonal relationships and mediations that it fosters between local communities, and can help solve their needs. Fab City Foundation promotes a model to develop systemic solutions and impact positively in the hyperlocal scale of neighborhoods, meso scale of cities and regions and macro scale of bioregion and planet (Ladera et al., 2024). But this model primarily applies to manufacturing and production that can be solved using digital fabrication spaces, but my goal when starting this research was the curiosity of what that mentality could be expanded to when it was extended beyond digital fabrication to biology.

Scientific tools are both an enabler and an impediment. The fab lab network began as an argument about access: the tools of digital fabrication were reaching a cost and capability point at which they no longer needed to be concentrated in institutions (Gershenfeld, 2007). Coming from a background of community DIY biology, in this thesis I wanted to explore how to expand access to metrology to relatively remote locations through utilising the fab lab as a mediation space to not only build tools but also build trust with communities and move to expand the capabilities of a fab lab towards the more colloquial meaning of the word "Lab".

1.3 Contributions

This thesis aims for the following contributions:

A specification for a community field lab, variations and reviews of biology and metrology inventory for the evaluation of hygiene products and a set of efficacy protocols for hygiene technologies developed jointly with industrial scientists and run locally by community participants, together with their results.

A co-creation and alignment methodology for research relationships between Indigenous communities, a research institution, and a multinational corporation and a survey of benefit-sharing model pathways grounded in the Nagoya Protocol and Peru's domestic access and benefit-sharing (ABS) framework.

2 HyTech

HyTech (Hygiene Technologies) is a collaboration between the MIT Center for Bits and Atoms, fab lab Peru, fab lab Chile, Indigenous Amazonian communities, and Procter & Gamble, which applies the principles of personal fabrication to hygiene products. Hygiene is an unusually good testbed. Personal hygiene products, while essential for human health and well-being, pose significant environmental challenges throughout their lifecycle. Many contain synthetic chemicals such as parabens, triclosan, and microplastics, which are persistent in the environment and can disrupt ecosystems. For instance, parabens, commonly used as preservatives, have been detected in wastewater and aquatic environments, raising concerns about their potential to disrupt endocrine systems in wildlife (Bilal et al., 2020; Juliano & Magrini, 2017). This description most applies to contemporary mass-produced hygiene products, which are subject to supply chains and stabilisation requirements due to long shipping routes. Much of that chemistry solves a logistics problem rather than a hygiene one: goods must survive long supply chains and are formulated for preservation rather than their 'job to be done'. When visiting the Amazon Rainforest on one of the research trips, one of the most shocking visuals was the accumulation of trash inside these nature living communities. Since they are so remote from cities there is no 'recycling' infrastructure so all supply chain products with non-compostable packaging have nowhere to go other than to remain in the forest.

Figure 1: Trash on the side of the Amazon River in northern Peru

These communities become the final stop of the supply chain by-products. Economically, the global chain concentrates value away from the community: raw materials and knowledge flow out, finished products and their prices flow in, and the community's role is confined to final consumer. But the global chain also delivers consistency, safety assurance, and availability: the commercial references in this thesis which play the counterparts to the natural products are good products. They are comprised of P&G products that were developed using the methods, which the scientists in this work are sharing and teaching the community members. But the consumer at the end of a global chain cannot interrogate, adapt, or own what arrives.

HyTech applies the principles of personal fabrication to hygiene products. What if people could make what they need? And from that question on - how could a community more easily support itself with the knowledge it already has?

"Job to be Done" Throughout this thesis, this phrase will reoccur on occasion. It is taken from the collaboration with P&G on the HyTech project. It is a theory and framework (developed by Clayton Christensen) used to understand consumer needs, focusing on the 'job' a consumer is trying to get done. Within the capacity of HyTech the JTBD were aiming to:

- Be open source
- Use local materials
- Leverage local community resources, capabilities, and entrepreneurs, such that all new projects support local economies
- Be better than what is commonly available to consumers in the region

2.1 The Start and the Twist

The HyTech project began in the summer of 2024, with the initial design idea surrounding expanding fab labs to facilitate indigenous communities manufacturing products based on the historical knowledge which was passed down through generations but remained underused in the commercial world of globally shipped products.

But shortly after sending out an open call to fab labs to see if they were working with any communities who might be interested in participating in this collaboration, a surprising realisation came from the conversations. The communities didn't need help in manufacturing, but what they did want was to measure and assess the efficacy of their solutions with a similar accuracy as their commercial counterparts. The knowledge wasn't dying out between generations, but it was suffering from the fact that historically indigenous solutions were tested by time and generational use, rarely anything concrete, and with many of the communities the driving emotion appeared to be personal curiosity of trying to understand the plants that they already use in their daily life. Understand and also *share*, share safely without fear of exploitation and abandoned projects.

From that point on this thesis shifted to the exploration of metrology tools in field settings, the design of protocols and the establishment of collaboration pathways using fab labs as mediating spaces to protect and enable communities.

Thank you ahead of time for reading.

3 Background and Related Work

3.1 Tools

Within the digital fabrication movement, the predominant phrase one stumbles upon is “making almost anything”, an argument that is facilitated through the infrastructure built by the fab inventory: a selection of machines and tools for rapid prototyping. The fab lab movement makes the argument that access to those machines should be spread rather than concentrated and became a network of workshops sharing a common set of tools - laser cutters, mills, electronics - so that people could make what they needed rather than buy it (Gershenfeld, 2007). Fab labs standardise fabrication - cutting, milling, printing - but what happens when the same mentality is applied to biology and metrology?

The advance of computer science was expedited endlessly by the personal computer and later on the laptop: placing the tools to learn directly into the users’ hands. Biology has had a similar acceleration; however, it remains to this day mainly limited by the specialised equipment that is restricted to ‘high academic’ spaces. From the initial sequencing of the human genome in 2000, whole sets of technologies came to fruition. Not only are we able to read and write DNA, but the cost at which we do so keeps dropping as the speed increases. This accessibility enables what were once large efforts conducted in research labs to now be happening on kitchen tables (Wohlsen, 2011). Within open biology, open science and open biotech there is a rich history of open-source tools attempting to make biology a more accessible means.

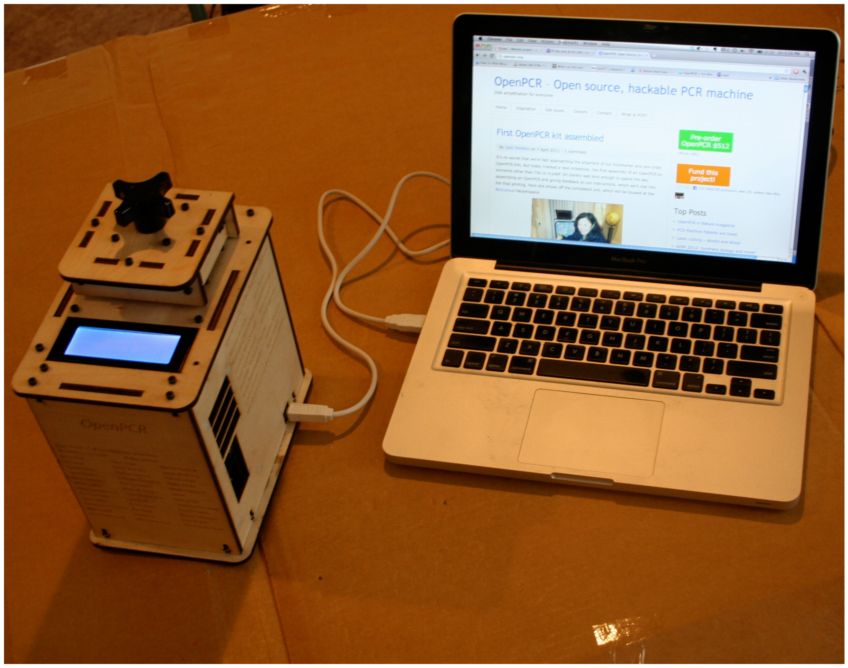

Figure 2: original openPCR connected to computer

BentoLab and **OpenPCR,** fully functional consumer products that came onto the market in the early 2010s, mark the beginnings of allowing scientists, DIY-biologists and citizen-scientists to have portable yet functional personal laboratories. The OpenPCR allows low-cost ($499) thermocycler capacity to control PCR reactions for DNA detection and sequencing. Sold in parts, it is a DIY solution to expensive and restricted lab equipment.

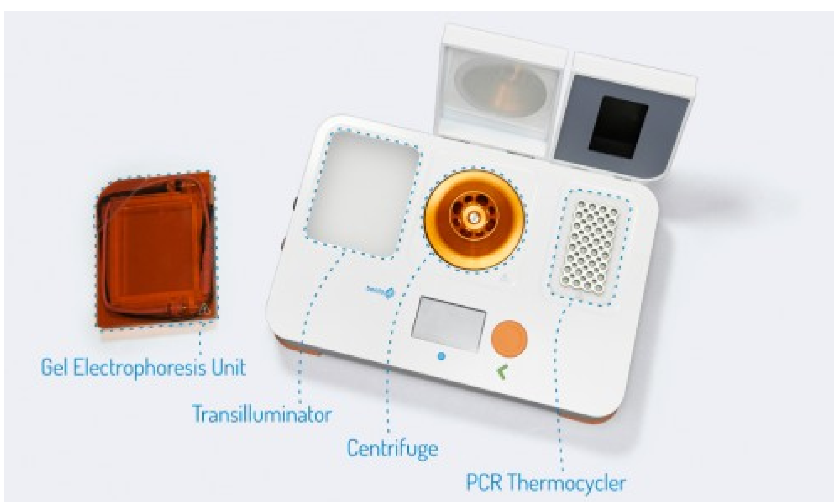

Figure 3: BentoLab - from bento.bio

From the foundational bones of these pioneering low-cost tools several open-biolabs sprouted across the world, built on much of the same principles as fab labs, but whilst their existence significantly democratised access to bioengineering and synthetic biology and education in general, they were still tied to physical spaces with significant infrastructural limitations. Despite the fact that the early open source tools were quickly followed up with smaller and even more portable versions - the openPCR paved the way for its smaller siblings, the miniPCR and pocketPCR (the latter one of those especially with a cost of around $100 at the time of the completion of this thesis). The physical restraints of wetlab biology were progressively erased as the tools allowed us to make the process the size of our palms.

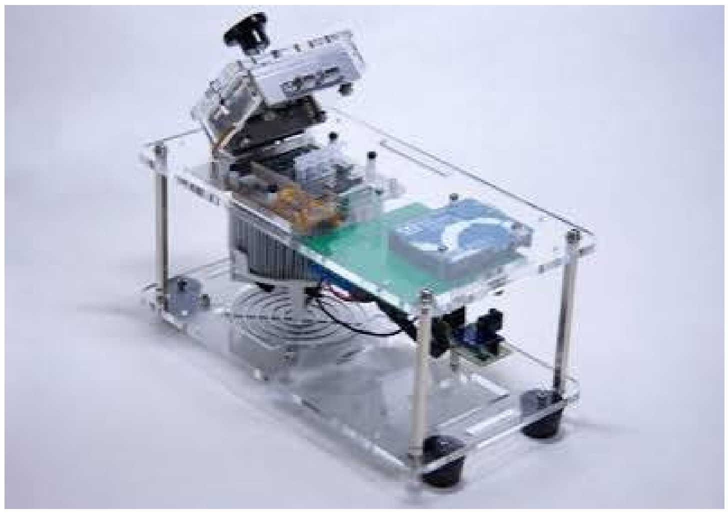

Figure 4: MiniPCR, followed in the footsteps of OpenPCR

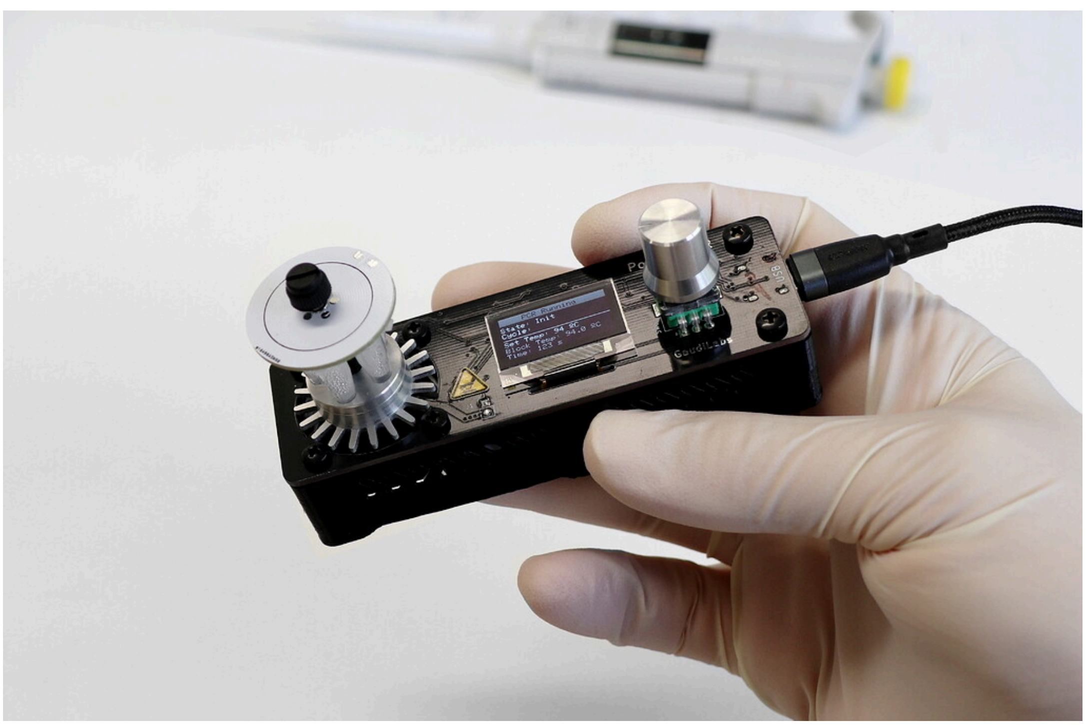

Figure 5: PocketPCR, the latest of the thermocycler evolutions, still connects to a laptop but is fully portable

But the barriers were not just infrastructural, but also oversight and policy limitations. Relinquishing biological research from the shackles of even just adjacent academic infrastructure proved significantly difficult. And while the machines slowly became cheaper, reagents and consumables remain a cost that is difficult to remove.

Manu Prakash in his *frugal science* research is also making an argument on the side of instrumentation: not simply just building tools, but reading the world through them at radically low costs. The Foldscope, a microscope made from paper and under a dollar in parts, rugged enough to be taken into the field and operated by the most untrained of users, outsources its key optical components to the most expensive device most of us already carry in our pockets every day: our phones, and thus holds optical quality comparable to conventional instruments (Cybulski et al., 2014).

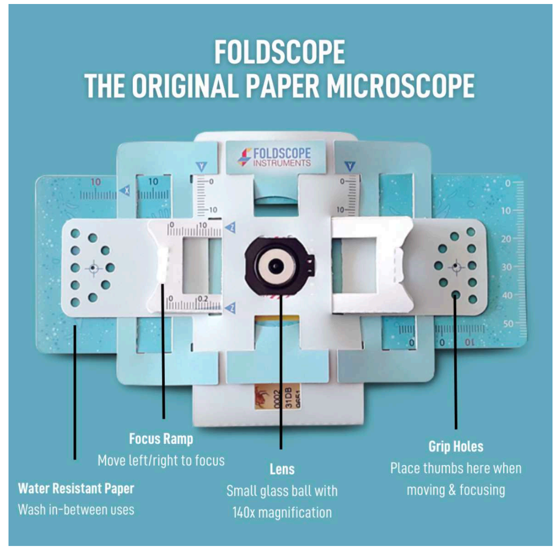

Figure 6: Foldscope

The paperfuge is a centrifuge of paper and twine, modeled on a whirligig, that separates plasma and isolates malaria parasites without electricity (Bhamla et al., 2017).

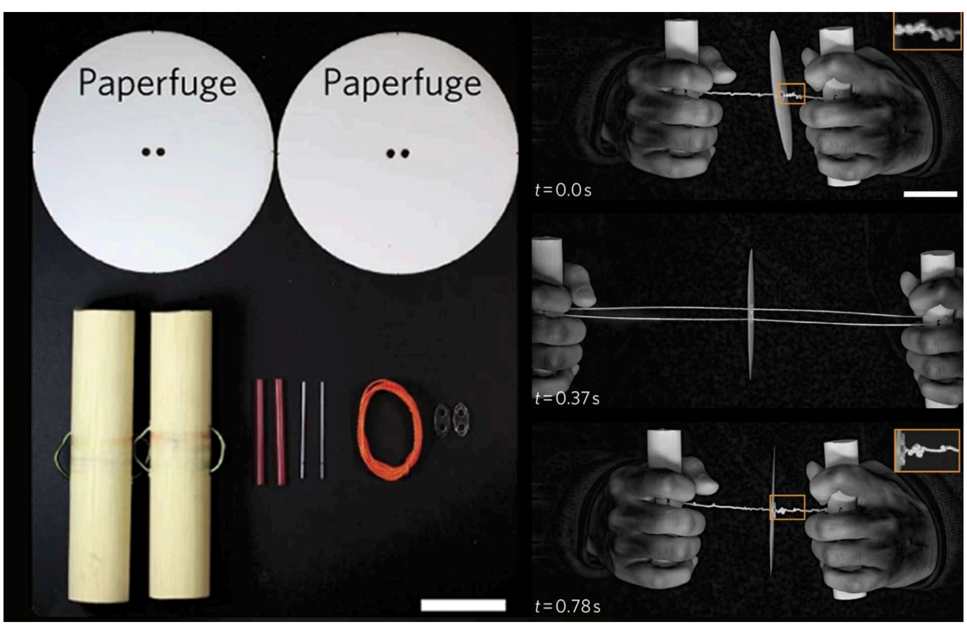

Figure 7: Paperfuge

Prakash and his researchers continued the thread of utilising the computational and metrological power of the cellphone by turning them into acoustic sensors to map mosquito species by wingbeat (Mukundarajan et al., 2017).

3.2 Citizen Science

Citizen science is not new, though the name is. Members of the public have contributed to scientific data collection for over a century: the National Audubon Society's Christmas Bird Count has run annually since 1900, and long-term efforts like the North American Breeding Bird Survey (1966) built ecological datasets across spans and scales no professional team could cover (Aceves-Bueno et al., 2017). What these projects shared was a division of labor. Volunteers observed and recorded; professional scientists designed the studies, held the data, and drew the conclusions.

The term itself was coined twice, independently, in the mid-1990s, and the two definitions pointed in different directions. In the United States, the ornithologist Rick Bonney at the Cornell Lab of Ornithology used "citizen science" to describe projects in which non-scientists voluntarily contribute data to research designed by professionals (Bonney, 1996). In the United Kingdom, the sociologist Alan Irwin used the same term to argue something broader: that science should be responsive to citizens' concerns, and that citizens themselves could produce reliable knowledge (Irwin, 2002). Irwin described a redistribution of authority. Most projects that carry the label today follow Bonney: knowledge is produced outside scientific institutions but according to their norms, with validation and ownership remaining with professionals (Cavalier & Kennedy, 2016).

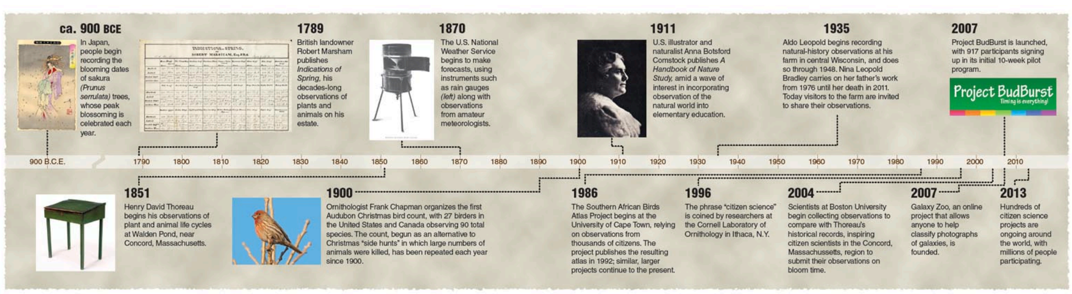

Figure 8: A timeline of the citizen science as printed in the *Scientific American*. Citizen Science Past and Present In a sense, all scientists were once citizen scientists. Illustration by Barbara Aulicino. Albany Institute of History & Art/archival photograph Sean Linehan, NOS, NGS/Concord Museum, photograph by David Bohl

The persistent question asked of this tradition is whether data collected by non-professionals can be trusted. A quantitative review of peer-reviewed comparisons found that citizen-science datasets frequently match or exceed professional accuracy, but only when projects are designed for it, using volunteer training, replication across observers, expert validation, and statistical modeling of systematic error (Aceves-

Bueno et al., 2017). Data quality appears to be a property of how the project is built and the public is equipped to evaluate their data if they are trained to do so.

A separate line of work asks not whether the data is accurate but who holds it. Community-based participatory research reframes the relationship between researcher and researched, treating community members as equal partners across the whole research process and integrating knowledge with action for the community's benefit rather than the researcher's alone (Israel et al., 1998); the field has since grown into a substantial body of partnership methods and evaluation tools (Israel et al., 2026). Running alongside this is a sharper critique from Indigenous scholarship of "helicopter research," in which outside researchers enter a community, extract data, and leave without returning results or benefit (Carroll et al., 2020). The CARE Principles for Indigenous Data Governance - Collective Benefit, Authority to Control, Responsibility, Ethics - formalize the response, insisting that Indigenous communities hold rights and authority over data derived from their knowledge and territories (Carroll et al., 2020). Where the open-data movement's FAIR principles press for data to be shared, CARE presses for it to be governed, accounting for the power differentials and histories that sharing alone ignores (Carroll et al., 2020).

HyTech as a test case for metrology infrastructure in the field builds on the scholarly background of citizen science, with one key difference. This research searches not just for ways to give the general public the agency to evaluate their own science, and to own the results, but also to be able to collaborate with external entities while still being able to protect their knowledge. In the following work the test cases in particular explore the design of co-creation and collaboration infrastructures between various indigenous communities and Procter and Gamble, an American multinational consumer goods corporation, using the local fab labs as liaison spaces.

Shaped around the core principles of benefit-sharing, the relationship dynamics of these collaborations are designed to not just protect the knowledge of the communities but also to allow a two-way relationship of consultation, as the different scientific worlds engage with each other on equal footing.

4 Ancestral Knowledge and Alignment

In its earliest articulations, the local knowledge held by autochthonous cultures was disregarded as superstitious and primitive.

The phantom presence of indigenous/local knowledge is seen and felt viscerally, through the poetics of absence.

Ancestral knowledge is knowledge held by a community and carried across generations- refined against consequence over a long span of time. Its test is use. Contemporary western science has positioned traditional and generational knowledge into the realm of folklore: holistic and herbal approaches to scientific research are entertained but often dismissed for lacking the 'clinical clarity' and 'objectivity' of western scientific methods. I place these words in quotation marks as there are many issues to the implied objectivity of western science, though it is not fundamentally relevant to the core of this thesis and will not be explored. The civilizing mission, the radical ethnocentrism and the elitist gaze of twentieth century science deemed such forms of knowledge emerging as they did outside the canon of western science, or the sites of production of formal knowledge, i.e. institutions and laboratories, as 'primitive' and 'unscientific'. (Agrawal, 1995)

Fieldwork that swelled the canons of scientific literature during the late colonial period drew heavily upon the foundation of indigenous knowledge, with a characteristic elitism that obscured names of sources or muted indigenous voices.

The extraction of biological knowledge is old, and for most of its history it wore the mask of discovery. European botany advanced by collecting the world's plants, and the collecting rode on empire. Explorers were led to useful species by people who already knew them, then entered those species into the Western canon as finds (Scott, 1998). The knowledge was taken. The knowing was not credited. One such example takes place in the Amazon rainforest: Ayahuasca had been prepared and used in the upper Amazon for centuries, a history recorded as far back as pre-Columbian rock art. Western science dates it to the early 1850s, when the British botanist Richard Spruce observed Tukanoan people on the upper Rio Negro using the caapi vine, and to the naturalists who catalogued it after him (Schultes et al., 2001). Centuries of use collapsed into a moment of European first observation. The plant became legible to science, and in the same motion its holders became invisible. Even where indigenous knowledge was useful enough to extract, it was judged too unscientific to credit - treated as superstition, irrational and superfluous (Howes & Chambers, 1979).

The Convention on Biological Diversity affirmed the value of traditional knowledge in 1992 (Article 8(j)), and UNESCO followed in 2003. But valorization and extraction run along a single edge (Muniyappa, 2020). Interest in indigenous knowledge became a market: bioprospecting for patentable compounds (Congressional Research Service, 1993) (Brush & Stabinsky, 1996), and appropriation conducted in the vocabulary of participation and partnership (Eyzaguirre, 2001). Partnership is an interesting dynamic and language to use when one encounters a power relationship as it exists in community work.

Smith (1999) observes that in many Indigenous communities 'research' itself is among the most distrusted of words. Given the history of how research was conducted it is no surprise. The case studies and collaborators in this thesis were approached with this history in mind.

4.1 The Amazon Rainforest: A Case Study

One of my personal goals when deciding to work with indigenous communities was to avoid creating any situation in which we, the researchers, would be telling the communities what we thought they needed for their own well being. So instead of reaching out directly to communities I instead reached out to the fab lab network, inquiring for Labs that might have existing good relationships with their local indigenous communities and who might be interested in collaborating on hygiene products. Beno Juarez reached back out, saying that he was already doing a biodiversity based project, Regen[1], with his local communities in the Amazon Rainforest, investigating local plants, their purposes for the sake of forest reforestation and regeneration. They believed that the HyTech project and the exploration of fieldlabs within their communities was a fitting addition to the mission they were already working on. With that we weren't prescribing to them what I believed was interesting to research - but instead we were invited into their ongoing mission to preserve the forest from an accelerated extinction and the preservation of natural knowledge (Regen, n.d.).

[1] https://regen.now/

4.1.1 January 2025 Alignment Meeting

The Amazonian alignment work took place in and around Iquitos, Peru, in January 2025, within the HyTech collaboration between the Center for Bits and Atoms (CBA) at MIT, fab lab Peru, and Procter & Gamble, with Regen as an operational partner.

Representatives who attended the meetings: CBA fab lab Peru Iquitos Local Government Community leaders from the Murui Bue Community Community leaders from the Etna Kukama Community Community leaders from the central forest community (arrived with fab lab Peru)

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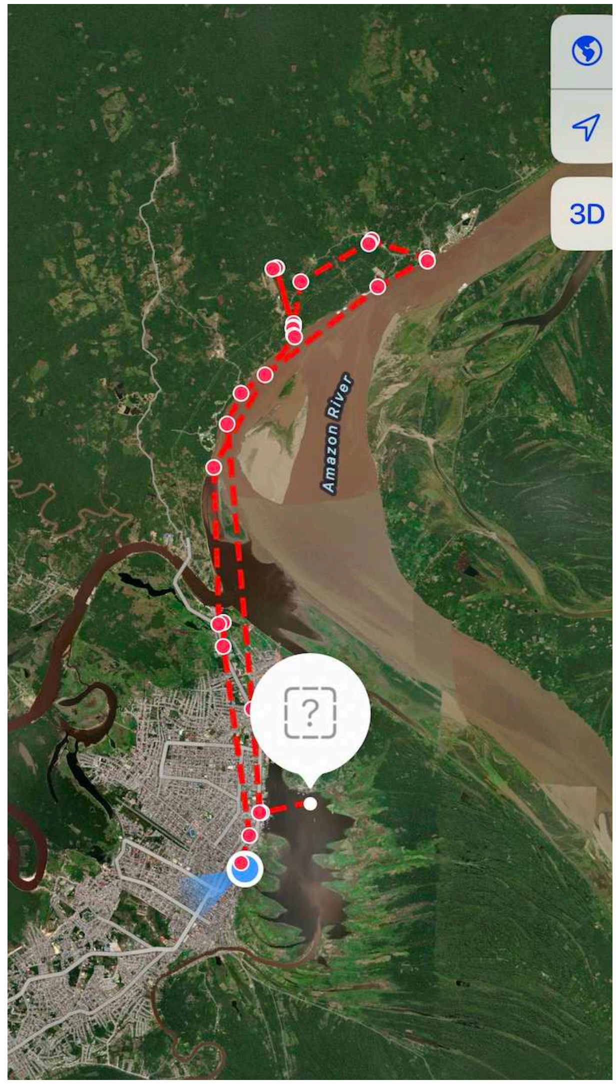

Figure 9: The pathway of travel into the Amazon Rainforest during the first meeting in 2025

The meeting involved a primary focus on hygienic materials and mosquito care. The week was bracketed by two workshop sessions in Iquitos: one at the beginning to open the topic space and one at the end to reconvene after site visits and interviews. I designed the workshop as a co-creation format rather than a presentation. The goal was to identify what the community leaders wanted to protect, share, or refuse when they considered how their stories, plants, and practices might be used in the future.

During the week, alongside the other research and workshops, 6 interviews were conducted to gather information about the possible stories and concerns in the lives of these communities. The interviews were focused on mosquitoes but were constructed in a human-centric approach to be led by the interviewee and their experience of life and desire to share.

Figure 10: the research group visiting the 'Mother of the Forest'

Figure 11: community member on the boat on the Amazon River heading to the Murui Bue community

4.1.1.1 The Workshop Method

The workshop drew directly on the Liberating Structures and physical-facilitation methods catalogued by SessionLab: Nine Whys as a way of driving from surface topic to underlying purpose (SessionLab, "Nine Whys"); Drawing Together as a way of surfacing knowledge that words did not carry well (SessionLab, "Drawing Together"); Choose Your Words Wisely as a way of exposing where translation was carrying more weight than we could see (SessionLab, "Choose Your Words Wisely"); and Blind Drawing as an icebreaker to name, physically, the cost of imprecise description (SessionLab, "Blind Drawing").

Figure 12: one of the 5 workshop tables during their discussion

The language barrier in this particular group of participants was more crucial than just English to Spanish. The indigenous communities living in the forest all have their own indigenous languages which were later replaced by Spanish, and within the Spanish - their dialects were very varied.

The choices for the physical warm-up exercises and the continued use of pen and paper and drawing tools was to enable more cross-senses engagement with the questions to avoid getting hung up on specific phrasing which might be due to mistranslation or might become a distraction on semantics rather than an exploration of the actual topics at hand.

4.1.1.2 Structure

The design responses were:

- **Cross-sensory framing.** Physical warm-ups, pen and paper, and drawing tools were used deliberately so that responses were not bottlenecked at translation. A participant could point, sketch, or gesture. The choice mirrors the standard argument for visual co-design in cross-cultural settings (Sheehan, 2011) and Liberating Structures' claim that nonverbal drawing can surface latent knowledge that words compress out (SessionLab, "Drawing Together").

- **Physical introductions.** Each participant introduced themselves with a name, a sound, and a movement. One community leader chose the word for "thank you" in her indigenous language as her sound; the whole room adopted it as the working greeting for the rest of the week.
- **Five parallel tables with rotation.** Five tables were run in parallel, each with a facilitator and one English-speaking scientist. Participants rotated at ten-minute intervals so that no single group could capture a topic. The five topics were: intellectual property; co-creation; "what is research?"; entrepreneurship, ecosystems, governance and public policy; and community and product design / biomaterials. Facilitators translated in both directions and captured mind-maps in bilingual (Spanish–English) post-its.

4.1.1.3 Alignment

January 2025 agreed axes of benefit sharing include the following parameters: Knowledge exchange. Consistent support. Support in conversations on IP sharing and IP definitions.

On the following days of the event we visited the physical sites of the Murui Bue Community and the Etna Kukama Community. Members of the communities beyond the community leaders met with me and members of the P&G team. These were meetings in which further discussion of the collaboration happened, the fears and desires of the community members were discussed. Individual community members shared their existing plant usages for which they wanted efficacy input from the scientists. This was also the period in which interviews by P&G were conducted.

On the final day of the alignment trip, after conversations with the general community members, another alignment meeting was held in Iquitos, to which the community members came again, as well as members of their communities who had previously had conversations with the scientists. During this meeting the P&G scientists gave their first presentation on efficacy processes to begin the benefit sharing commitment on teaching efficacy procedures.

Figure 13: P&G scientist shares the process on how to test the efficacy of a mosquito repellent using a Y-tube method and a human-experiment method.

4.1.2 The Interviews

Six semi-structured interviews were conducted across the week, in two clusters: one at the beginning, one during the community site visits. Interviewees were community members and community leaders across the participating communities, and included both women and men across a wide age range. The interview protocol was designed to be led by the interviewee and to let the conversation move where they took it. The interviews are internal to the collaboration. Transcripts were shared back with each interviewee and with the participating institutions. At the time of this thesis the agreement is that these transcripts are not for publication.

Constraints and caveats of the interview method:

- **Language.** Every interview passed through at least one layer of translation, and in some cases two (indigenous language to Spanish to English). Translation happened in real time through volunteer interpreters.
- **Trust and time.** All six interviews took place inside the first week of a longer relationship. Interviewees had, at most, days of prior contact with the interviewer. Sensitive topics were approached by allowing the interviewee to nominate their own examples rather than by asking directly.
- **Interviewer positionality.** I am not an Amazonian community member. I do not speak the indigenous languages involved. The interviews are not and should not be interpreted as an ethnographic study. They were part of the alignment seeking and benefit-sharing foundation to ensure that every participant of the collaboration felt heard and that they had the agency to speak up throughout the process.

Overlaps of findings across the six interviews:

1. When asked about struggles, interviewees named community-level problems first: land tenure and loss, forest fires, deforestation, waste, government relations, forced displacement, before naming individual or household concerns. Personal-scale answers required specific, leading follow-up. The impression given in these conversations felt like the community activity was placed before personal agency.

2. Ten years was described, unprompted, as a short period. Longer historical arcs - one to three generations - were the ordinary frame for talking about environmental change, plant availability, and disease burden. Short-cycle project timelines (six months, one year) do not align with the ways the community members view their own contributions and importance to their communities. From the conversation it became increasingly clear that they were expecting the same of us.

3. Concerns about ownership recurred throughout the interviews and the workshop mind-maps. The concern was not monetary. It was directed at the practice of stories, plant knowledge, and images being taken elsewhere and used without the community being able to see, correct, or benefit from the use. All of the communities were very clear in their request for transparent information about what was being done with what had already been shared.

4. Individual community members named specific plants they used and specific effects they observed, and asked directly whether the visiting scientists could confirm efficacy.

5. Interviews initiated on the topic of mosquito care moved fluidly into water quality, waste management, agricultural chemistry, and forest cover. The general state of life was deeply intertwined with the state of the forest.

6. Several interviews returned to the theme of ceremony - meals, greetings, and formal welcomes, as the surface on which trust was actually built. The symbolism of ceremony in these cases returns to respect and patience.

4.1.3 Outcomes of the Visit and the future

The alignment work accomplished during these visits resulted in the requirements constraints for the design of the field-lab inventory as well as the foundations of the ABS benefit sharing protocol which was developed from there on out.

Requirements for the field lab:

- ‣ **Local operation.** The lab must be operable by a community member after a short training, without dependence on a visiting scientist.
- ‣ **Result legibility in-community.** Efficacy results must be produced in a form that a non-specialist community member can read and use.
- ‣ **Plant-first inputs.** The measurement chain must accept locally prepared plant materials at the concentrations communities actually use, without requiring pre-purification in an off-site lab.
- ‣ **Bill-of-materials transparency.** Every component of the lab must be open, sourced with alternatives, and priced.
- ‣ **Physical durability in-forest.** The lab must survive the operating conditions of a rural community site - humidity, dust, intermittent power - without a lab technician.

4.2 Chile: A Case Study

The collaboration with Chile took place differently than the Peruvian one. A fab lab was still at the center of the collaboration, but instead of working directly with communities, in this case the collaboration was with Tomás Vivanco, one of the leads of fab lab Austral[2] the southernmost fab lab in the world, located in Chile, and his students at the *Pontificia Universidad Católica de Chile*.

This version of the collaboration focused on the design student cohort - and developing methodologies for them and with them to create sustainable hygiene solutions based on already known environmental knowledge specific to the Chilean biodiversity: we helped and advised the students as they sought to develop hyperlocal hygiene solutions in response to the suggested collaboration with P&G.

[2] https://www.fablabs.io/labs/fablabaustral

Hyperlocal Bio-Hygienic Technologies proposes a new approach for designing and producing sustainable hygiene solutions in Chile by recognizing local traditions, cultural practices, natural resources, and active community participation under the Fab City DIDO model (Vivanco, 2025). The course was designed to incorporate the same ethics and questions I asked when designing my own interactions with the groups participating in *HyTech-Peru*, but here the aim was to observe whether these methods would continue to be successful when multiple steps removed from the community. The students were working with knowledge already in the public domain, instead focusing on developing and evaluating their own prototypes created locally and how they might stand up to the commercial counterparts.

"**Jobs to be done**" is how P&G introduces their definitions of the product categories: instead of tackling individual products we were attempting to tackle their specific purpose in the consumer world. This also changes the lens of efficacy. Instead of identically replicating the product - the goal is to replicate the product outcome: if the same outcome can be achieved through vastly different locally sourced means - even if this requires a rethinking of the traditional 'product' this is a perfectly acceptable outcome.

Figure 14: P&G products used in the Chile Case study

The reverse engineering process started from seven P&G products. Laundry detergent: Ariel, Shampoo: Pantene, Toothpaste: Oral B, Deodorant: Old Spice, Dishwasher: Dawn, Shaving cream: Gillette, and Soap: Ivory. The students were tasked to approach each product from the point of view of the job it completes rather than an attempt to replicate the product itself. Throughout the 8-week experiment process the students had two designated sessions a week: one class session and one consultation session with myself, Tomás or a P&G representative to help answer questions and guide protocols.

The products were broken down into their characterising qualities: (e.g., cleansing, moisturizing, deodorizing), identifying each functional component (active ingredients, carriers, fragrances, preservatives), and mapping the manufacturing process (extraction, formulation, packaging). From the qualities they divided Chile into microzones to better analyse the biodiversity and the traditional use of the natural materials that was already known, in search of the qualifying materials that may help fulfill the sought-after quality: The North is arid, rich in minerals like lithium and copper. The Central zone is temperate, densely populated, and agriculturally productive. The South features forests, lakes, and a strong Mapuche cultural presence. The Austral zone includes Patagonia and Tierra del Fuego, marked by extreme climates and marine biodiversity (Vivanco, 2025).

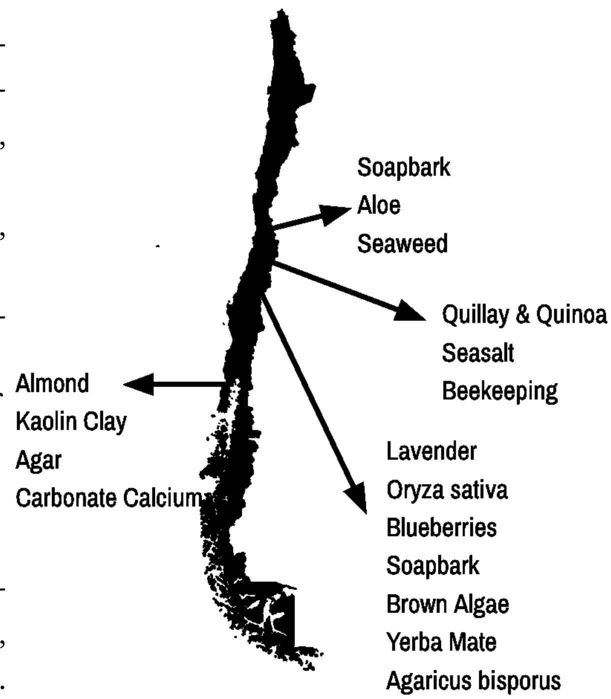

Figure 15: Map of Chile, with marked zones for naturally occurring biomaterials, created with the students of *Pontificia Universidad Católica de Chile*.

The mentorship and guidance in these sections on my end was advising the students and helping them develop the biomaterial recipes - as well as helping them understand how to assess if the ingredient that they were going to use was effective at the job they were wanting it to fulfill. For this chapter to outline process I will document one of the process protocols. In the efficacy chapter I will go through all the various prototypes designed within the scope of the class.

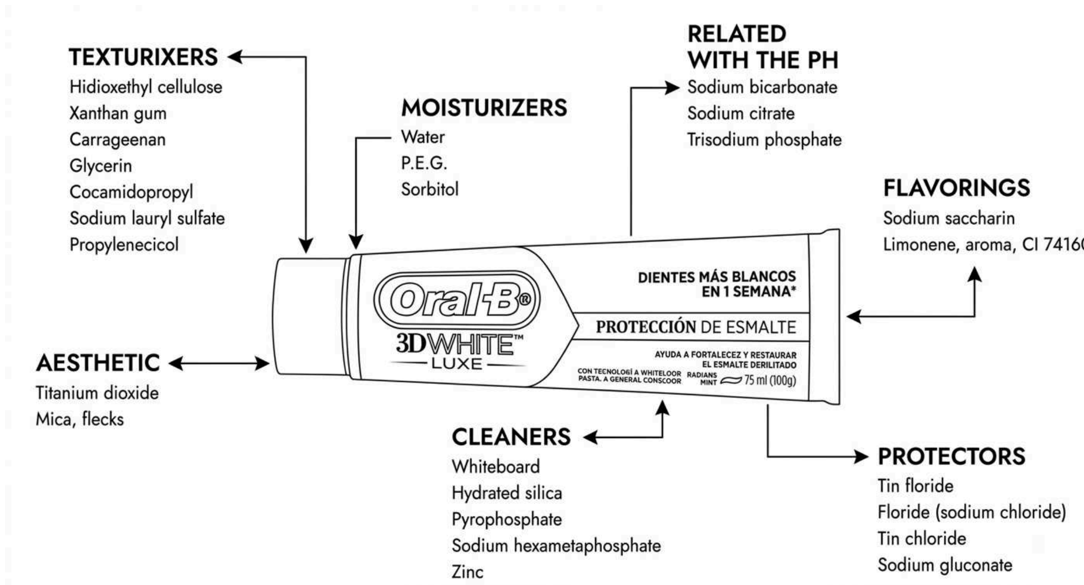

Figure 16: components in Oral-B toothpaste, as can be understood from the ingredients list

Firstly, each ingredient on the list of the original product is matched with a locally sourced alternative. Since we were working with the knowledge already in the public domain - the research was to investigate which separate ingredients had already been in conversation on being good locally sourced solutions for dental care: such as kaolin clay (Gonçalves et al., 2024) which was investigated amongst other clays as being a suitable mineral abrasive for dental care, as well as the antibacterial properties of xylitol and mint (Riley et al., 2015). Although the evidence for xylitol is somewhat disputed (Mickenautsch & Yengopal, 2012) if compared directly to fluoride.

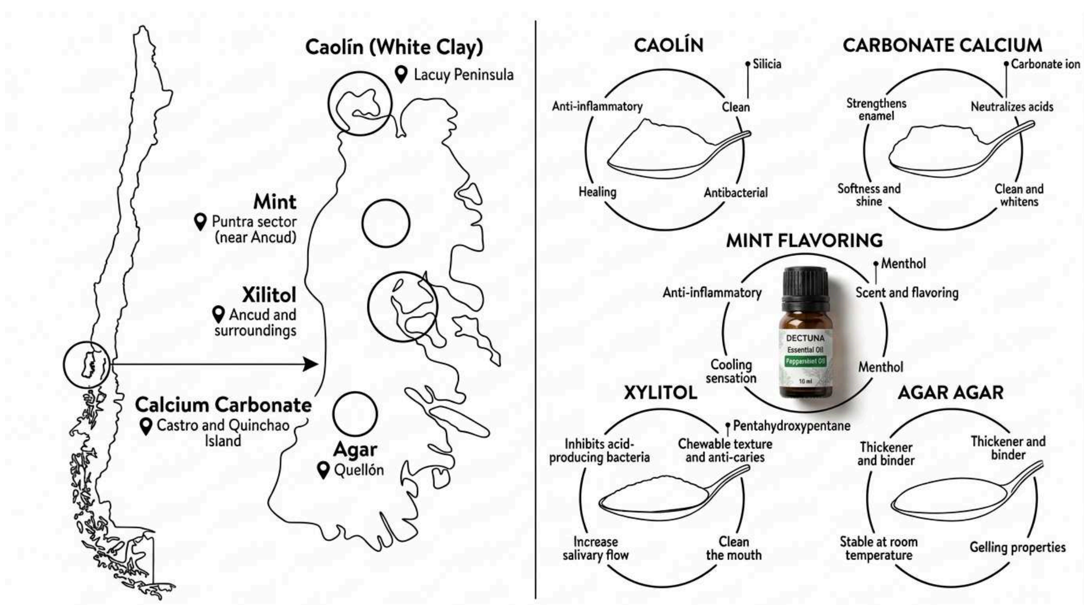

Figure 17: oral-b components replaced with locally sourced alternatives

After this I assisted the group of students to create 3 recipes of different formulations to test for flavour, texture and smell: optimizing for consumer experience, until ultimately choosing the 3rd recipe for the final formulation.

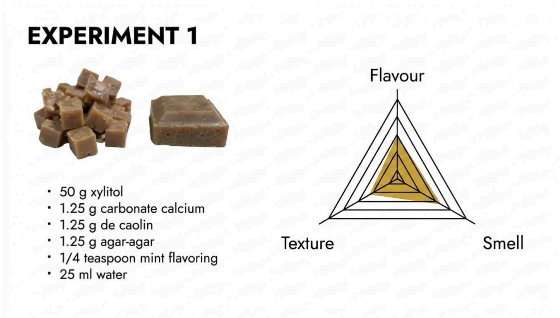

Figure 18: experiment 1 recipe breakdown

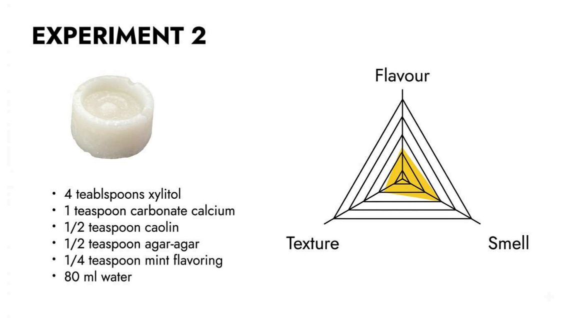

Figure 19: experiment 2 recipe breakdown

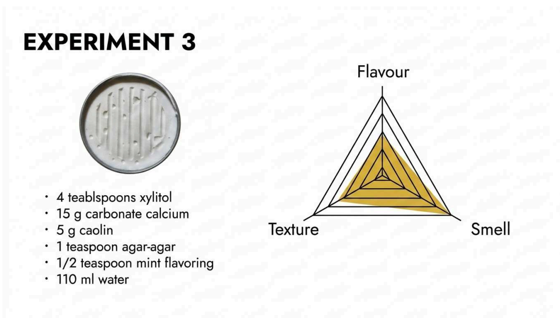

Figure 20: experiment 3 recipe breakdown

Figure 21: Territorial Bio-hygiene final solution: *Firkü*

A final - incremental - prototype was developed by proposing a specific interaction experience and offering a unique local identity, that could be produced by the local communities. The same process was completed by six other groups of students during the same cohort period. With all of them we collaborated on the formulation of the recipes as well as their evaluation. In the final outcomes *Ariel* detergent becomes a papaya-based bar of detergent inspired by the water crisis in northern Chile, optimised for less water usage. *Ivory* soap becomes *Küllayko*, a hypoallergenic powdered soap based on ancestral Mapuche knowledge using powdered soapbark.

Figure 22: the final hyperlocal prototypes developed by the students of the Diseño UC

Old Spice deodorant turns to *Nature*, a stick made from cornstarch, sodium bicarbonate, boldo and matico leaves, drawing on Chilean folk remedies for skin health. *Dawn* dish soap becomes *Raíces*, a solid bar built on quillay and quinoa saponins, bee wax, and sea salt, cutting out synthetic surfactants entirely. *Pantene* shampoo becomes *Pantenina*, a capsule shampoo blending soapbark, lavender, rice, yerba mate, blueberry, and brown algae, sourced from the Maule region's agricultural surplus. *Gillette* shaving foam becomes *Lacustre*, an almond-milk-based shaving soap with rosehip oil, almond oil, and kaolin clay, reflecting the dairy and lake culture of Los Lagos, taking its design inspiration from old fashioned shaving soap kits. (Vivanco, 2025)

5 Designing a Field Lab

A field lab in the context of this research is a miniature portable lab that should allow users to assess and measure the capabilities of biologically derived products from traditional knowledge. Of course the inventory of the lab is not limited exclusively to the use for indigenous science - however it is designed with the purpose of being operated by non-'expert' users and being able to withstand unstable power and weather conditions.

Inspired by the Fab Foundation's *FabinABox*[3] (which was a collection of minimal cost machines to complete the most minimal defining tasks of a fab lab) the fieldlab is aiming to approach metrology in the field through the same lens: What is the bare minimum inventory with the most diverse use?

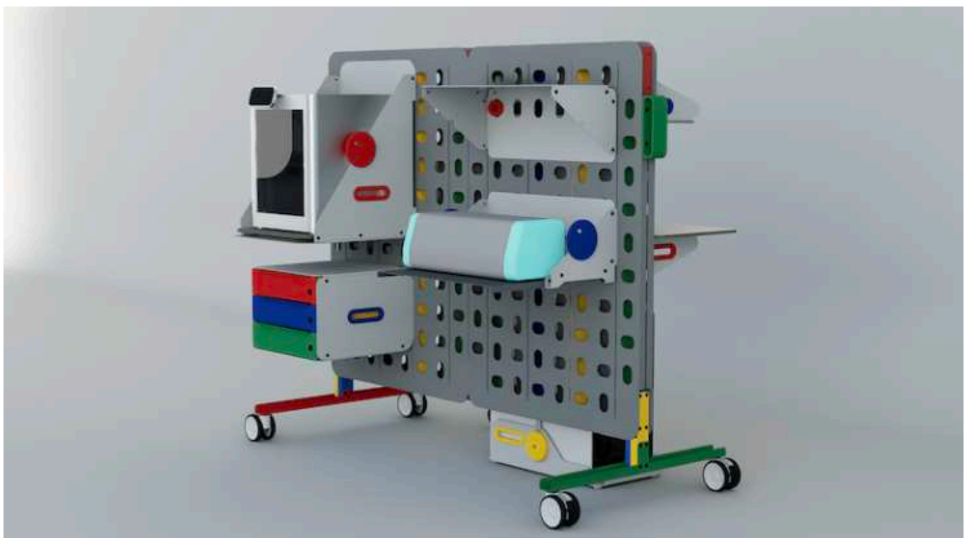

Figure 23: FabinABox render as taken from fabfoundation.org: Designed for field prototyping and training where a full Fab Lab isn't feasible. Featuring a 3D printer, a vinylcutter and a lasercutter

A key difference from the *Fab in a Box* model is that the field lab is not one unified product or box (although it is an active research topic for the future of the project) - but more a surveyed evaluation of the current low-cost accessibility points for various metrology and biology entry activities. The process of designing the inventory and surveying the state of the currently available metrology tools and the protocols they enable is possible because this work stands on the wide foundation of open-source biology tools created over the past 20 years. Prakash's frugal-science lab at Stanford (Bhamla et al., 2017; Byagathvalli et al., 2021; Cybulski et al., 2014; Li et al., 2019; Mukundarajan et al., 2017); Pearce's open-source-hardware programme (Pearce, 2012) (Pearce 2013); the Public Lab community's spectrometry work (Public Lab, n.d.); Bow-

[3]https://fabfoundation.org/fabinabox.html

man and colleagues' 3D-printed OpenFlexure (Collins et al., 2020); Bento Lab's suitcase molecular workstation (Bento Lab, n.d.); the Weidmann/Ahmed mobile suitcase-lab consortium (Kobialka et al., 2025); the OpenPCR and NinjaPCR open thermocyclers; the Hackteria and GaudiLabs DIY-biology networks; the DIYbio community anchored at Genspace and BioCurious (Kean, 2011; Landrain et al., 2013); the Global Open Science Hardware movement (*Global Open Science Hardware Roadmap - Gathering for Open Science Hardware*, 2017; *GOSH Manifesto - Gathering for Open Science Hardware*, 2016).

The background of created tools is vast in the 21st century, but in my particular case I was aiming to identify a limited set of tools that could benefit the communities in the forest in a variety of ways. The worst outcome of this work would be to add to the mass of useless plastic and metal that would pollute the forest because no one had anything useful to do with it. I wasn't looking for glamorous machines or to dazzle the occasional conference audience member with the *out of this world bioengineering feat we achieved in the forest*. Slow and steady, the goal was to select tools that could be used in a variety of ways without needing much maintenance, through which the communities could repeatedly complete effective protocols to fulfill their requested inquiries, and then build from there.

5.1 From Making to Measuring: What Makes a Lab in a fab lab a LabLab

A field lab, in the sense that it is used in this thesis, is the smallest set of capabilities that lets a community test their own hygiene products for efficacy. It must be operable by the community, not by a visiting researcher. It must - at its most intense - survive humidity, dust, transport, and inconsistent power. High performance, low cost, easy access, portability: drawing on the articulation of *frugal science* as given by the Bhamla Lab (Byagathvalli et al., 2021). Across this research multiple different labs were set up for varying purposes for different uses, in each case to be used by relatively 'untrained' individuals.

5.1.1 Capabilities

From the original alignment workshops in Iquitos with the communities several key capabilities stood out that were flagged as being of key importance to the communities themselves.

Within the HyTech - Peru case-study we aimed to develop two different types of lab.

- Level 1 Lab: The community Lab - These are stationary Labs capable of housing more energy demanding infrastructure. These are labs that users travel to - but that are more accessible than seeking out a university or industry lab for external lab work.
- Level 2 Lab: Mobile Lab - this is a smaller and cheaper subsection of equipment that is less power-hungry, and thus able to withstand the conditions of being out and about in the forest.

From those requirements multiple versions of the fieldlab inventory were developed. In a key difference to the fab lab inventory - biology remains a highly customised and specialised field - between wetlab biology, synbio and metrology there are many different directions a lab infrastructure could decide to go. Across our case studies we got to explore multiple different directions.

In my initial conversations with Beno he had a wishlist: Tools and machines he believed would make the biggest difference to the communities.

In this chapter I will outline the wishlist and take us through the first iteration of the lab inventory and then review the mistakes and one-way streets we stumbled down in our minds when chasing fancy toys.

5.1.1.1 Microscopy

Across most use cases, whether for education or evaluation, microscopy remains one of the most versatile tools in our repertoire.

The low-cost microscopy landscape is well populated. The Foldscope (Cybulski et al., 2014), the Hackteria DIY microscope stage, the OpenFlexure microscope (Collins et al., 2020) is fully 3D-printed with sub-micron resolution, demonstrated for malaria diagnosis in Tanzania. The Prakash lab's Octopi (Li et al., 2019) and Octopi 2.0 (2025) push into automated slide scanning with on-device AI, driven by open Squid electronics (Li et al., 2020). Planktoscope extends the same platform to flow-through aquatic microscopy.

Figure 24: OpenFlexure microscope

Since the initial protocols of this research focused on hygiene and assessing specifically haircare and mosquito repellency, the primary capability of the microscope we needed was to be able to investigate skin to be able to assess moisture.

When selecting a machine it was key to avoid anything that required a laptop or computer to be operational but instead relied on phones as their screens. I selected a benchtop HDMI digital microscope with an LCD screen, a wireless USB microscope that connects straight to any phone via Bluetooth and a skin analysis microscope - which due to its built-in display and skin-friendly adapter was surprisingly robust and travel-friendly.

5.1.1.2 Spectrophotometry

One of Beno's key desires from the very beginning was a spectrophotometer. The spectrophotometer reads absorbance of a liquid across a wavelength range. It could help with the quantification of active compounds in plant-based repellent formulations, and surfactant concentration in shampoo formulations. The open-hardware spectrometry literature is smaller than microscopy's but active. Public Lab's DIY spectrometry kit (Public Lab, n.d.) pairs a webcam with a diffraction grating and there have been other subsequent designs published. The initial selection for the kit was a "721" class visible-light benchtop spectrophotometer, however it would not help with any UV-based chemistry. While a spectrophotometer is still on fab lab Lima's wishlist, for this current iteration it was removed from the kit.

5.1.1.3 Moisturemeter

Since so much of the hygiene world is analysing a compound's effect on skin and moisture, a moisturemeter was a capacity that the communities asked for to assess the actual skin moisture barrier. The Delfin MoistureMeterSC[4] is a 4000USD device, so instead one of the protocol designs in the efficacy chapters makes use of skin microscopy to assess moisture levels in the scalp instead.

5.1.1.4 Water Analysis

A simple set of tools to analyse pH, EC, TDS, temperature, via a pocket multi-parameter.

5.1.1.5 Viscometry

While not part of our initial protocols, a viscometer will be helpful for future repetitions of protocols to ensure consistent viscosity, especially of haircare products.

[4] https://www.delfintech.com/products/moisturemetersc

5.1.1.6 UV Imaging

We added a simple UV mirror to the kit for the communities to review topical UV coverage qualities that some plants may have. While it cannot provide any indication on SPF, it is an easy tool to assess whether or not any UV reactiveness is present.

5.1.1.7 Sample Preparation

Across the board for biomaterials and general extractions, emulsions, resuspensions: a blender is always a good choice from the DIY bio world.

5.2 The Kit:

The very first version of the kit ran just under 2500 dollars, but also featured multiple ambitious machines that were not strictly necessary for the protocols we were finalising, but did open up pathways for future growth.

Item	**Cost**
Digital Microscope	$199.99
Portable Spectrophotometer 721	$269.00
Cuvettes (disposable)	$43.99
Multi-Parameter Pocket Tester Kit	$131.64
Rotary Viscometer	$299.00
Thermal Imaging Camera	$198.95
Infrared Thermometer Temperature Gun	$64.99
UV Camera for Sunscreen Test	$37.99
Wireless Digital Microscope	$28.48
Countertop Blender	$129.99
Total	**$2,429.52**

As with most cases the first iteration of anything never truly fulfills what one sought after. After the first attempted iteration the kit became radically smaller and focused itself on its usefulness to the current efficacy test cases, which were haircare and mosquito repellency.

Porto Copa Equipment (Level 1)
Y-tube olfactometer (glass, two-arm)
Air pump
Pressure regulator and gauge
Tubing
Humidifying flask

Porto Copa Equipment (Level 1)
Charcoal flask
Flow meters (×2)
Sample vials
Pipette
Collection chamber (ventilated)
Stopwatch
Camera
Benchtop digital microscope (HDMI, LCD screen)
Wireless digital microscope (phone-connected)
Skin analysis microscope
Rotary viscometer
Multi-parameter pocket tester kit
Infrared thermometer
UV camera
Countertop blender

Northern Forest Labs - Level 2: portable equipment
Skin analysis microscope
Benchtop digital microscope (HDMI, LCD screen)
Wireless digital microscope (phone-connected)
Graduated syringes (dosing)
Graduated cylinders, 25 ml (foam)
Graduated containers (rinse volume)
Stopwatch
Camera
Participant data sheets
Rotary viscometer
Multi-parameter pocket tester kit
Infrared thermometer
UV camera
Countertop blender

The new kit variants were more specialised to both the tasks the communities are currently facing as well as their location and needs. The level 1 lab is placed in Porto

Copa, a physically permanent lab with a dedicated community team that maintains it. The level 2 lab travels to the northern communities when they find or want to test their plant solutions.

The efficacy chapter will unpack protocols for both inventories within the framework of haircare and mosquito repellency.

6 Proving Efficacy

The efficacy protocols were developed in collaboration between myself and P&G scientists who agreed to share their methodologies as part of the benefit sharing agreement. The guidance took place multiple times during the shared visit as well as continuously digitally via Zoom calls with fab lab Lima (who then shared the guidance with the communities) and with the students of the biolocal-design cohorts.

6.1 Peru

The protocols for testing were developed by myself, P&G scientist consultants and fab lab Lima at a distance. The protocols were executed locally by the fab lab Lima employees with members and participants from the indigenous communities with the purpose of educating the participants.

6.1.1 Mosquito Repellency

The first test case of both the design methodology, the toolkit, and the collaboration and communication infrastructure was the evaluation of the mosquito solutions in the community. This efficacy test has to evaluate multiple things in parallel. On the one hand it is evaluating the efficacy of the mosquito repellent itself; on the other hand it is evaluating the viability of the designed lab-kit.

The repellency assays were conducted at the Instituto Ashaninka in Satipo. Twenty members of the native communities of Puerto Ocopa, Atahualpa, San Pascual, and Cubant, together with representatives of the Tsipana Jampi Association, participated in the session.

For the mosquito repellency samples, the Native Community Cubantia (Satipo) brought three of their own samples coded R-AS-01, R-AS-02, and R-AS-03. For the protection of the natural resource within the collaboration the decoded name of the samples is kept by the appointed community research lead within the Cubantia community - for the disclosure of current research the sample names shall remain coded.

Materials

1. Y-tube olfactometer: A Y-shaped glass tube with two arms: https://www.insectolfactometer.com/product-page/y-tube-olfactometer-for-entomology
2. Mosquitoes: Mosquitoes captured between 10 to 60 minutes before the test, at a distance of 10 m from the laboratory.
3. Air supply: Air pump with clean air for the olfactometer.
4. Test Materials: 3 substances to test (separate trials).
5. Collection chamber: Mosquitoes stored separately in a ventilated space.

6. Data recording tools: Manually operated stopwatch.

Figure 25: The participants in the mosquito repellency test with the experiment materials and set up

The dual-choice Y-tube olfactometer assay was implemented following the design principles shared with the community by the P&G scientists who were advising the community on how to conduct the experiment.

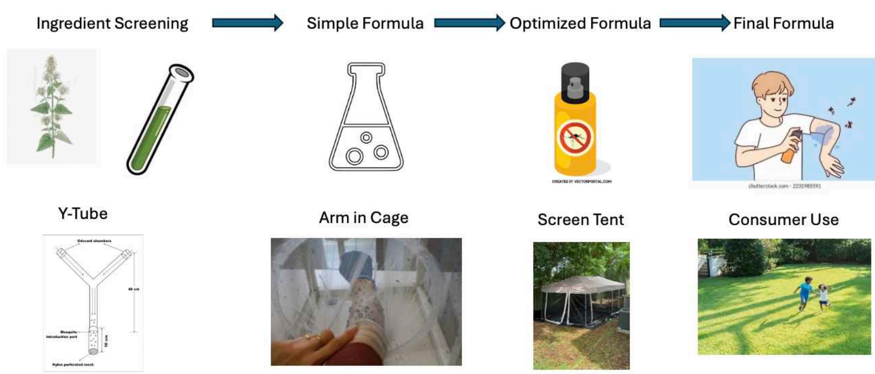

Figure 26: mosquito repellency efficacy process

The Y-tube was cleaned, dried, and connected to two odour reservoirs: the treated arm containing the test sample at defined concentration, and the control arm containing clean air. A constant airflow of 200–300 mL·min^{-1} was drawn through both arms simultaneously to produce a laminar odour gradient at the choice point.

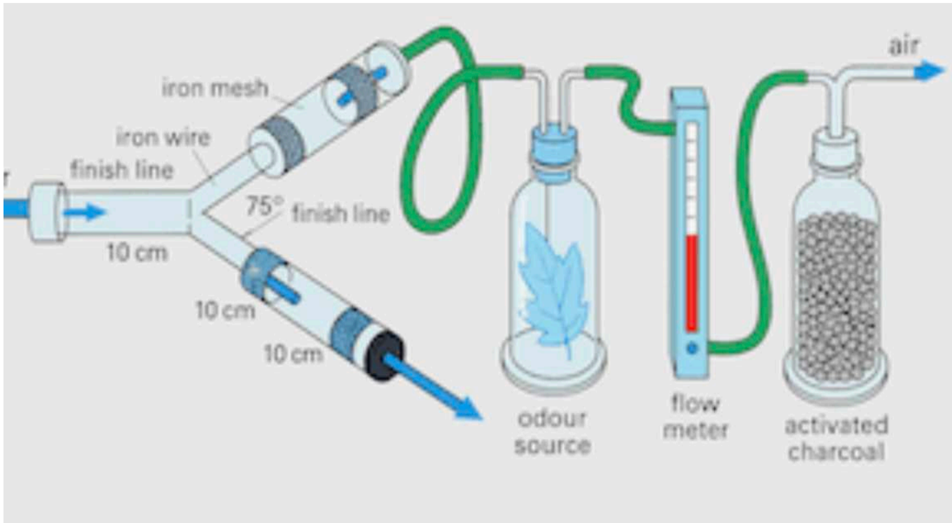

Figure 27: Olfactometer set up diagram

Mosquito Assay protocol

1. Preparation of the Y-tube olfactometer

1. Clean and dry the Y-tube.
2. Connect the pump, pressure regulator, and gauge to the tubing system.
3. Route tubing through humidifying/charcoal flasks into each arm of the Y-tube.
4. Set the air pump to deliver a constant flow (200–300 mL/min) through each arm.
5. Confirm flow rates are equal on both arms using the flow meters before starting a trial.

2. Setting up odor sources

6. Load the test material (repellent/odor sample) into a vial using a pipette.
7. Place the loaded vial at the inlet of one arm.
8. Leave the second arm connected to clean air only - this is the control side.

3. Preparing mosquitoes

9. Select healthy, non-blood-fed female mosquitoes.

10. Use mosquitoes fresh - no holding period before the assay.

4. Conducting the assay

11. Introduce 10 mosquitoes into the central arm of the Y-tube.
12. Allow 10 minutes for mosquitoes to choose an arm.
13. Observe and record how many mosquitoes enter each arm.

5. Data collection and analysis

14. Photograph/video each arm at the end of the choice period.
15. Count mosquitoes per arm: repellent side vs. control side.
16. Repeat across replicates and concentrations.

$$\frac{\text{Total number of Mosquitoes} - \text{Mosquitoes in active arm}}{\text{Total number of Mosquitoes}} \times 100\%$$

Results

<table>
<tr><th></th><th>Sample</th><th>Concentration</th><th>Total # of Mosquitoes</th><th># of M. in active arm</th><th>% Repellency</th></tr>
<tr><td>1</td><td>R-AS-01</td><td>100%</td><td>10</td><td>4</td><td>60%</td></tr>
<tr><td rowspan="4">2</td><td rowspan="4">R-AS-02</td><td>100%</td><td>10</td><td>0</td><td>100%</td></tr>
<tr><td>50%</td><td>10</td><td>0</td><td rowspan="2">90%</td></tr>
<tr><td>50%</td><td>10</td><td>2</td></tr>
<tr><td>30%</td><td>10</td><td>0</td><td>100%</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">R-AS-03</td><td>100%</td><td>10</td><td>0</td><td>100%</td></tr>
<tr><td>50%</td><td>10</td><td>2</td><td>80%</td></tr>
</table>

Table 1: Repellency results across samples R-AS-01 to R-AS-03

Analysis of repellency test results

The table summarizes repellency tests performed with three natural repellent samples (R-AS-01, R-AS-02, and R-AS-03) at different concentrations (100%, 50%, and 30%). Each test involved 10 mosquitoes, and repellency was measured by the number of mosquitoes entering the active arm and the resulting percentage of repellency.

Sample R-AS-01 at 100% concentration, repellency ranged from 60% to 100% across two replicates. This variability may indicate differences in application uniformity, evaporation rate, or test conditions. No tests were performed below 50% concentration for this sample.

Sample R-AS-02: Achieved 100% repellency at both 100% and 30% concentration, and 90% at 50% concentration. These results suggest a strong and consistent repellency effect even at lower concentrations. The low number of mosquitoes in the active arm (0–2) indicates good efficacy and stable performance.

Sample R-AS-03: Showed 100% repellency at 100% concentration and a drop to 80% repellency at 50% concentration. This suggests a strong dose-dependent effect and potentially lower volatility or persistence compared to R-AS-02.

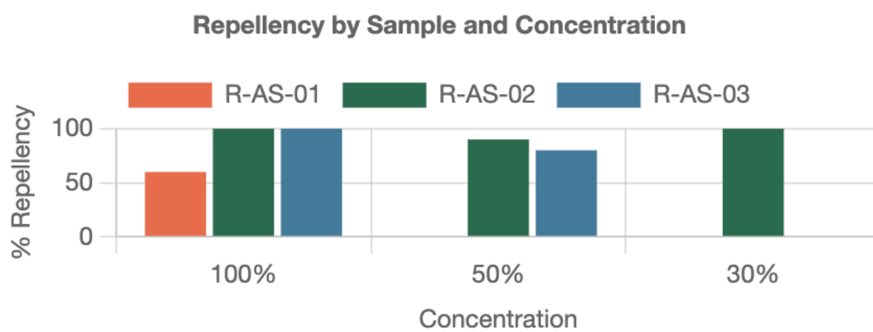

Figure 28: Repellency by concentration (chart)

6.1.1.1 Conclusions

All three samples demonstrate strong repellency at full concentration, with R-AS-02 also performing exceptionally well at reduced concentrations. Formulation Potential: R-AS-02 appears particularly promising for formulation optimization, as its high efficacy at 30% suggests the possibility of lower production cost per unit without sacrificing performance.

In a feedback session with Beno and the participants following the assay test in Satipo the following conclusions were made: These preliminary trials have strengthened the capacity of the local team to conduct efficacy assessments. Further experiments are planned, including tests with plant combinations, for which clear mixing criteria will be established.

The community members requested that, to enhance measurement accuracy, future protocols should incorporate real-time behavioral monitoring using infrared cameras integrated with AI analysis, enabling detailed characterization of mosquito responses throughout the assay.

6.1.2 Hair Care

Following the same structure as the mosquito samples, here again we asked the community leaders to share their samples with us under codenames only. The choice to share the compounds of their research should remain with the communities.

The Haircare tests were a test case for the **Level 2 Lab**, which is the smaller inventory that can be more distributed across multiple communities as they identify plants with helpful properties. The primary tool of the investigation was the portable skin microscope. 13 participants across 4 communities participated in these tests: Pangoa, Mazamari, Cubantia, and Río Tambo, with ages ranging from 17 to 63. For these tests the participants agreed to disclose their own names and genders. The Fab team was present in person during all experiments, as it was requested by the participating communities.

For haircare, the samples were not singular extractions, but combinations of multiple plants tackling different needs of a haircare product. The most traditional hair products used in Native communities focus on hydration, toning, and overall scalp health, rather than sebum removal. The methodology consisted of exploring similar applications (fat removal) for other uses. In the three Amazonian communities studied, more than forty plant species were identified for hair care applications. These included roots with foaming properties, leaves with hydrating mucilage, fruits and peels with natural astringency, seeds rich in proteins and lipids for repair, and aromatic leaves that stimulate scalp circulation and hair growth.

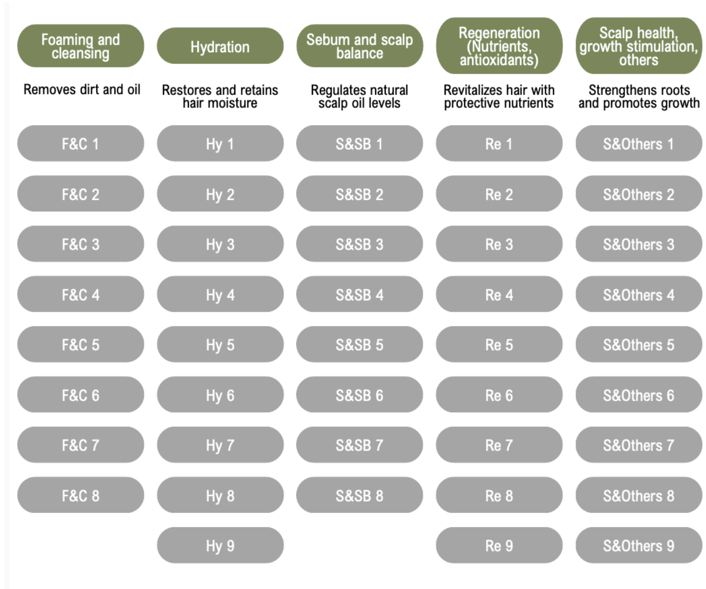

Figure 29: a list of all plants the participating communities collected with qualities applicable to haircare - plant identities coded for discretion.

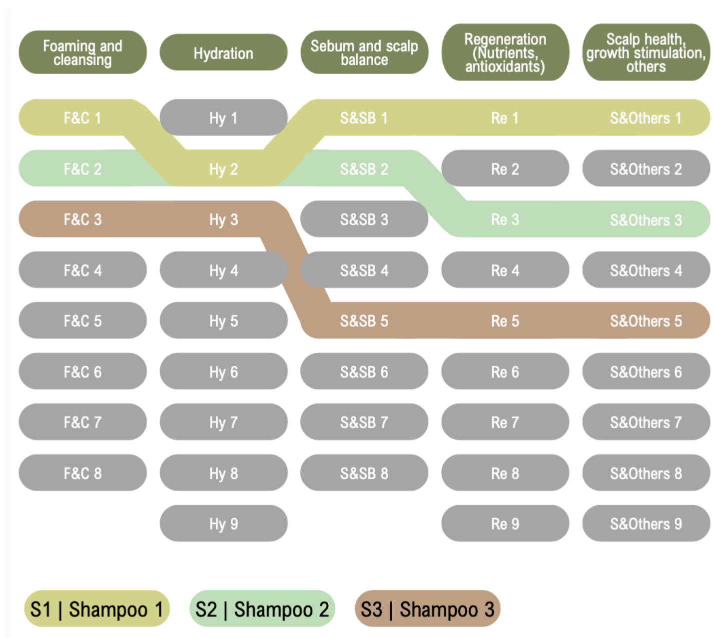

Figure 30: 3 Formulations for shampoo created out of a combination of multiple ingredients

Three formulations - S1, S2, and S3 - were developed from these ingredients, each drawing on different combinations across the five categories. Formulation choices were constrained by seasonal availability and the empirical knowledge of local elders. Some identified species were not in season or were difficult to obtain at the time of testing.

The samples underwent 3 different types of evaluation:

- Foam Test (to assess lather production)
- Scalp microscopy observation
- Olfactory

Materials

1. Native product formulations: Three shampoo formulations (S1, S2, S3) produced from locally sourced plant materials.
2. Reference product: Herbal Essences (P&G), used as the commercial comparison (HE).
3. Dosage measurement: Graduated syringes and cylinders for volumetric dosing (ml).
4. Rinse measurement: Graduated containers for recording total rinse water volume (ml).
5. Scalp imaging: Handheld digital microscope for pre- and post-wash scalp and hair-strand documentation.
6. Foam testing apparatus: 25 ml graduated cylinders for foam height measurement.
7. Data recording tools: Stopwatch, camera, and standardised participant data sheets.

6.1.2.1 Foam test

To evaluate the foaming capacity, a graduated-cylinder foam test was conducted. Two millilitres of the sample product were measured into a graduated cylinder, eight millilitres of water were added, and the cylinder was agitated for 3 minutes. Foam height was read immediately and documented.

Figure 31: image taken during the foam test

Foam Test protocol

1. Preparation

1. Measure 2 ml of the sample product (e.g. S1) into a graduated cylinder.
2. Add a fixed volume of water (e.g. 8 ml) to the same cylinder.
3. Cap or seal the cylinder to prevent spillage during agitation.

2. Agitation and measurement

1. Shake the cylinder for a standardized duration to generate foam.
2. Immediately read and record the resulting foam height (ml) against the graduated scale.
3. Calculate foam yield as a percentage relative to the starting liquid volume.

3. Stability comparison over time

1. Run two formulations (e.g. HE and NP) side by side, recording a start time for initial foam height.
2. Leave both samples undisturbed and record a closing time for final foam height.
3. Compare initial foam volume (higher = stronger surfactant activity) against retained volume (higher = better foam stability).

Results

Figure 32: Foam Experiment 1 - S1

Figure 33: Foam Experiment 2 - S2

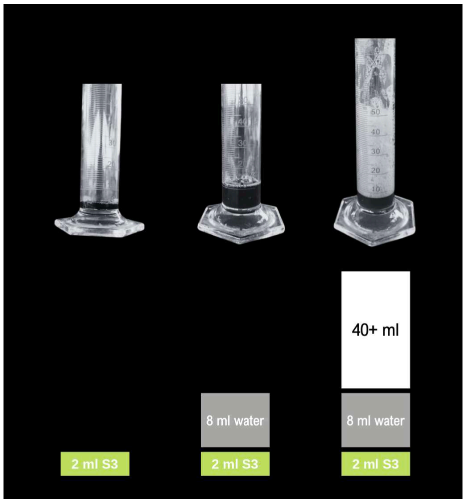

Figure 34: Foam Experiment 3 - S3

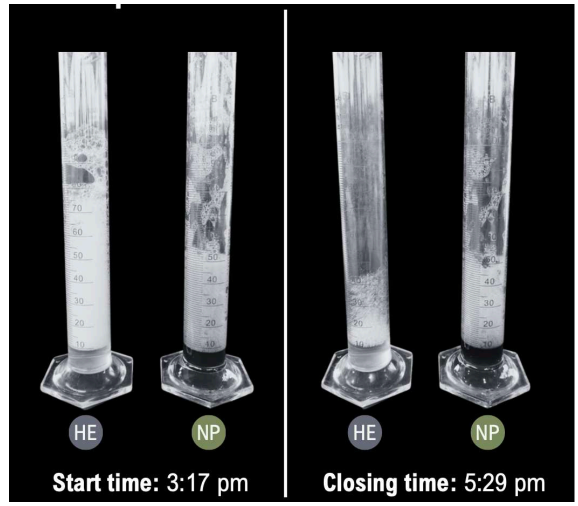

Figure 35: Foam Experiment 4 - two formulations HE: Herbal Essences (P&G Control) and NP: Native Product side by side

S1 generated a foam yield of 25%. S2 generated 250%+, overflowing the 25 ml cylinder. S3 generated 400%+, exceeding the capacity of a 50 ml cylinder.

Product	Sample (ml)	Water (ml)	Foam height (ml)	Foam yield
s1	2	8	2.5	25%
s2	2	8	25+	250%+
s3	2	8	40+	400%+

Table 2: Foam generation test: 2 ml sample + 8 ml water, agitated in a graduated cylinder. Yield = foam height ÷ starting liquid volume × 100%.

A foam stability comparison was conducted between Herbal Essences (HE) and a native product (NP) over a two-hour period. By the closing time, HE had decayed to approximately 30 ml, while NP maintained approximately 50 ml. Although the native product produced less foam initially, it seemed more stable over time, resisting collapse and drainage longer than the P&G commercial reference.

Product	Start time	Start foam (ml)	End foam (ml)	Decay
Herbal Essences (HE)	3:17 pm	70	30	−57%
Native Product (NP)	3:17 pm	50	50	0%

Table 3: Foam stability comparison over 2 hours (3:17 pm – 5:29 pm). HE generated higher initial volume but decayed to 30 ml; NP maintained its foam height throughout.

6.1.2.2 Scalp microscopy observation

Each participant underwent a split-comparison wash: one half of the scalp was washed with Herbal Essences (HE), the other with the assigned native product (NP). The protocol recorded three metrics per product per participant: dosage in millilitres, rinse water volume required for complete removal, and a subjective 1–5 comparison score. Hair was photographed before washing and after each product under standardised conditions, with a split-view image for direct side-by-side comparison.

Scalp microscopy observation protocol

1. Pre-wash documentation

1. Photograph participant's hair and scalp under standardised lighting.
2. Capture microscope images of hair strands and scalp surface for baseline.

2. Split-wash application

3. Divide participant's hair into left/right sections.
4. Apply the measured dose of Herbal Essences (HE) to one section.
5. Apply the measured dose of Native Product (NP) to the other section.
6. Record the exact volume (ml) of each product used.

3. Rinse and measurement

7. Rinse each section separately using measured water.
8. Record the total volume of rinse water (ml) required for complete product removal on each side.

4. Post-wash documentation

9. Photograph each half of the hair after drying for split-view comparison.
10. Capture microscope images of hair strands and scalp surface for each side.

5. Olfactory

11. Ask the participant to score each product on a 1–5 scale based on smell and texture.

Results

Participant	Age	Community	Formula	HE dose (ml)	NP dose (ml)	HE rinse (ml)	NP rinse (ml)	Rinse saved
Celyn	20	Pangoa	S1	10	30	2400	1800	25.0%
Veliza	50+	Mazamari	S1	10	10	2400	1200	50.0%
Myker	17	Cubantia	S2	10	10	1800	500	72.2%
Leonor	26	Pangoa	S2	15	40	3000	1800	40.0%
Elio	30	Pangoa	S2	10	10	1800	600	66.7%
Violeta	63	Pangoa	S2	15	40	2400	1200	50.0%
Isabel	54	Pangoa	S2	15	15	2400	1200	50.0%
Lili	17	Río Tambo	S1	10	20	2000	1000	50.0%
Disenia	17	Río Tambo	S2	10	15	2000	1500	25.0%
Rocio	17	Río Tambo	S1	10	20	2000	1500	25.0%
Astrid	17	Río Tambo	S2	10	20	3500	2500	28.6%
Tyobiri	17	Río Tambo	S2	5	15	1500	1000	33.3%
Jenifer	28	Cubantia	S3	10	20	2700	2300	14.8%

Table 4: Hair care trial results: Herbal Essences (HE) vs Native Product (NP) across 13 participants. Rinse saved = percentage reduction in rinse water when using the native product.

For better visualisation of the outcomes I broke the data down into multiple different views.

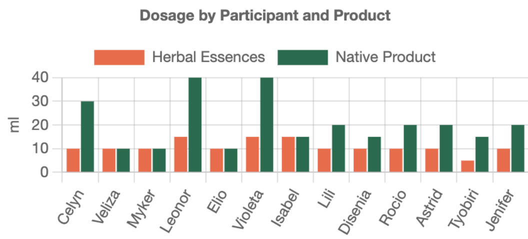

Figure 36: Products compared by dosage and participant

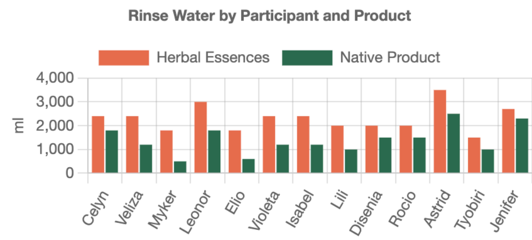

Figure 37: Products compared by amount of water required to fully rinse from hair

Overall the observable trends across the experiments show that whilst Herbal Essences requires less product to achieve clean results - it also requires more water to be removed from the hair. The participants, where the dosage of the native product was significantly larger than HE or the other NP, appear to have the longest and densest hair of the participants, which may have affected those results.

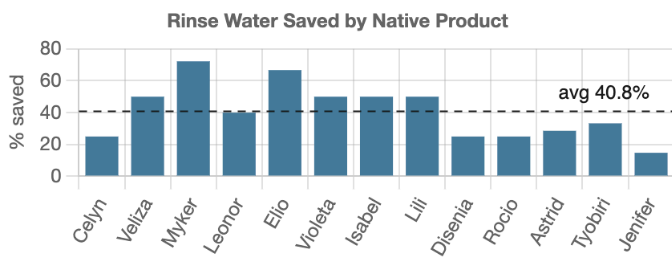

Figure 38: visualisation of rinse water saved by NP ordered by participant

S2 was tested on the largest number of participants (8 of 13) and showed the widest variation in rinse savings (25–72%), suggesting that individual hair type and application technique interact significantly with this formulation. Since it was also the larger sample size it is unclear if the other formulations would behave the same if tested on more people.

Figure 39: Jenifer

Figure 40: Astrid

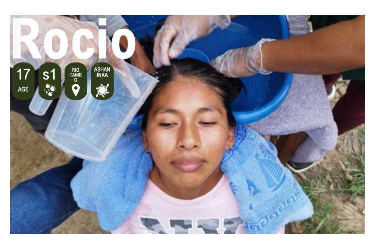

Figure 41: Rocio

Figure 42: Disenia

Figure 43: Lili

Figure 44: Isabel

Figure 45: Violeta

Figure 46: Elío

Figure 47: Leonor

Figure 48: Myker

Figure 49: Veliza

Figure 50: Celyn

6.1.2.3 Conclusions

The skin microscope allowed for a very detailed visual investigation of the hair follicle to assess the efficacy of the protocol and the natural ingredients. Across the sample size of the three formulations and the 15 participants, there was a visible trend that less water was needed to wash out the native ingredients. During the feedback sessions with Beno and the participants, the wish was expressed to continue these experiments with further formulations.

6.2 Chile

The Chilean protocols were developed under a different constraint than the Peruvian ones. The material under test was newly formulated by a design cohort from knowledge already in the public domain, and the question was narrower: does a locally sourced formulation reach parity with the commercial product it was derived from, on the job that product is bought to do?

The formulations of these Prototypes were done by the students of *Pontificia Universidad Católica de Chile*. The experiments were conducted locally by the students. I conducted mentorship and helped design the formulations for the experiments.

Reference	Prototype	Format	Primary functional test
Oral-B	*Firkü*	Chewable tablet	Sensory panel, 4 formulations
Pantene	*Pantenina*	Capsule shampoo	Wash trial, 12 users; pH
Ivory	*Küllayko*	Powdered soap	Paint-removal vs. water; pH
Gillette	*Lacustre*	Shaving soap bar	Shave trial, 3 rounds, 5 users each
Old Spice	*Nature*	Powder antiperspirant	Full-day wear, 2 users
Dawn	*Raíces*	Solid dish soap	Degreasing vs. Dawn, matched plates
Ariel	*Papay*	Laundry bar	Six-stain removal, 6 formulations

Table 5: The seven prototypes of the Diseño UC cohort, their commercial reference, and the primary functional test used to evaluate each.

The prototypes were evaluated through visual observations on moisture/cleanliness and user experience.

6.2.1 *Firkü* toothpaste tablet

Magdalena Carbone, Gracia Cruz, Monserrat Fernández, Agustina Phillips, Susana Ovalle

Ingredients sourced from Chiloé: kaolin (Lacuy Peninsula), calcium carbonate (Castro, Quinchao), xylitol (Ancud), mint (Puntra), agar (Quellón).

Exp.	Xylitol	$CaCO_3$	Kaolin	Agar	Mint	Water
1	50 g	1.25 g	1.25 g	1.25 g	¼ tsp	25 ml
2	4 tbsp	1 tsp	½ tsp	½ tsp	¼ tsp	80 ml
3	4 tbsp	15 g	5 g	1 tsp	½ tsp	110 ml
4	50 g	¼ tsp	¼ tsp	½ tsp	¼ tsp	45 ml

Table 6: *Firkü* formulations. Scored on flavour, texture, smell.

Results. Experiments 1 and 2 scored low on all three axes. Experiment 3 reached mid-scale. Experiment 4 scored highest and evenly, and was taken as final. Tablet holds in the mouth over two minutes. Six ingredients against the reference's twenty-six. Anticaries and antibacterial claims rest on published ingredient evidence; no microbial assay was available.

6.2.2 *Pantenina* capsule shampoo

Magdalena Corthorn, Francisco Encina, Antonia Farías, Daniela Olivares, Francisca Würth

Component	Per 100 ml
Quillay saponin	70 ml
Vitamin B5	6 ml
Vitamin B3	6 ml
Caffeine	6 ml
Alginate	12 ml
Linalool	6 drops
Sodium benzoate	5 ml

Table 7: Final *Pantenina* formulation. Twelve recipes made, four scored. pH 5.5.

Results. Combing after washing was reported as easier than the participants' usual product. Grainy texture divided opinion. Almost every participant raised the absence of lather; several could not judge when rinsing was complete.

6.2.3 *Küllayko* powdered soap

Antonia Leon, Sofía Navarrete, Monica Olivos, Valentina Pavesi, Josefa Venegas

From Mapudungun *küllay* (soapbark) + *ko* (water). Soapbark bark 45g - cleansing agent (triterpenoid saponin) Water 500ml cold, 50ml hot Agar agar 20g - gelling agent Aloe vera pulp 20g, rested 24h - moisturiser

Recipe	Variable	Outcome
1	Soapbark 25 g in 500 vs. 600 ml water	600 ml closest to reference; lacked density
2	Olive oil 137 g vs. 300 g	Separated into two phases; oily residue
3	Homemade glycerin 225 g vs. 450 g	Still separated; glycerin failed as emulsifier
4	Agar agar 2 vs. 4 tsp	4 tsp denser; carried forward
5	pH adjustment	All already within 4.5–6.5; no adjustment needed

Table 8: *Küllayko* formulation series.

Step	Specification
Boil	45 g soapbark bark in 500 ml water, 10 min
Dissolve	20 g agar agar in 50 ml hot water
Blend	Solution + agar + 20 g aloe vera pulp; rest 24 h
Dehydrate	50 °C, 30–40 min
Grind	To powder

Table 9: Final *Küllayko* preparation. Released open source with attribution to the named team.

Results. Users had to learn the dose, asked for a finer grind, and expected a scent.

6.2.4 *Lacustre* - shaving soap bar

Milla Aguirre, Bernardita Barros, Valeria Marsino, Isidora Vergara, María Luisa Vial

Almond milk soap 100g- base, cleansing Vegetable glycerin 18ml - humectant Rosehip oil 14ml - regenerating Almond oil 12ml - emollient Kaolin clay 10.5g - foam density, oil absorption Peppermint essential oil 0.5ml- soothing, fragrance

Round	Change	Panel	Result
1	5 recipes, oils and extracts varied	5 users, 22–60	Freshness and hydration without irritation; lather insufficient
2	Recipes 2 and 3 remade; brush introduced	5 users, 17–60	Brush materially aided lather; foam still short on density
3	Kaolin clay added	5 users, 14–59	Foam quantity and quality significantly improved; smoothness and hydration up

Table 10: *Lacustre* rounds. Panel axes held constant: smoothness, freshness, moisturising, cleaning, foaminess, soothing.

Component	Quantity
Almond milk soap	100 g
Vegetable glycerin	18 ml
Rosehip oil	14 ml
Almond oil	12 ml
Peppermint essential oil	0.5 ml
Kaolin clay	10.5 g

Table 11: Final *Lacustre* formulation.

Results. The addition of the clay added opaque abrasiveness.

6.2.5 *Nature* - powder antiperspirant

Function	Component	Proportion
Antiperspirant	Cornstarch	50%
Antiperspirant	Sodium bicarbonate	20%
Deodorant	Boldo	8%
Deodorant	Matico	8%
Deodorant	Rosemary	6%
Fragrance	Mint	8%

Table 12: *Nature* formulation, sourced from the Valparaíso region. Cornstarch from corn by-product under the INDAP programme.

Applicators: shaker (spillage), pressed powder (bicarbonate oxidised under compaction), sponge-tipped cardboard pen (retained).

6.2.6 *Raíces* - solid dish soap

Benjamín Arce, Álvaro Carvajal, Maksim Baeza, Sofía de Martino, Catterina Martini

Beeswax 44% - hardener, preservative Quillay and quinoa saponins 25.5% - surfactant Agar agar 12.5% - solidifier Sea salt 8.5% - pH stabiliser, preservative Sunflower glycerin 6.5% - humectant, solvent Distilled water 3%

Iteration	Outcome
1	Effective liquid at neutral pH; aroma too intense
2	Solidified; lacked homogeneity
3	Solidifier changed; homogeneous but insufficiently hard
4	Formalised: hardening, homogeneity, grip, aroma, texture

Table 13: *Raíces* iteration series.

Component	Proportion
Beeswax	44%
Quillay and quinoa saponins	25.5%
Agar agar	12.5%
Sea salt	8.5%
Sunflower glycerin	6.5%
Distilled water	3%

Table 14: Final *Raíces* composition.

6.2.7 *Papay* - laundry bar

Amelia Cathalifaud, Tomislav Cvitanic, Vicente Gajardo, Josefina Gutiérrez, Loreto Lagos, Camila Oliva

Quillay saponin 34% - surfactant Quinoa flour 33% - thickener, consistency Sea salt 16% - friction, oil absorption Cornstarch 9% - consistency Citric acid 4% - from lemon; antimicrobial, whitening Papain 4% - protease, from Chilean papaya Papaya essence 1.5% - water softening, fragrance

Exp.	Hypothesis	Quillay	Papain	Citric acid	Water
1	More surfactant improves removal	3.2 g	2.4 g	2.4 g	3 ml
2	Citric acid does not shift pH	3.2 g	0.8 g	4 g	3 ml
3	More enzyme is required	3.2 g	4 g	0.8 g	3.2 ml
4	Works at minimum water	3.2 g	2.4 g	2.4 g	1 ml
5	Works better at higher water	3.2 g	2.4 g	2.4 g	8 ml
6	Needs no water	3.2 g	2.4 g	2.4 g	0 ml

Table 15: *Papay* trials against a fixed six-stain panel: oil, soil, blood, coffee, tomato sauce, wine.

Component	Proportion
Soapbark (quillay) saponin	34%
Quinoa flour	33%
Sea salt	16%
Cornstarch	9%
Citric acid	4%
Papain	4%
Papaya essence	1.5%

Table 16: Final *Papay* composition.

Results. No formulation removed oil - papain is a protease, and the strongest effect was on blood and coffee. The zero-water condition failed because saponins need water to release. Applied without mechanical action the bar was ineffective. Chlorophyll from the quillay leaves stained the fabric.

6.2.8 Conclusions

The cohorts asked whether a locally sourced formulation performs against a P&G reference. Without the use of equipment or a dedicated labspace beyond the fab lab that they had access to, they were able to manufacture and test their prototypes to the most minimal viable efficiency.

6.3 Usability and Review of Future Work and Side-Quests

What the current kit cannot do is tell a user what is chemically inside a sample. The next stage that would be beneficial across the board is equipping the infrastructurally stable labs with those possibilities. There have been HyTech side-quests that pursued such a capability. Spectroscopy was already repeatedly on the communities' wishlists, and the most intriguing candidate for it was Raman spectroscopy. Raman spectroscopy reads the vibrational modes of molecules from scattered laser light. Unlike the wet chemistry it could partially replace, it is non-destructive, requires no reagents or consumables, and works on samples as they are: a formulation in a vial, a paste, a leaf extract. A reagent-free technique is attractive, lab consumables are consistently an issue in all community and open lab set ups as they are always subject to supply chains and running costs. However Raman also remains one of the more expensive specialist metrology tools, but being able to have a Raman spectrum would help the communities work towards understanding the consistency across their extractions.

6.3.1 Raman trials and side-quests in the lab

Not in the field but back in our CBA lab Sarra Fernandez and I embarked on a Raman quest: To assess whether the hygiene products are viable Raman targets, we tested multiple with the aid of Bruker on two instruments at opposite ends of the deployment spectrum: the HyperFlux PRO Plus (HFPP)[5], a high-sensitivity benchtop analyser, and the BRAVO[6], a handheld field spectrometer.

Neither of those would financially be an option for the field lab set ups, despite one being a handheld option, but it did give us interesting insights. For hygiene we analysed 5 products: a natural mosquito repellent, a DEET-based one, CREST toothpaste and Head&Shoulders Shampoo and a generic hand soap.

Figure 51: generic soap for spectra analysis

Figure 52: DEET-based mosquito repellent

Figure 53: head and shoulders shampoo

Figure 54: STEM natural mosquito repellent

Figure 55: crest toothpaste

[5] https://www.bruker.com/en/products-and-solutions/raman-spectroscopy/raman-process/hyperflux-raman-analyzer.html

[6] https://www.bruker.com/en/products-and-solutions/raman-spectroscopy/raman-spectrometers/bravo-handheld-raman-spectrometer.html?language_tags_1=English

Since mosquito was one of the Peru test cases, it was of particular interest to me what a comparison between a natural and a DEET-based repellent would look like, especially since the test cases of the communities performed so well in their local Y-tube tests.

In the repellent comparison, the dominant peak of the commercial sample was identified as diethyltoluamide (DEET), which is the identifiable red peak at 1000 spectrum. In future analyses I would be particularly interested to compare the commercial natural deterrent data to the data from the communities if we ever have the opportunity to analyse their samples.

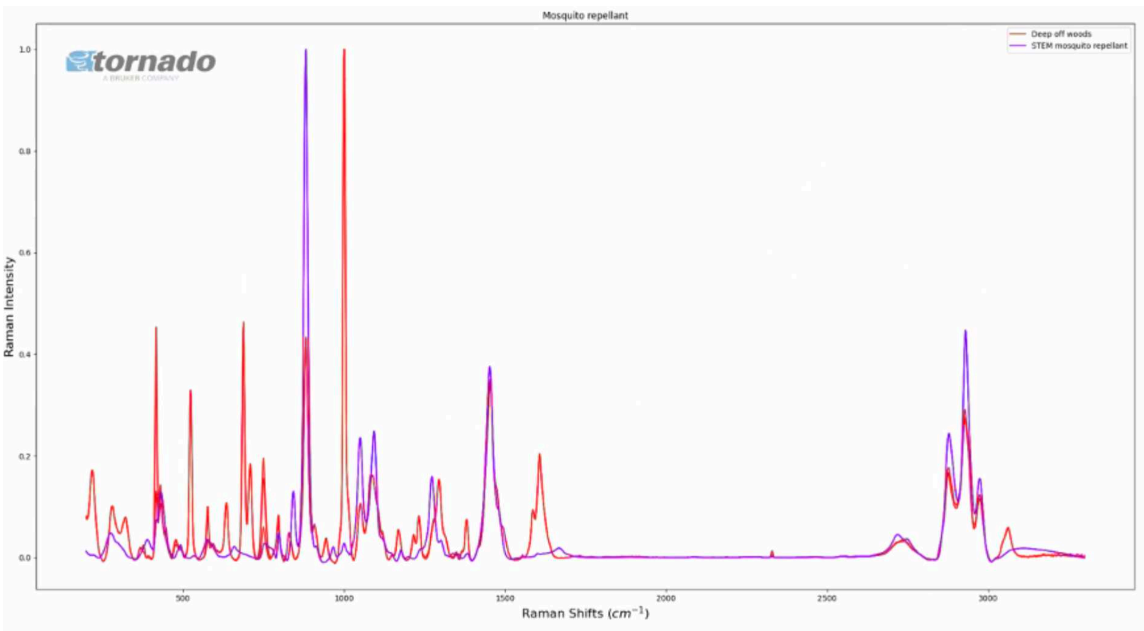

Figure 56: Raman spectra analysis of deepwoods off (red) and STEM repellent (purple) preprocessing: Savitzky-Golay smoothing, AsLS baseline correction, max normalization; data collected with Bruker/Tornado.

In general the hygiene products show high-quality, differentiable spectra suitable for quantification or classification; having this type of metrology in the field lab setting would be of significant benefit to the communities. Toothpaste and shampoo also provided differentiable data, collected using the portable BRAVO tool, which is a handheld device.

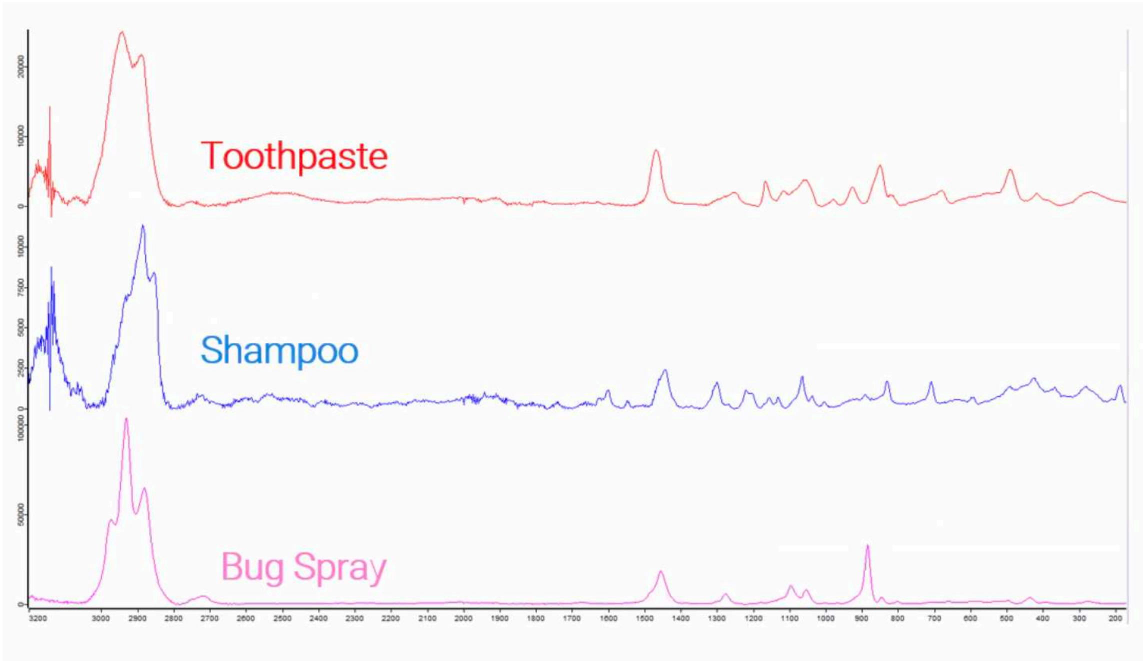

Figure 57: spectra of personal hygiene products collected using the BRAVO portable device.

6.3.2 Open Water

The other *HyTech* side-quest was *Open Water*: which asked whether the sustainability logic of HyTech could be applied to water purification. P&G's Purifier of Water is a sachet product that treats 10 liters of contaminated water in about thirty minutes by combining two ingredients: ferric sulfate, a coagulant that flocculates suspended solids, and calcium hypochlorite, a disinfectant. It is an effective and widely distributed product. *Open Water* didn't progress far enough to be considered a test case, however parts of the project are an interesting review of a further instrumentalisation roadmap. Crushed Moringa oleifera seeds have been used as a traditional water clarifier, and their use has long been recommended for water treatment in regions where imported chemical coagulants are costly (Desta & Bote, 2021).

Because of this we also wanted to run an analysis of six water samples, in preparation for when we could start investigating more water purification with the Peruvian communities: Milli-Q water, Charles River water raw and purified, saturated salt solution raw and purified, and the sludge by-product of purification.

But water samples told the opposite story to the other hygiene products. Water is a weak Raman scatterer, and dissolved species at environmental concentrations produced too little signal on the handheld instrument to discern much; the benchtop HFPP, with its higher sensitivity, is the better fit for dilute aqueous samples. The purified samples showed a strong sulfate band at 980 cm^{-1}, consistent with the ferric sulfate coagulant used in purification.

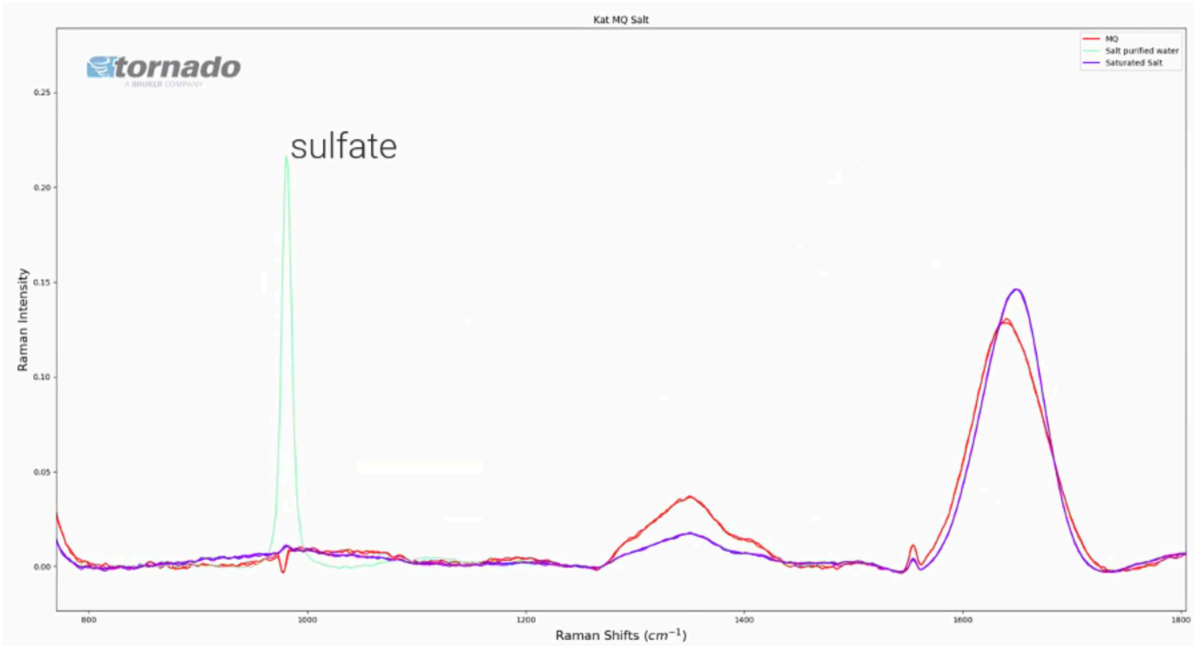

Figure 58: raman spectra comparison of water samples MilliQ (red), purified water (green), saturated saltwater (purple)

The purification sludge produced usable spectral features (512, 710, and 980 cm^{-1}), suggesting that drying sludge into a film or powder is a viable preparation path where water itself is not.

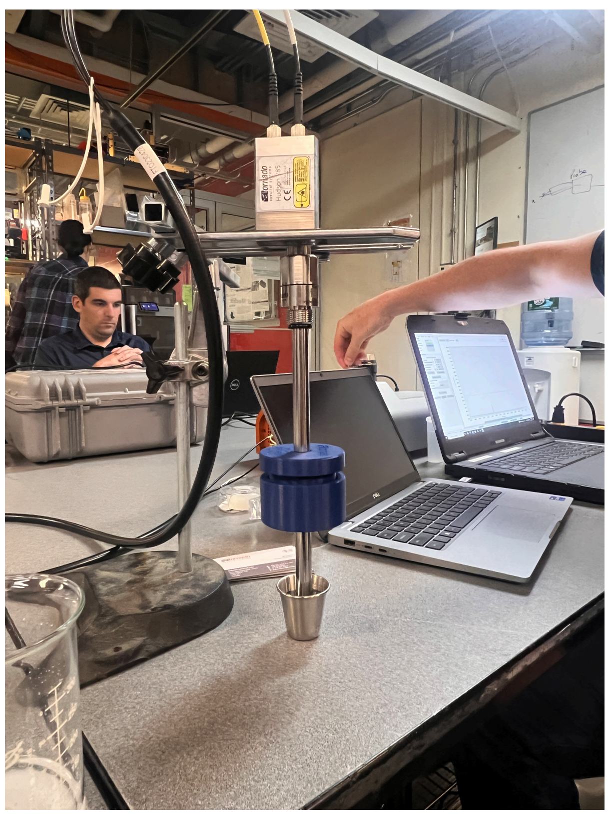

Figure 59: the process of analysing the water purification sludge

Based on the results from these analyses, it is pretty clear that Raman spectrometry would be a good addition to the fieldlabs that are in the central forest for the analysis of hygiene products - but its use for water analysis is limited, and with the current cost of the field-device it is an option, but is part of the future plans.

A long-term point of interest are community spectral libraries, while the open-hardware work for Raman is young and not yet widely popularized but the possibility of a shared open access location for spectral analysis that the communities can travel to would be beneficial for the process and could help build a reference library of coded community formulations against which future batches are matched.

7 Benefit-Sharing and Governance

The benefit sharing work has been primarily done explicitly with the Peru counterparts of the fieldlab research. The goal was to establish a clear roadmap for the communities to own their own research while also being able to collaborate with external scientists as consultants to expand their capabilities.

While working on HyTech, the project ran into a surprising roadblock. Protecting the communities' knowledge, informed consent, and benefit sharing were part of the project design from the very beginning: from the way the participating communities were selected to the alignment workshops and the continued steps to ensure that the communities felt that their knowledge was protected at every stage of the project. Beno and I worked together over the span of two and a half years to ensure that the relationship to the communities was healthy, and to our mutual surprise and gratitude P&G shared the same dedication and point of view continuously along the way.

The access and benefit-sharing (ABS) workflow — the legal process governing who may access genetic resources and traditional knowledge, and how resulting benefits are shared — was surprisingly more complicated than most online sources indicated and while the facilitated workshops were aimed towards consent and identification of benefit sharing - within the stakes of the pipeline it does not fully fulfill the needs. The project thus also included developing a pathway to accomplishing a research oriented ABS agreement between fab lab Lima and the indigenous communities.

One of the most interesting aspects was that even when I turned to experts at MIT, I could only find very limited advice on ABS infrastructure. So outlining and bringing into the light the steps necessary for ABS approval have become key contributions of this work. MIT's lack of support in the ABS is additionally interesting considering that this thesis is being written during a period in which the international ABS framework moved substantially. First, the WIPO Treaty on Intellectual Property, Genetic Resources and Associated Traditional Knowledge, adopted in May 2024 (WIPO, 2024). It is the first WIPO treaty to include provisions specifically for Indigenous Peoples and local communities. It establishes a mandatory disclosure requirement: patent applicants whose inventions are based on genetic resources or associated traditional knowledge must disclose the country of origin and the Indigenous Peoples or local community that provided the knowledge. The treaty is not yet in force, but Peru is one of the countries that signed it.

Second, the Cali Fund, launched in February 2025 under Decision 16/2 of the CBD's COP16 (Convention on Biological Diversity, 2024) (UN, 2025). While this is specifically oriented towards sequencing of biological matter and ensuring that the Indigenous

Peoples and local communities named among the intended beneficiaries from the DSI (Digital Sequence Information). Recent work documents how ABS compliance actually proceeds for research institutions, including the persistent finding that noncommercial research is often unintentionally restricted by regulation designed for commercial actors.

7.1 The Nagoya Protocol, ABS, and FPIC

The Nagoya Protocol governs access to genetic resources and the traditional knowledge associated with them. It requires three things before that access happens: prior informed consent (PIC) from the country and community holding the resource, mutually agreed terms (MAT) for how it will be used, and a mechanism for sharing benefits that result. Peru ratified the Nagoya Protocol in 2014. Its domestic ABS framework predates that ratification and runs in parallel with it. Decision 391 of the Andean Community, adopted in 1996, governs access to genetic resources at the regional level. Law 27811, passed in 2002, protects the collective knowledge of indigenous peoples specifically, independent of whether a genetic resource is also involved.

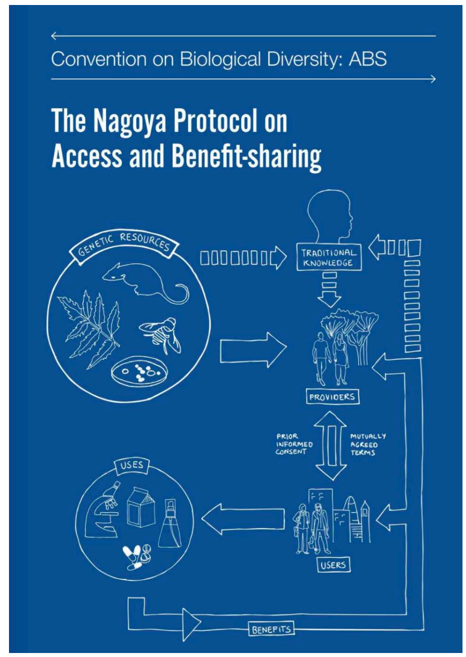

Figure 60: The Nagoya protocol flow as taken from the international convention on biological diversity.

https://www.cbd.int/abs/resources/factsheets.shtml

Peru's Ministry of Environment (MINAM) is the national focal point for ABS. It does not act alone. Access requests route through one of several competent national authorities depending on the resource: SERFOR for forest and wildlife resources, INIA for agricultural genetic resources, PRODUCE for resources used in industrial production, and INDECOPI for matters touching intellectual property and traditional knowledge protection. INDECOPI also houses the National Commission Against Biopiracy.

FPIC (Free, Prior, and Informed Consent) is the operating standard by which access is legitimated. It appears in Article 8(j) of the CBD, in Articles 6 and 15 of ILO Convention 169, and in Articles 11, 19, and 32 of the United Nations Declaration on the Rights of Indigenous Peoples (United Nations, 2007). Article 31 of UNDRIP is the most direct: indigenous peoples have the right "to maintain, control, protect and develop their cultural heritage, traditional knowledge and traditional cultural expressions, as well as the manifestations of their sciences, technologies and cultures" (United Nations, 2007).

7.2 The Pathway

HyTech falls within the jurisdiction of SERFOR, the national authority for forest and wildlife resources.

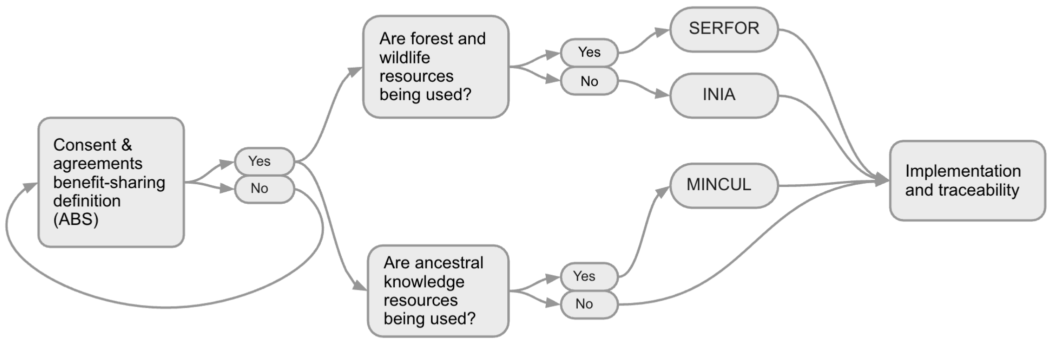

Figure 61: ABS Pathway for HyTech

The consultations with SERFOR resulted in the advice that the access application is to be made by fab lab Lima, for a research collaboration between fab lab Lima and the participating indigenous communities. The foreign institutions in the collaboration, MIT and P&G, hold no access rights of their own, myself included. Which is also why it is my wish for the plants, solutions and ingredients used in this work to remain coded in compliance with the community elders' wishes, so they can choose when and how to publicize the material behind the results. The communities retain the right to veto our external participation at any moment.

FPIC is often implemented as a one-time event: consent is given, documented, and filed. In our pathway I want to ensure that it is clear that consent is a continuous activity that can be withdrawn at any moment, if the community ever feels uncomfortable.

The pathway as currently mapped:

1. fab lab Lima prepares the application for a research [authorization] with SERFOR, naming the participating communities as collaborating knowledge holders.
2. Prior informed consent is documented with each community through their own representative structures, building on the alignment agreements of January 2025.
3. Mutually agreed terms are negotiated between fab lab Lima and the communities.
4. External collaborators (CBA, P&G) enter through agreements with fab lab Lima, subordinate to the community terms.

At the time of the completion of this thesis we are in the process of finishing the required documentation necessary for the authorization with SERFOR.

So what did happen? Alignment infrastructure was built. Free, prior, and informed consent (PIC) was established through the communities' own representative structures and treated as continuous rather than one-time; the axes of benefit sharing agreed in January 2025 (knowledge exchange, consistent support, and support in IP conversations) were honored through the efficacy training and the shared protocol development documented in the previous chapters. The jurisdictional question was addressed through consultation with SERFOR: the application will be made by FabLab Lima, the communities are named as collaborating knowledge holders, and the foreign institutions (MIT, P&G, and myself included) hold no access rights of their own and enter only through agreements subordinate to the community terms. The efficacy methodologies transferred by P&G scientists, and the field lab capacity built in Satipo and Porto Copa, are benefits that have already begun.

What will happen? The documentation for the SERFOR research authorization is being completed at the time of writing. The sequence from here is above: authorization, documented PIC per community, mutually agreed terms between FabLab Lima and the communities, and only then agreements admitting the external collaborators.

7.2.1 Commercial Pathways

From that point on it's about what the communities want to do with their data and the next steps they would like support in. The interviews and workshops made clear that several participants think of their formulations as potential livelihoods: building small businesses on sustainably used forest resources, achieving the financial independence to pay for essentials like legal support for land rights and waste management, and equipping their youth with skills and professions that benefit the community. From the beginning of the collaboration P&G was interested in this research as an exploration of how they might evolve as a company, if it were possible for them to step away from the proprietary, supply-chain-based manufacturing model towards a more holistic model where they could utilize the research they have conducted over the years into mentorship. They wanted to explore a model where they could exist as consultants to help indigenous communities grow their products for their regions where it would have the deepest impact. Commercial use of collective knowledge in Peru triggers the full machinery: an access contract through the competent national authority and, under Law 27811, a license for the use of collective knowledge, distinct from the research track. The flywheel exploration of how to take the mosquito work from plant to business makes most sense as an addendum to the research authorization that we are applying for first.

8 Discussion, Conclusions, and Reflections

This thesis asked what the smallest set of capabilities lets a community evaluate the efficacy of its own hygiene products, and whether such a lab can be operated and governed locally. The first contribution was a field lab specification with protocols and results, evaluated by the fact that the repellency and hair care protocols were run locally, by community members and fab lab Lima staff, without a visiting scientist operating the equipment. Knowledge sharing successfully occurred at a distance during the design of the protocols.

For the past year we continued to adhere to the alignment and consent we came to during our initial alignment workshops. The relationships I have built with community members and leaders, medicine men and women without sharing a language but communicating based on what we were trying to achieve, is on a personal level an achievement I'm really proud of.

8.1 Limitations

The limitations of this work to me lie in the sample sizes, as work with such communities takes place on a slightly different timescale to academic timelines, the goals of HyTech will improve with more time. Another limitation is the encoding of the natural ingredients, while I consider this the correct trade, it is a limitation for any reader wishing to replicate the chemistry rather than the method.

8.2 Reflections and Learnings

As hindsight is always 20/20, there are many things I would have done differently if I had started this project from scratch a second time around.

However I am also incredibly proud of how strong the bond with the communities working on this has become. When I was starting this project one of my main and absolute boundaries was that I did not want to ever put anyone in the position where I was prescribing them what would be best for their community. I am happy that at least at the time of the writing of this thesis, this has remained the case. We have only worked with communities who actively wanted to participate in the work because they were already working on plant products.

Learnings I had not anticipated: the distance between what a community wants to do and what the legislative frameworks built for its protection will allow. Had I known the bureaucratic pipelines beyond the community's autonomous desires, I wish I had started the policy process a lot earlier. In our first alignment meetings the interviews gave insight into how tense the relationship between the communities and the local government was, but I did not infer that a big part of that tension was that the decision making surrounding their ability to collaborate with consultants of their choosing was limited. These protections exist for good historical reasons, and this thesis has documented those reasons at length. But protection is not neutral. The communities in this work asked, repeatedly and specifically, to understand the compounds behind the effects they had already demonstrated, but the legal setting limits the possibilities for sample exchange; compound-level analysis sits beyond its current inventory. The analysis the field lab cannot do should go to a local laboratory under Peruvian institutional support, even beyond the capacities of the fab lab, and in future iterations of this work I would set these possibilities up ahead of time in the first weeks of the process.

The local institutional labs are still not exempt from the ABS limitations but including them in research approvals appears to be significantly easier than receiving permission for a gifted sample to travel even to MIT.

8.3 Future Work

There are many future work directions left to pursue. I would like to create a fully portable kit that is modular but not separately customized for each application. Further, Beno and I plan to develop educational content based on this work, which is meant to give users an introduction to using the field lab and learn various protocols within a structured course.

The Satipo participants asked for real-time behavioral monitoring of mosquito assays using infrared cameras and AI analysis. So this is something we would like to develop together in a way that helps them with further research. The hair care participants asked to continue with further formulations and larger panels. A spectrophotometer remains on fab lab Lima's wishlist. On governance, the immediate next step is carrying the ABS pathway through to a signed agreement. The documented pathway is intended to be reusable by other fab labs entering similar collaborations. Beyond that the hope is to extend the project to other test cases as we expand the capabilities of the fieldlab and tackle different problems.

9 Guidance to a Future Researcher

From this I can summarize the following points as guidance to a future researcher as they may embark on a similar journey

1. Do not underestimate the importance of a community liaison - when starting a project like this trust is a tender process that is easily lost. When the collaboration includes a commercial corporation - especially if you are navigating cultural differences - it is your role as the researcher to establish a precedent in which the pace, the flavour and the power of the collaboration is defined by the community, not by the commercial counterpart.
2. as part of the establishment of that precedent and community buy-in co-creation is one of the best tools at your disposal. You are not trying to set rules for other people as much as you are designing a circumstance in which rules and ethics are at the top of the conversation and they are followed by desire and not force.
3. work with your community liaison to involve additional local research institutions and local policy connection to draft research agreements as you progress on work.
4. Expect your premise to be wrong. This is not new advice; it will be given to you in almost every circumstance - however it is important to keep at the forefront so as not to miss a window because you are chasing a door. Desires change, Focus changes, and sometimes very often goals of a project shift for one or more parties. HyTech started out with manufacturing and ended with measuring.
5. This builds on points 1 and 2, but front load the benefit sharing. Approach the collaborations with indigenous communities in a dynamic where you are the consultant and they are the lead - their benefits come first and consent is built from there.
6. Speaking of consent: Make sure it is understood by all parties that consent is not binding but continuous. A community's agreement to a step in one point of the collaboration is not set in stone for the rest of time.
7. Allow the communities the privilege of coding their samples. You are working with someone else's sacred knowledge here; your position is in assisting in their desires - and allowing them to maintain their agency in *choosing* when and how they want to disclose which plant they are actually investigating should be their choice. Results can be shared, published, and compared while the knowledge itself stays home. Consider that plant work spans multiple communities and even within those it is not one singular community's choice whether to share something with an outsider.

8. Expect background information to be confusing and not straightforward. ABS-related and indigenous community-based work and law varies largely from country to country. Even during the treaties there was no real consensus between various parties. As pathways are being untangled and attempted each time one of us works on this, each time it will get easier for someone else.
9. Ten years is a short period to the communities in this work. You are working on a relationship that requires maintenance. You should not walk away once a small section is done, if you are building a pathway for someone else to be able to step their way into scientific discourse you should dedicate time to it on their timescale - not your own.
10. Contributions are theirs, not yours. My biggest and final piece of advice: you are helping more people participate in science; your work should also enable them to speak about it.

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