



Labour Provenance as a Lens to Reveal More-Than-Human Ecologies in Biological Design and HCI

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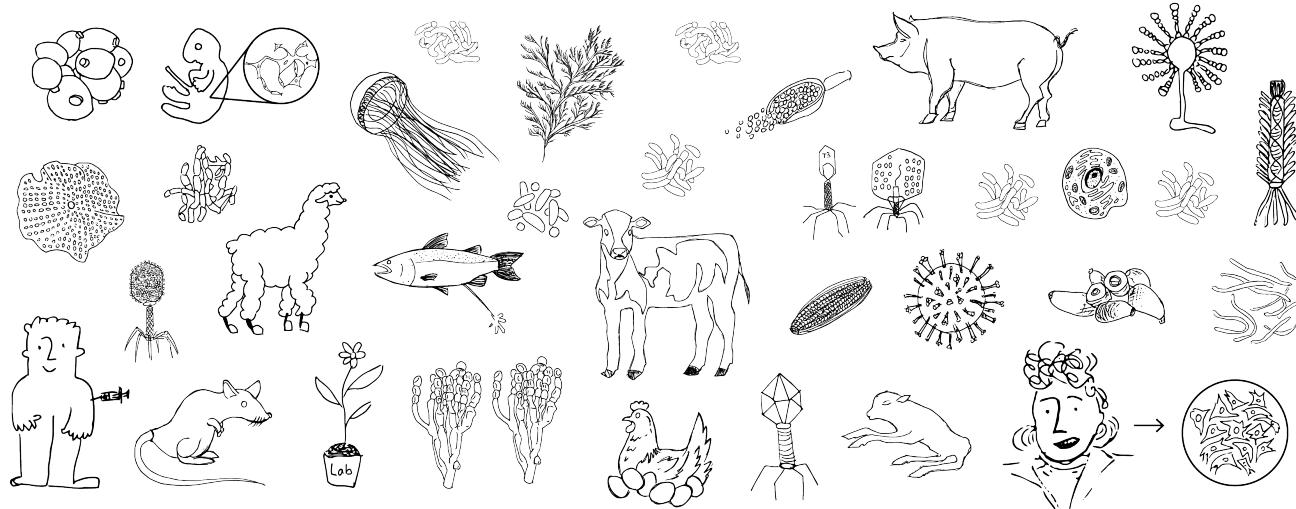


Figure 1: An illustration of the organisms identified during the labour provenance analysis in the presented biodesign case study

Abstract

Efforts to integrate living organisms in the design of new technologies are often motivated by prospects of greater sustainability and increased connection with more-than-human worlds. In this paper, we critically discuss these motivations by analysing the vast and mostly hidden ecologies of more-than-human organisms implicated in a biodesign lab experiment. Through the lenses of labour theory, we investigate the extent to which organisms' bodily functions and relationships can be subsumed into capitalist modes of production. In order to help reveal and map out the network of more-than-human contributors to biodesign, we develop a workshop method and a labour provenance analytical framework that identifies five types of more-than-human labourers, stretching from the centre to the periphery of biodesign. We conclude by discussing how sustainable approaches should account for wider more-than-human ecologies, and how the labour lens could help stress conflicting

goals, implicit anthropocentric agendas and ways of improving organismal welfare in biological design and HCI.

CCS Concepts

- Human-centered computing → Interaction design process and methods.

Keywords

Labour Theory, Provenance, More-Than-Human, Ecologies, Sustainability, Design, Ethics, Multispecies, Bio-HCI, DIY-Bio, Microbe-HCI, Biodesign, Posthumanism, Care

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1 Introduction

Bio-related research is becoming increasingly prominent within Human Computer Interaction (HCI) and Design, motivated by the potential of living organisms to unlock novel applications across various domains [24, 35, 78, 89, 90], including fabrication

and material development [3, 10, 11, 34, 114, 116, 119, 122], gaming [59, 62, 96], electronics [65, 81, 85], living media/digital interactions [14, 18, 31, 41, 46, 97], etc. By leveraging organisms' ability to adapt, regenerate and biodegrade, these applications are often considered more sustainable than those employing traditional materials and technologies [39, 112, 117]. By supporting designers and/or users' attunement to specific living organisms, they are also seen as able to forge a greater connection to more-than-human worlds [8, 49, 50, 68, 86, 87, 120, 121].

In this paper, we critically reflect on these core motivations by analysing a biodesign experiment through the lenses of multispecies ecologies and labour theory. The experiment includes advanced forms of biodesign practices which not only integrate but also modify living organisms for particular purposes. These practices often draw on specialised tools and techniques borrowed from other fields such as molecular and synthetic biology, and are becoming increasingly accessible [4, 30] and popular within HCI (particularly through the proliferation of biolabs [63]). We deconstruct the experiment, which uses synthetic biology methods to hybridise cells, first by describing each of its steps, and then by tracing the living origins of different components employed in each of these steps - through what we call a *provenance mapping* exercise. This exercise reveals the large number of organisms that play a role in promoting the conditions necessary for transformation, sustenance, and reproduction of primary experimental subjects - forms of life that were hidden behind laboratory reagents, barcodes, and serial numbers. This provenance analysis leads to the first main contribution of this paper: the expansion of considerations of biolab and biodesign practices, from a few organisms of interest to vast more-than-human ecologies.

Following a critical trend within HCI that attempts to consider best practices to engage more-than-human organisms in research [17, 20, 40, 73, 87, 120], and particularly recent work that aims to analyse more-than-human participation through the lens of labour theory [17], we investigate the implications of interpreting participation of organisms as metabolic, resistance and sustenance labour, discussing a trend for such labour to be increasingly subsumed by capitalist practices, both within research and in resulting design applications. This critical position leads to the design of a workshop method that invites those who routinely work with interventional forms of biodesign research to a) situate organisms within an ecology of species, b) reflect on the labour of organisms through assigning job titles, and c) consider ways to improve their welfare.

The labour analysis and workshop culminate in the second main contribution of this paper: a novel analytical framework that we call *labour provenance* and which aims to help researchers trace the living labour behind various components and reveal how structural positions within design practices can condition the visibility of organisms' contribution and the levels of subsumption they can be subjected to. The framework identifies five types of more-than-human labourers: 1) *primary biological labourers*, or the main organisms considered in the design; 2) *specific skills labourers*, those that provide new features or complement the primary organisms 3) *tool-based labourers*, organisms that contribute to the control of primary and skills labourers, 4) *support and sustenance labourers*, who contribute to nurture different organisms, and 5) *evaluation*

and feedback labourers, organisms employed to give feedback on the experiment outcomes.

We conclude by discussing the contribution of the work to a) drawing attention to extended more-than-human ecologies in biodesign, b) expanding notions of sustainability, and c) providing a platform to discuss ethical practices in biological HCI. By using labour provenance as a lens, we can expand more-than-human perspectives and prompt a re-evaluation of what it means to engage with life in design and HCI.

2 Reframing the living in HCI

HCI and Design researchers have developed new frameworks for integrating living organisms in digital technologies through concepts such as "Biological HCI" [90], "Living Bits" [91], "Living Media Interfaces" [78], "Living Artefacts" [55], "Microbe-HCI" [60], etc. Emergent frameworks have further attempted to synthesise taxonomies to "surface the livingness of Microbial Displays" [61], or explore bio-digital "habitabilities" [118] and case studies have explored the integration of specific organisms' unique attributes into novel interfaces, such as dinoflagellate's bioluminescence [85], flavo- [37] and cyanobacteria's [121] vivid colours, mycelium's ability to grow into resilient shapes [34, 116], *Bacillus subtilis* (natto) cells' responsiveness to moisture [117], or the increasing accessibility of yeast's DNA manipulation [42]. Often, explorations are underpinned by an assumption that products that are based on living matter might be more sustainable, typically due to organisms' ability to grow, adapt and/or decompose [39].

In parallel to this trend to integrate living organisms in new products and interfaces, we have also seen an expansion of methodological and critical approaches. Such approaches aim to pluralise perspectives and include the voices of more-than-human species, (re)shaping the ways in which HCI engages with the natural world and responds to increasingly pressing ecological issues. Such approaches include participatory methods for more-than-human [2, 19, 67] as well as multispecies interaction and cohabitation [49, 57, 73, 106], recognition of more-than-human labour [58] and "non-participation" [17], among others. There have also been a breadth of examples that look at the more-than-human as a way to critically expand notions of time [8, 8, 48, 86, 94], materiality [50, 120], care [68, 84, 87], and reframe communal [10, 20, 40] and individual [9, 83, 120] experiences around the living. These approaches attempt to challenge human-centric attitudes, intersecting with emergent notions of feminist care and posthumanist HCI [58, 107], feminist care ethics [58, 108], unmaking [7, 69, 99, 109], temporal design [93], sustainability [77, 101], and ethics [32, 44, 79] in HCI.

In this paper, we are particularly interested in the characterisation of labour outside of human experience [17, 58] and in using labour as a lens to legitimise the contribution of more-than-human organisms in design practice [17]. We attempt to apply the concept of labour to our analysis of ecological provenance in order to sensitise researchers towards the unique ways in which different organisms contribute their skills and bodies to design practice. While some more-than-human species can be seen to perform labour similar to that of humans – such as horses transporting goods, dogs guarding herds and whales being trained as military spies – many others, as we will discuss in this paper, require a rethinking of what

constitutes labour and what could translate into imbalances and modes of domination. This rethinking, as we will address later in the discussion, can in turn invite reflection on the broader spectrum of more-than-human labour beyond the living, suggesting directions for future work.

In the following sections, we report on our biodesign case study, the mapping of its labour ecologies, and review literature on more-than-human labour to later analyse the different manifestations and define different types of more-than-human labourers.

3 Biodesign case study: constructing the hybrid

Our case study centres on a hybridisation experiment, conducted as a sequel to another arts-science project, *Crossing Kingdoms* [110], now with a renewed aim to question "organism-agnostic" [15] approaches in biotechnology. As discussed by Calvert & Szymanski [15], in lab practices, microorganisms such as yeast and *Escherichia coli* (*E. coli*) are often treated as vessels for standardised interchangeable genetic parts, or "BioBricks" [102] akin to Lego bricks. Such approaches are echoed within HCI research, where these organisms are often referred to as "living biological computers" [91], "bio-digital interfaces" [31], "living interfaces" [80], and "bio-hybrid devices" [82]. Our experiment aimed to critique these approaches using common synthetic biology techniques to 'hybridise'¹ yeast with human cells. The idea was that the combination of cells with very different moral statuses would complicate and unsettle the organism-agnostic framework.

The experiment involved us engaging with lab practices, and delving into various specialised knowledge and the community of researchers around it. Supported by a collaborative grant, we conducted the experiment in our university's synthetic biology lab. The background of the first and third authors brought to the experiment a new perspective, allowing a critical and reflexive engagement with routine lab practices. Being aware that many lab components originated from living organisms, we started a provenance analysis to trace the impact of our actions on the more-than-human world. Initially focused on cell lines and genetic components, our scope expanded through closer review of lab records and reflective discussions. This led us to critically analyse the extent to which a variety of organisms had and were contributing, that is, labouring, for our experiment to take place. By retracing this experiment through the lens of labour, we were able to illuminate the extensive network of human and more-than-human contributions underpinning well-established lab protocols. We see this as a natural extension of the critique prompted by the project. In what follows, we detail the six main experiment steps and contextualise them within our provenance framework.

Step I Sourcing primary organisms and planning: (Fig 2) For the experiment, we used "standardised cell lines", which are commercially available cells commonly used in labs and sourced from providers like atcc.org and neb.com. The main cells used were: Human Embryonic Kidney 293 (HEK) cells and *Saccharomyces cerevisiae* BJ5465 (Brewer's yeast). In this standardisation process, human cells were

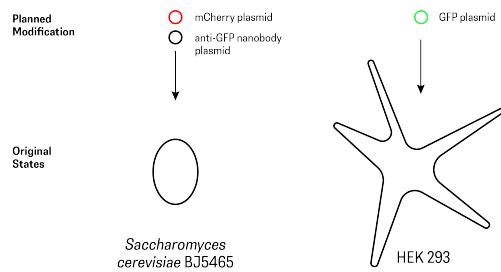


Figure 2: Step I - Diagram of sourcing primary organisms and planning genetic modifications.

"immortalised" [56] once they were removed from the source and replicated in the lab for commercialisation. The hybridisation involved adding "molecular hands" — binding molecules — to the surfaces of both cell types to facilitate their connection. We did so by introducing genes encoding the binding molecules into the cells using small DNA carriers called plasmids. We used genetic editing "tools" like restriction enzymes (to cut DNA), polymerases (to copy DNA), and ligases (to join DNA pieces). The hybridisation experiment took about five months of trial and error, which we elaborate in the following sections, focusing on the part involving yeast.

Step II Identifying genes of interest and selection mechanisms: (Fig 3 and 4) We used modified HEK cells whose surfaces are covered with "Green Fluorescent Protein" (GFP), provided by our lab colleagues. For yeast cells, we introduced genes to surface anti-GFP nanobodies (which would bind with the GFP of modified HEK cells) and a red internal fluorescent protein, mCherry (to make the yeast glow red, aiding microscopic observation of their interactions). Together with our lab colleagues, we added each of them to a different plasmid for cell transformation. To ensure that only successfully modified cells survived, we devised a two-step "selection mechanism": for the mCherry plasmid, we planned to add genes that protect yeasts from an antibiotic in the medium; for the anti-GFP plasmid, we planned to add a gene that allows cells to produce an essential amino acid that was missing from the medium, so that only modified cells could survive.

Step III Constructing plasmids with genes of interest: (Fig 4 and 5)

With the help of lab colleagues who designed the plasmids and guided construction, both plasmids were created by combining the different DNA parts, including the desired genes, the antibiotic resistant genes, essential amino acid producing gene, and basic components for a plasmid: the backbone (the plasmid's basic structure), promoters (which drive gene activity), terminators (which mark the end of a gene), and markers (to help track genes).

Step IV Multiplying plasmids with *E. coli*: (Fig 6 and 7)

¹In the experiment we refer to hybridisation in the sense of pairing and connecting two organisms instead of the strictly biological definition of fusing two organisms into one single organism.

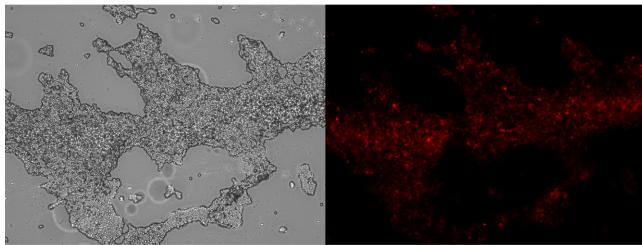


Figure 3: Step II - Microscopic photo of yeast under natural light (left), and under fluorescent light (right), red cells on the right confirm the success of modification.

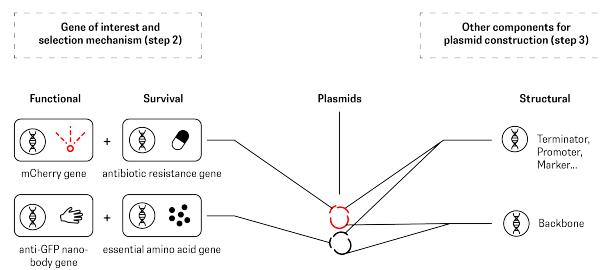


Figure 4: Step II and III - Diagram showing genes of interest, selection mechanisms and other components in the plasmids



Figure 5: Step III - Photo of plasmid construction experiment (left) and a map showing one of the plasmids, designed by lab colleagues, with assemblage of different DNA components (right)

The plasmids were then introduced into *E. coli* for multiplication. The bacteria were defrosted, heat shocked to uptake the plasmid, and then placed in the medium with antibiotics, which ensured that only successfully transformed bacteria would grow. Colony appearance, which indicated initial success, was then confirmed with two tests. First, colony PCR (Polymerase Chain Reaction) amplified the DNA to check if the plasmid was present (a method also used in COVID testing). Second, we used gel electrophoresis to separate DNA by size, comparing it to a “DNA ladder” (a ruler to measure DNA) to confirm the presence of the target DNA.

Step V Transforming yeast cells with the constructed plasmids: (Fig 8 and 9)

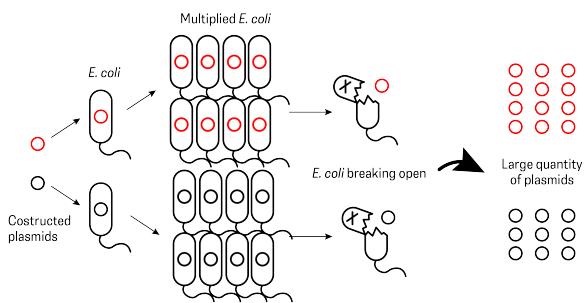


Figure 6: Step IV - Diagram of multiplying and extracting plasmids from *E. coli*



Figure 7: Step IV - Photo of failed transformation of bacterial culture (left), and photo of gel electrophoresis (right)

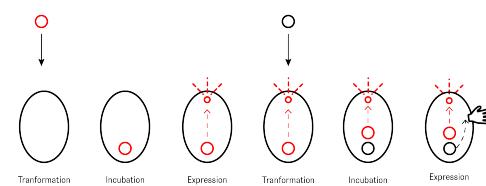


Figure 8: Step V - Diagram of transforming yeast with the constructed plasmids

After extracting plasmids from *E. coli* through a process called Miniprep, we transferred them into yeast cells. This involved growing the yeast, mixing it with the plasmids, and then placing the cells again in a medium with antibiotics - now antibiotic G418 which allowed only modified yeast to grow. We used colony PCR and gel electrophoresis to confirm that yeast cells took up the desired genes, including anti-GFP nanobody and mCherry.

Step VI Co-culturing the transformed yeast and HEK cells (Fig 10 and 11)

Finally, we grew the modified yeast and human (HEK) cells together in a special culture medium that helped HEK cells, which are more delicate, to survive. HEK cells attached to the culture plate, acting as a surface for yeast to “hybridise” with. After a few hours, we washed away any loose cells, leaving only the hybridised cells... voilà!

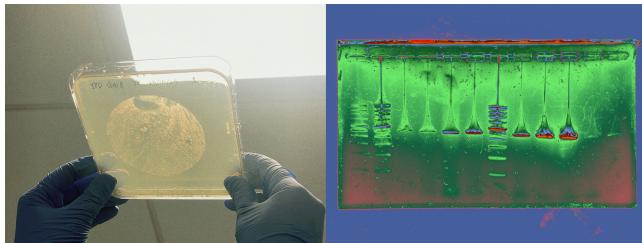


Figure 9: Step V - Photo of transformed yeast on selective media (left) and photo of gel electrophoresis image (coloured) of yeast colony PCR, showing different DNA fragments separated by weight (right)

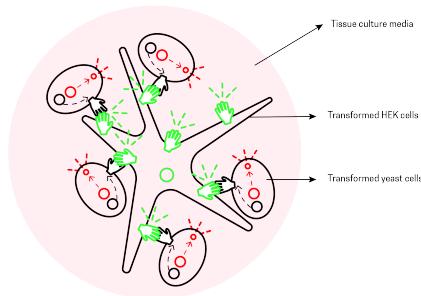


Figure 10: Step VI - Diagram of co-culturing yeast and HEK cells in tissue culture media



Figure 11: Step VI - Microscope photos of co-cultured yeast and HEK cells, we can see yeast cells under red fluorescent channel (left), both cells under natural light (middle), and HEK cells under green fluorescent channel (right), the overlapping positions after washing off loose cells indicates potential cell-cell connection and successful "hybridisation"

We see this experiment as a rich site of investigation. Its lab practices connect to other works in the fields of biodesign, bio-HCI and bioart, which increasingly employ a range of synthetic and microbiology techniques. Common protocols include gene editing, plasmid construction [42], PCR [64], tissue culture [123], bacterial culture and media preparation [8, 63], which, as we will discuss, often obscure underlying more-than-human ecologies.

4 Biodesign case study as a more-than-human ecology

Closer analysis reveals that experiments like this one rely not only on the primary organisms – here, human and yeast – but also on a complex more-than-human ecosystem. From the microbes

that provided genetic editing tools to the plants and animals that contributed to the production of reagents and media, a myriad of often overlooked organisms played crucial roles in sustaining these practices. In this section, we revisit the experiment step-by-step, illustrating and commenting on what we call a *provenance analysis*, which traces the contribution of organisms involved in different components. Where possible, we reduce repetition, noting that some organisms supported multiple steps (e.g. recurring agents and reagents).

Step I Sourcing primary organisms and planning: (Fig 12)

As mentioned above, primary organisms originated from yeast and Human Embryonic Kidney (HEK) Cells, as illustrated in figure 12.

Step II Identifying genes of interest and selection mechanisms (Fig 13):

Genes of interest can come from various species, including animals, plants, and microbes, which are chosen based on desired functions. For instance, camelids are valuable sources of nanobody genes for immunological purposes [33], while organisms like jellyfish and sea anemones provide fluorescent genes commonly used as reporters [22].

For selection mechanisms, many antibiotic and resistance genes have evolved as natural defence and competition tools in microorganisms. In the lab, these microbial traits are repurposed to ensure that only host cells incorporating the desired genes can survive under selective conditions.

Step III Constructing plasmids with genes of interest (Fig 14):

Many genetic components in the plasmid and editing tools were sourced originally from various organisms. However, many are now mass-produced through "recombinant" methods, where genetic sequences are extracted from their natural source and replicated using host organisms, typically *E. coli*. Additives such as glycerol and bovine serum albumin (BSA) for genetic editing tools may nevertheless primarily come from living sources.

Step IV Multiplying plasmids with *E. coli* (Fig 15):

The bacterial transformation process involves three main procedures that rely on living organisms: 1) Bacterial culture: organisms that provide components supporting bacterial growth, including storage agent glycerol, nutrients and antibiotics in culture media; 2) Colony PCR: organisms that provide tools that identify and amplify specific genes, i.e. primers and polymerase; and 3) Gel electrophoresis: organisms that provide ingredients for the gel matrix and DNA ladder.

Step V Transforming yeast cells with the constructed plasmids (Fig 16):

In this step, we identified organisms implicated in: 1) Miniprep gene extraction: organisms behind enzymes used to break bacterial cell walls and purify DNA; 2) Cell culture: organisms behind yeast storage and culture media; 3) Yeast transformation: additives in the transformation reaction mix.

Step VI Co-culturing the transformed yeast and HEK cells (Fig 17):

In this stage, organisms are mainly involved in tissue culture media and cell maintenance. Yeast extract, peptone, and agar represent common organism-derived

I - Sourcing primary organisms and planning

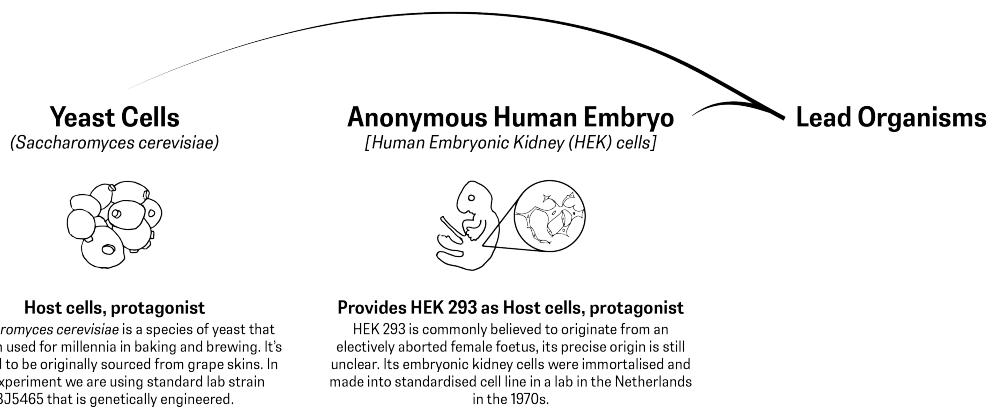


Figure 12: Step I - Illustration showing primary organisms (Human (HEK) cells and yeast cells) as well as their origin stories

nutrients in bacterial and yeast culture media. Tissue culture media, however, implicate a much wider range of organisms, including those that contribute to foetal bovine serum (FBS), amino acids, vitamins, and glucose. These components are essential for providing the nutrients, energy, and environmental conditions that mammalian cells need to grow and function in vitro.

The involvement of these organisms in our experiment could be interpreted through several lenses. Here we chose the lens of labour theory as it allows us to question typical organism-agnostic approaches that initially motivated the project. The following section reviews recent literature on more-than-human labour, which informed our analysis.

5 Conceptualising more-than-human labour

5.1 Levels of control: from formal to real subsumption of more-than-human labour

Classic literature on labour identifies two forms of subsumption to capitalist production. *Formal subsumption* involves co-opting existing activities into capitalist production, which usually means turning producers into wage workers without fundamentally altering the productive activities. *Real subsumption* is a more advanced stage that transforms the labour process and production methods to maximise value [75].

In *Animals and Capitals* [115], Dinesh Wadiwel extends such notions to animal labour. Formal subsumption can be seen in traditional animal husbandry, where pre-capitalist practices, like using animals for transport and milk, are integrated into capitalist systems to generate surplus value. Real subsumption is evident in industrial farming, where animals' entire life cycles are restructured to maximise efficiency and profit. Wadiwel describes real subsumption in the fish industry as "*the whole life and death of these*

animals is brought into alignment with the rhythms of production, in such a way as the lives of these animals look nothing like the lives of fishes in ‘nature’." He continues to say: "*the history of animal agriculture moves this formal subsumption towards a ‘real subsumption’, in so far as animals become inseparable from the productive processes within which humans place them, such that the morphology and livelihoods of animals become intertwined and interdependent on human utilisation.*"

These concepts can be extended to other biological kingdoms and the realms of biodesign and biotechnology, where the subsumption of more-than-human labour is manifested in the utilisation of organisms' biological processes, or the extraction of substances from these processes. *Formal subsumption* occurs when existing biological processes – like microbes breaking down pollutants, worms oxygenating the land – are incorporated without altering the organisms. *Real subsumption* arises when selective breeding or molecular biology techniques are employed for optimisation, whereby the lives of these organisms – be they animals, plants, or microbes – are fundamentally shaped by imperatives of value creation. In this case, the microbes introduced to break down pollutants would then be engineered and/or mass produced to enhance efficiency.

Biotechnology exemplifies real subsumption vividly. As research evolves, organisms are literally designed for experimental and industrial use, with genomes streamlined to facilitate complex experiments or produce valuable compounds. Since it is accepted that genetically altered organisms can pose threats to natural ecosystems, they are typically subjected to strict containment measures at physical, chemical, or genetic levels [111]. This containment ensures zero survival outside of their designated role in knowledge production, expressing a totalising form of real subsumption. An example of this approach is *Escherichia coli* (*E. coli*), which is often referred to as the quintessential 'machinery' [66] for turning naturally occurring substances from a diverse array of organisms into

II - Identifying genes of interest and selection mechanism

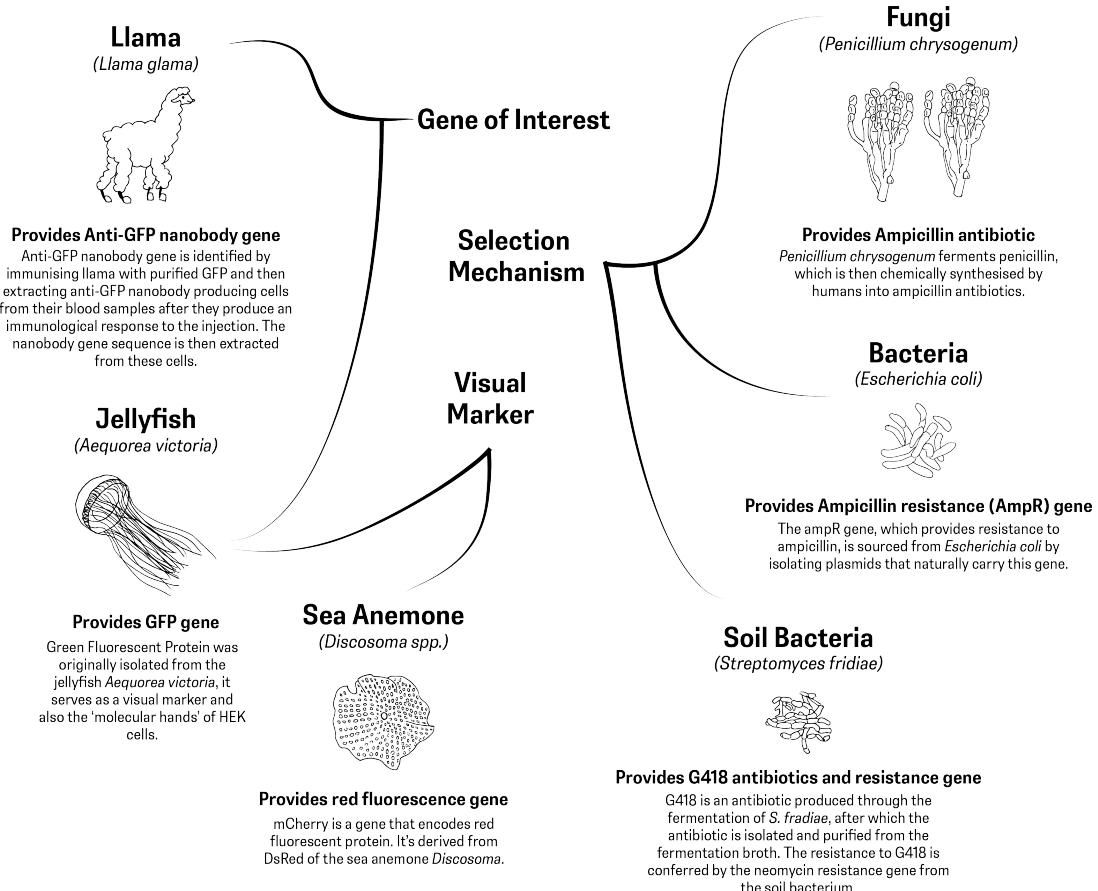


Figure 13: Step II - Illustration and origin stories of identified organisms contributing to genes of interest, selection mechanisms and visual markers

highly controllable, large-scale microbial productions. The ability to harness *E. coli* in this way represents a clear example of real subsumption, where the natural capabilities of the organism are not merely utilised but fundamentally reshaped and optimised for production.

Overall, common experimental techniques and components in biotechnology reveal a tendency for the field to move from formal subsumption towards real subsumption. When tracing the histories, origins and production methods of common substances used in laboratories, one often finds a progression from natural sources to genetically modified alternatives [29] - a progression that is tied to the integration of these processes into capitalist logics, and potentially other drivers such as product safety. Often, a living organism might serve as the natural source for a particular substance, in an example of formal subsumption. As demand for research on this particular organism increases, or a drive to integrate its outputs into

consumer products is manifested, there is a move towards streamlined production methods, typically involving genetically modified organisms. Through this process, their living functions become more controlled, leading to more "real" forms of subsumption.

The consideration of the ways in which biodesign practices can be situated within a system of production can help us deepen and extend reflections on the relationships between human and more-than-human organisms in biological HCI. Through the concept of more-than-human labour subsumption, we can start to consider not only how organisms are handled during the design process, but also how the scaling of research practices and translation into commercial products beyond academia may affect the more-than-human.

III - Constructing plasmids with genes of interest

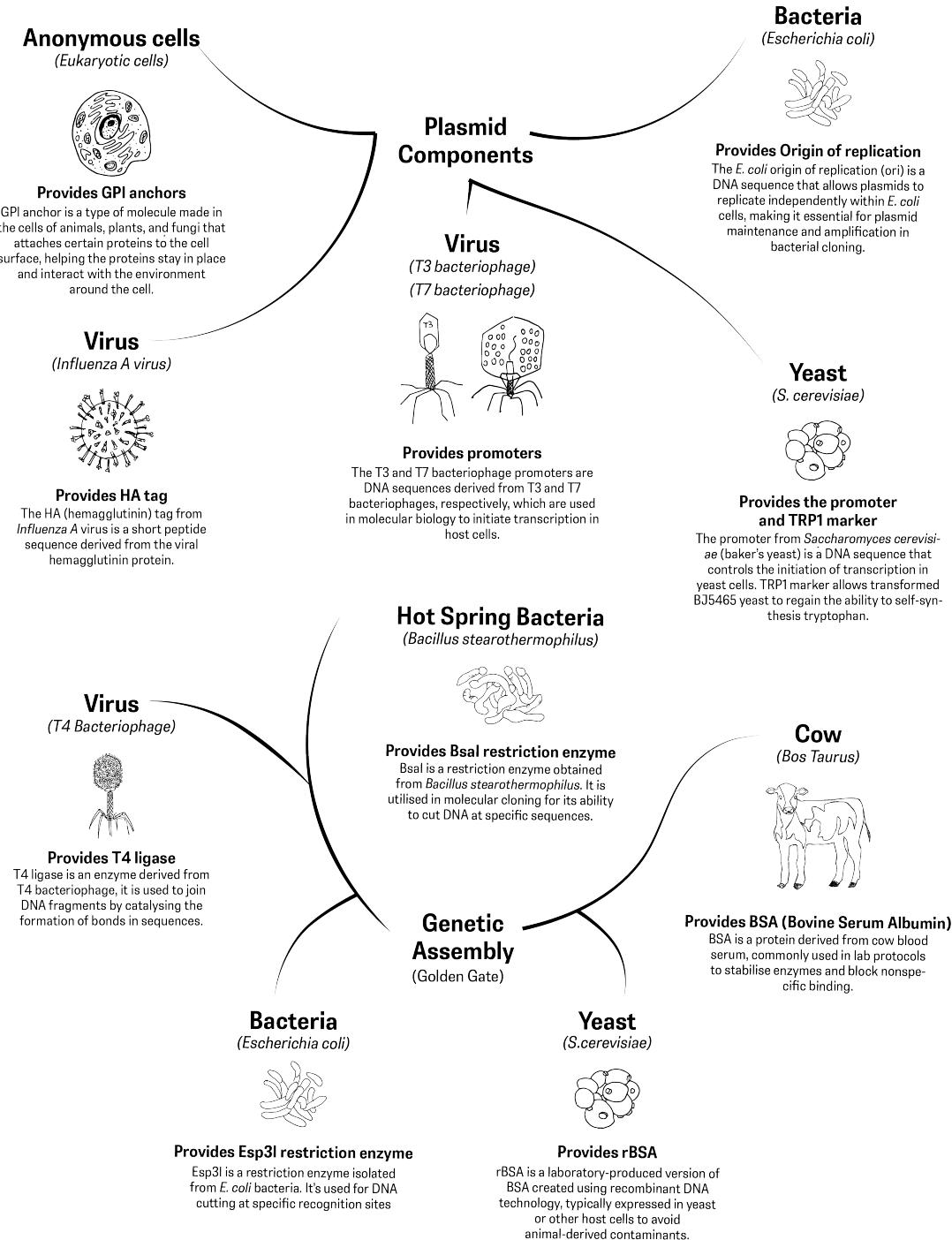


Figure 14: Step III- Illustration and origin stories of identified organisms contributing to plasmid components and genetic assembly

IV - Multiplying plasmids with *E.coli*

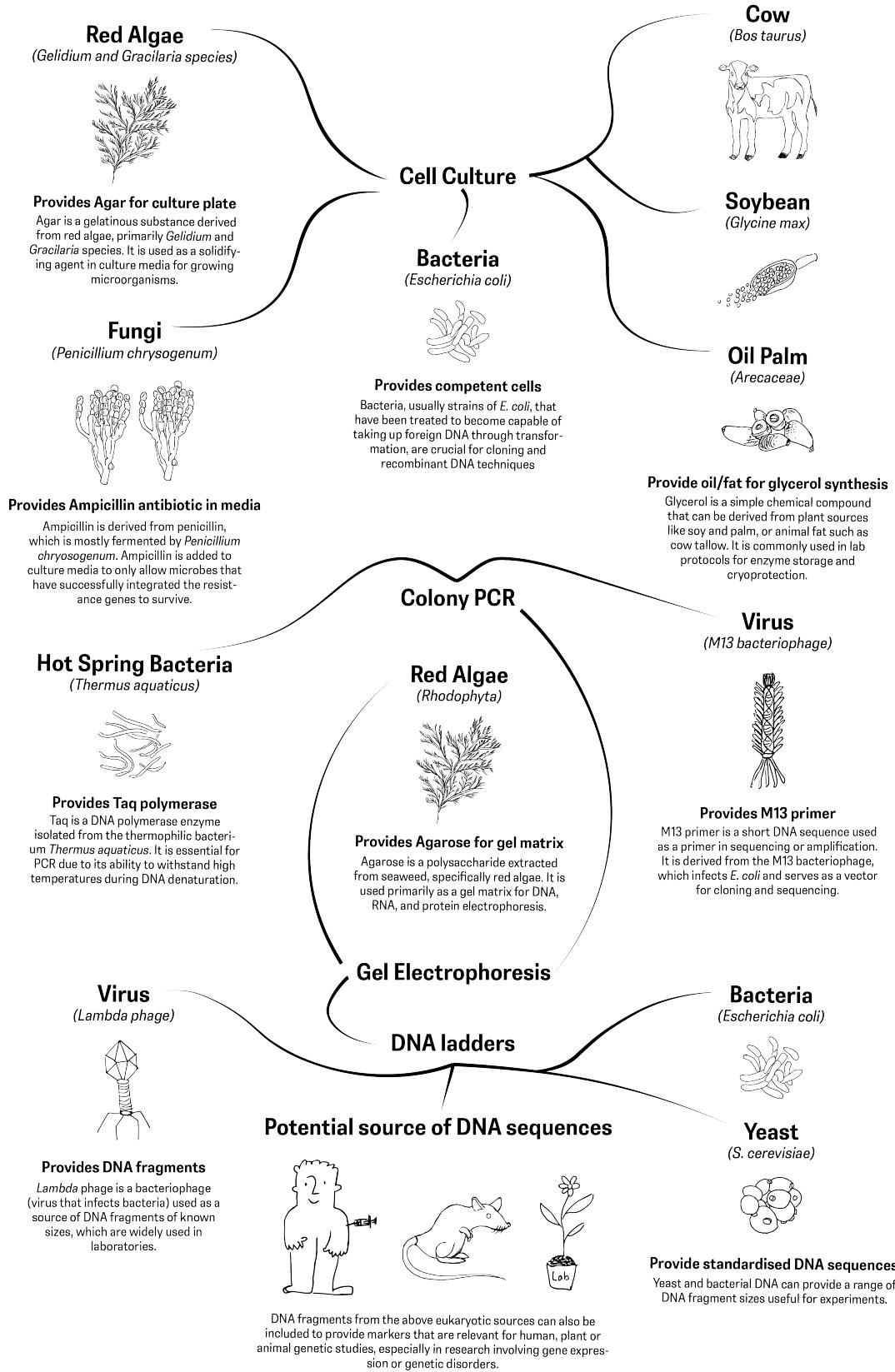


Figure 15: Step IV - Illustration and origin stories of identified organisms contributing to cell culture, colony PCR and Gel electrophoresis process

V - Transforming yeast cells with the constructed plasmids

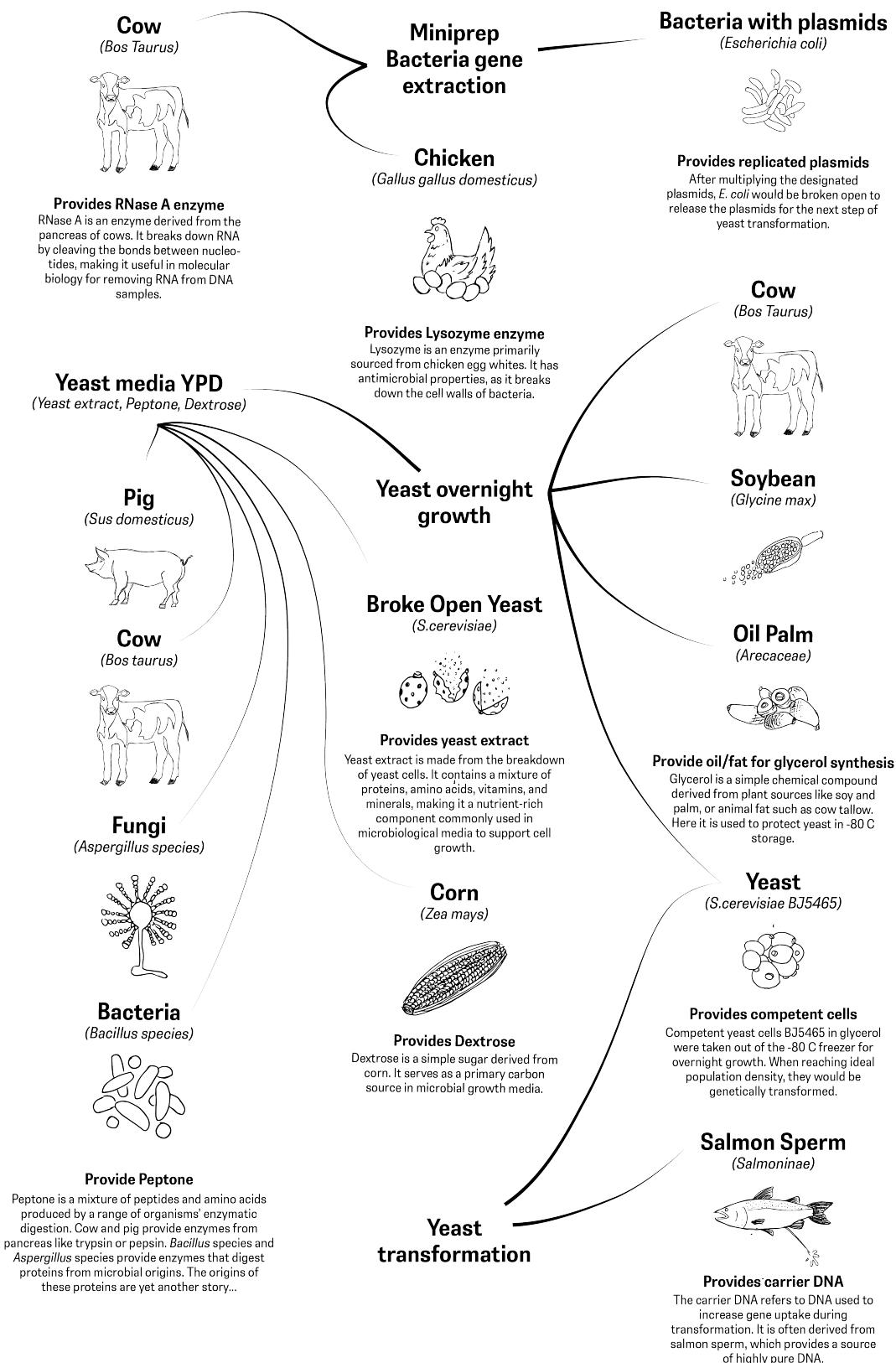


Figure 16: Step V - Illustration and origin stories of identified organisms contributing to Miniprep gene extraction, yeast overnight growth, and yeast transformation

VI - Co-culturing the transformed yeast and HEK cells

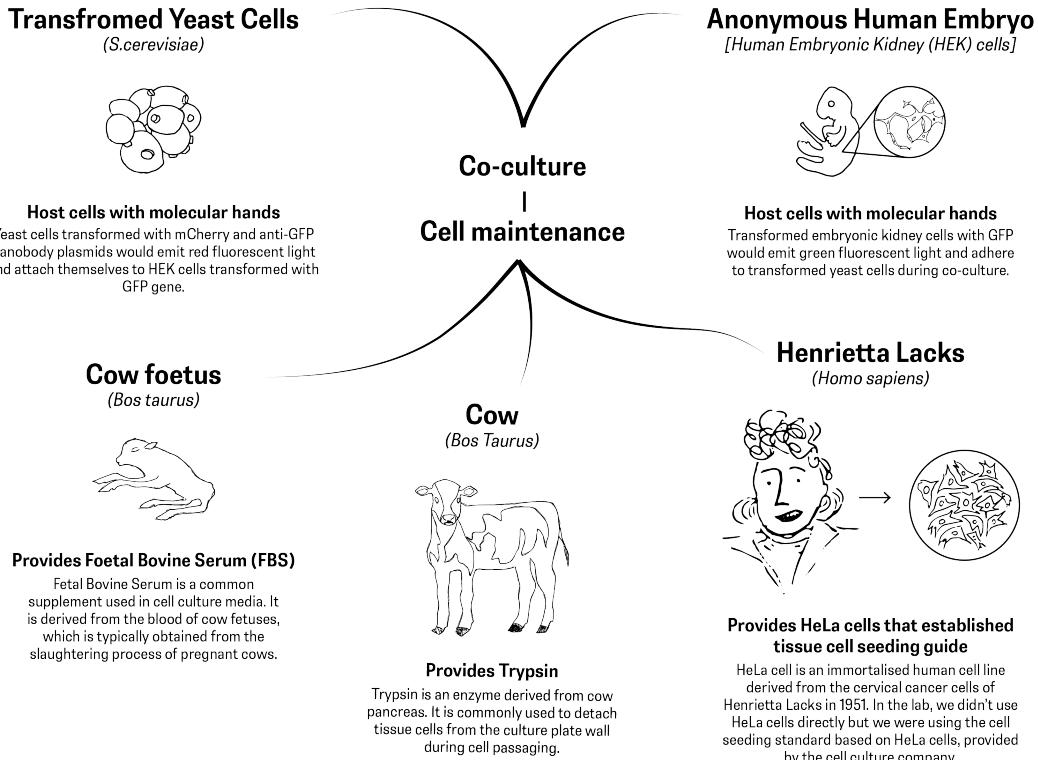


Figure 17: Step VI - Illustration and origin stories of identified organisms contributing to co-culturing and maintaining the hybrid cells

5.2 Forms of labour: metabolic, resistance, sustenance

While the notion of subsumption can help us evaluate levels of control over and intervention on organisms, it is also useful to consider the kinds of labour that more-than-human organisms can perform in design and HCI research. Below, we draw on existing literature to discuss three types of living processes that commonly underpin more-than-human contributions to design practices, in the section after this, we will map the identified organism labourers into the three categories.

Metabolic labour focuses on the bodily and biological processes of organisms – energy expenditure, self-regeneration, reproduction, and other metabolic activities that are directed towards value creation. Scholars like Beldo [6], Coulter [21] and Wadiwel [115] describe this through concepts like "microbiological labour", "bodily work" and "reproductive labour", extending traditional ideas of labour to include organisms as legitimate subjects of labour. In the context of biodesign, metabolic labour represents the most prevalent forms of organismal work.

Furthermore, scholars have identified organisms' contribution to value production in sites of encounters [5, 43] and even resistance

[115]. Wadiwel specifically points out the potential of animal resistance to be co-opted into further capitalist value generation, with such resistance often driving technological innovation. Such forms of 'non-compliant' contribution can also be seen in laboratory microorganisms, with its resistance (e.g. to antibiotics) being fully operationalised as genetic editing tools. Resistance labour offers a lens for examining contributions that are a by-product of organisms non-compliance, recognising the possibility of shaping technology to appropriate all forms of living processes.

Drawing on social reproduction theory [12], 'sustenance labour' looks at how the support and sustenance of organism can be provided by other organisms or environmental factors. This "backstage" labour is essential for the continuation of metabolic and resistance labour, as it underpins the conditions for these contributions to persist over time. Here, we see a shift in focus towards the social and ecological dependencies necessary for the ongoing productivity of organisms, extending the framework of care and environmental support to more-than-human contexts.

These forms of labour broaden our understanding of what counts as labour and productivity, providing a more inclusive lens to assess

organismal contribution while acknowledging their interconnectedness. Metabolic labour involves direct value generation, resistance labour captures value created through conflict or non-compliance, and sustenance labour focuses on the supportive roles of other organisms in these processes. In some projects, these roles can overlap, e.g. with a metabolic function manifested as resistance.

Additionally, the above-mentioned labour forms can be carried out in varying capacities. Here we distinguish between constant producers (e.g. microbes used in recombinant production) and one-off contributors (e.g. jellyfish that provide GFP gene sequence, or soil microbes that provide resistance gene sequences). Constant producers continuously generate value through ongoing ‘living labour’, while one-off contributors offer a singular input that becomes standardised and synthetically produced in labs.

5.3 Living labour vs automation/synthetic production

Nowadays, some components that originated from organisms as one-off producers can be recombinantly produced, and some could be replaced by alternatives that do not even come from living organisms. However, the majority of components utilised in biotech research and production still remain largely sourced from living organisms. This is due to cost-effectiveness, as it is still hard to synthesise the complexity of their living processes, let alone scaling them up. For example, while certain components and genetic editing tools, such as glycerin and primers, can be synthesised more easily, processes like DNA replication can be performed using machines (instead of using in-cell replication, such as through *E. coli*) at very small scales. The use of synthetic methods and machineries in biotechnology, and *in vitro* DNA manipulation [70] that enables researchers to perform controlled, small-scale DNA synthesis and assembly outside of living organisms is still in very early stages. Synthetic/automation techniques are still seen as falling short in terms of replicating the complexities and scale of living systems. In other words, microbes like *E. coli* and yeast provide environment for DNA replication and protein production at a scale and speed that are difficult to reproduce synthetically, due to their *in vivo* cellular mechanisms. Similarly, sustenance components such as yeast extract and FBS are combinations of complex growth factors and nutrients, which pose significant challenges for developing synthetic alternatives.

Therefore, while there are alternatives, more-than-human labour still remains at the core of laboratorial practices. Even high-end platforms such as genome foundries [113] rely on living organisms for components and gene replication. Additionally, synthetic and automated methods themselves carry unique labour ecologies that could be the subject of further scrutiny.

5.4 Biodesign case study: mapping more-than-human labour

The list presented in Table 1 reflects our best attempt at offering a non-exhaustive glimpse into the intricate and expansive labour ecologies underpinning our design experiment. However, we acknowledge that even more organisms could have been implicated in the design process. Indeed, each investigation into lab components or exploration of ready-made materials (such as reaction mixes,

genetic snippets, or components manufactured through diverse methods) unveiled new organismal sources.

6 Labour provenance workshop

Considering the value of identifying the many forms of life and their contributions to research, we designed a workshop that aimed to help participants expand ecologies of laboratory settings and recognise hidden forms of more-than-human labour. The workshop was comprised of three stages (Fig. 18):

- (1) **Organisms Identification:** Participants map the organisms involved in a chosen experiment. To broaden their perspective, we provide prompts informed by our provenance and labour analysis, featuring reagents and tools not typically associated with living organisms, such as primers, restriction enzymes, carrier DNA, etc. This exercise aims to reveal the ecologies of often-overlooked organismal contributors in laboratorial work.
- (2) **Labour Recognition:** Participants are then tasked with describing each identified organism’s role in the experiment and assigning them a job title that acknowledges their contribution. This step encourages participants to reconceptualise organismal involvement as a form of labour.
- (3) **Welfare Reflection:** In the final exercise, participants consider the ‘employment journey’ of the listed organisms. They are prompted to identify points where the welfare of these organisms could be improved, fostering ethical reflections from the more-than-human perspective.

We tested the workshop with 4 groups of 4-5 postgraduate MSc students from the School of Biological Sciences who carried out biolab experiments as part of their day-to-day activities. We were particularly interested in testing the method with participants who are habituated to traditional laboratory practices within biotechnology. Participants completed the three activities in about 30 minutes.

Overall, the exercises proved to be generative and thought-provoking. Participants were generally surprised by the number of organisms involved in their experiments and some expressed having started to think about usage of lab and genetic tools differently. When prompted to think about how organisms can be better treated in their experiments, they revealed a spectrum of inclinations to ethical reflections on more-than-human labour.

6.1 More-than-human labourer identification

Guided by the prompts, each group identified a range of organisms directly or indirectly contributing to their experiments. Most groups started with organisms that were the experimental subjects, provided main genes of interest, or common genetic “parts”.

“So firstly we have different genes that come from Drosophila, which is the insect providing us olfactory receptors and also the jellyfish providing the sfGFP [a fluorescent protein].” (Group 1)

“So, basically, we infected mice with breast cancer cells, which is a nice way of saying that we injected them and gave them breast cancer.” (Group 2)

“We use GFP protein as a reporter. So the GFP protein is from the jellyfish” (Group 3)

Table 1: Labour Format and List of Labourers

Labour format	List of labourers
Metabolic labour	<p>One-off providers:</p> <p>Human embryo: Providing the original embryonic kidney (HEK) cells to be transformed into standardised cell lines.</p> <p>Derivative cell lines: Growth and reproduction, incorporating and expressing new genes.</p> <p>Llama: Generating anti-GFP nanobody-producing cells as an immunological response to antigenic challenges, providing the corresponding nanobody gene sequence.</p> <p>Jellyfish and sea anemone: Providing fluorescence gene sequences used as visual selection mechanisms for plasmid construction.</p> <p>Cow: Providing BSA from serum to store enzymes in buffers and ensure the success of genetic assembly reactions, and providing enzymes for gene extraction from <i>E. coli</i>.</p> <p>Yeast: Providing functional DNA sequences for selection mechanisms.</p> <p>E. coli: Providing functional DNA sequences and genetic editing enzymes.</p> <p>T3 and T9 bacteriophages: Providing promoters that regulate gene expression.</p> <p>Anonymous eukaryotic organisms: Providing GPI anchor gene sequences that attach proteins to cell membranes, enabling the formation of 'molecular hands'.</p> <p>Influenza A virus: Providing DNA sequences in plasmids that simplify protein tracking and purification.</p> <p>T4 bacteriophage: Producing the gene sequence of the T4 ligase enzyme to connect different DNA sequences.</p> <p>Geobacillus stearothermophilus: Providing the gene sequence of the BsaI restriction enzyme to cut DNA sequences.</p> <p>Thermus aquaticus: Providing the gene sequence of the Taq polymerase enzyme that amplifies plasmid DNA.</p> <p>M13 bacteriophage: Providing sequences of primers that identify specific genes within the plasmid, ensuring precise genetic manipulation.</p> <p>Providers of DNA sequences for DNA ladder: Providing DNA sequences to form standardised gene ladders for measuring sequence length and validating experiment results.</p> <p>Haemophilus influenzae: Providing restriction enzymes (genetic scissors) to cut DNA sequences into standardised lengths for gene ladders.</p>
Resistance labour:	<p>One-off providers:</p> <p>Streptomyces fradiae (soil bacterium): Providing G418 antibiotic and its resistance gene.</p> <p>E. coli: Obtaining the ampicillin resistance gene through horizontal gene transfer and being integrated for plasmid construction.</p>
Sustenance labour:	<p>One-off providers:</p> <p>Henrietta Lacks: Providing standardised HeLa cells, which form the basis for cell seeding density guides in tissue culture labs.</p> <p>Constant producers:</p> <p>Cow: Providing fat for glycerol synthesis to protect cells in cryostorage and culture media.</p> <p>Cow foetus: Providing foetal serum with growth factors, hormones, and proteins for culture media.</p> <p>Pig: Providing digestive enzymes for the production of peptone as a nutrient source in culture media.</p> <p>Corn: Providing dextrose as an energy source in culture media.</p> <p>Oil palm and soybean: Providing oils for glycerol synthesis, contributing to cell protection.</p> <p>Red algae: Providing agarose for solidifying culture media in petri dishes and gels for DNA sequence testing.</p> <p>Bacillus bacteria and Aspergillus fungi: Contributing microbial proteases for making peptone.</p> <p>Yeast: Induced to break their own cell walls for nutrient extraction to make culture media.</p>

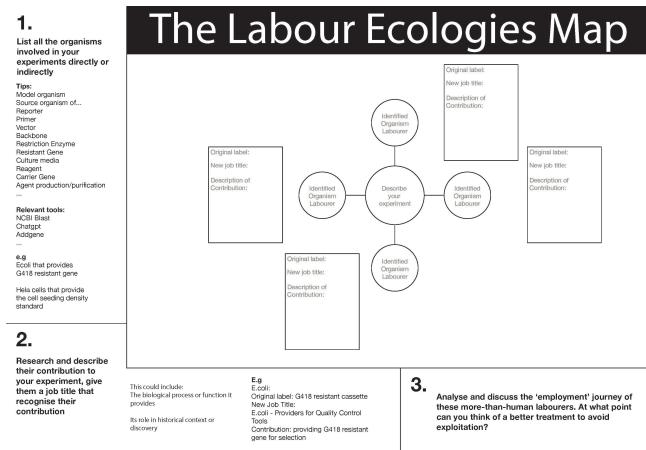


Figure 18: The labour mapping workshop template

"We have the packaging, which is from the jellyfish."
(Group 4)

As the exercise progressed, groups expanded their focus to indirectly involved organisms, such as microbes that provided resistant genes or restriction enzymes used in their experiments.

"We also have ampicillin genes coming from bacteria, we give them [as a job title] the 'plasmid makers'."
(Group 1)

"And then we use the Taq polymerase to, like, duplicate our DNA. [...] It's from Thermus Aquaticus [a bacterium]. And we call it the production engineer."
(Group 3)

"And then we have the resistance genes which come from Streptomyces Griseus and we call them the head of security."
(Group 4)

Some participants were surprised by the multitude of organisms involved in their experiments. Others expressed a sense of gratitude to the organisms.

"I think I just realised how many organisms actually go into this. Because I don't think about it when I'm in the lab doing an experiment, especially the restriction enzyme. You don't really think about it as something that's given to you by an organism. You just assume that, yeah, you actually do the research right now about where do those enzymes come from and where do the media, does it consist of any animal related or plant related or bacteria related things? So I think it's a really good shout for me to think about these things."
(Group 1)

"So first and foremost, our big MVP [Most Valuable Player] with this was the mice that actually received cancer, which we've affectionately given the name Cancer Bearers. [...] I think they need a medal for that."
(Group 2)

Interestingly, with the labour identification in mind, Group 2 was able to differentiate two roles for the same organism. They not only identified the directly contributing mice, who received cancer

cells, but also the mice behind the stage who produced the cancer cell lines.

"There were also the mice that we didn't get to see their faces, but they were the ones that the cell lines were derived from, these breast cancer cell lines that we were then infecting the other mice [...] So we've chosen to kind of make that separation between the two roles, even though it's the same organism." (Group 2)

6.2 Describing more-than-human job titles

Under the context of this labour mapping exercise, participants were guided to recognise the contribution made by more-than-human organisms in their experiment and view that as labour. Such acknowledgement is strengthened by giving job titles to the identified more-than-human labourers.

Group 1 used descriptive roles for job titles, mainly acknowledging organisms as providers of vital components for the experiment:

"And we also have the E. coli to multiply the reporter plasmid. So it's generally a 'plasmid replicator' for us. And also we have the reporter mammalian HeLa cells which report the production of the protein length."
(Group 1)

Other groups applied a range of analogies for the job descriptions. Group 2 described the mechanical aspect of the labour, such as referring to the bacteria that provided CRISPR, a technique for DNA modification, as the 'scissor manufacturers' and the virus responsible for CRISPR delivery as the 'delivery guy':

"Then we have ah, the bacteria that CRISPR actually originated from that we've adopted that tool from which we've called the Scissor Manufacturers. [...] We have the way that we actually were able to use CRISPR to knock down the gene in the cells was by delivering them to the cells with a virus. [...] We've chosen to put it with the job title of facilitator slash delivery guy because they're really facilitating this introduction of CRISPR. They're delivering it to the cells." (Group 2)

Group 3 and 4 came up with more value-based roles. Group 3 referred, for example, to the bacterium *Thermus Aquaticus*, who helps duplicate DNA, as the 'production engineer' and the bacterium *Bacillus stearothermophilus*, who provides restriction enzymes to select and combine DNA fragments, as the 'HR'. Notably, the group even started to critically represent human organisations in this 'multispecies work context', addressing humans as 'the CEO' or 'evil overlord'.

"We used E. coli to contain that library. So we would call it like the 'warehouse manager'. So the GFP protein is from the jellyfish, we'll call it like the 'visual specialist' because it's provided us [with] the reporter gene and then we use the Taq polymerase to like duplicate our DNA. [...] It's called Thermus aquaticus and we call it the 'production engineer'. [...] And so because it's their job to duplicate the DNA and then for the DNA assemblies, we used Bsal, which comes from Bacillus stearothermophilus. And the title we gave them was HR, because it selects the DNA and combines them [...]

at this point I would say maybe the human is the CEO, maybe the 'evil overlord'.” (Group 3)

Group 4 created roles that described more abstract functions provided by the organisms. The group interpreted the ability to signal a successful transformation as “quality assurance manager” and acknowledged microbes’ ability to know what it is to be built through the title of “construction specialist”:

“We have the packaging, which is from the jellyfish. I do remember the name. So we titled it as the quality assurance manager because my thinking is that the reporter used acts as a visual aid. Right. Essentially. And if there’s something good and that’s quality. So that’s something. Yeah. And then we have the backbone, which is the T7 bacteriophage and we call the construction specialist as it is the building block, is the one that is built for the whole construction. And then we have the resistance genes which come from Streptomyces griseus and we call them as head of security, [...] Yeah, it provides a resistance.” (Group 4)

6.3 ‘Be a better boss for more-than-human workers’

The last exercise of the workshop asked participants to reflect on the ‘employment journey’ of the more-than-human labourers and consider opportunities for better treatment. The responses varied from exploring concepts such as consent and coercion from microbial perspectives, to a relativisation of organisms’ welfare. Group 1 analysed forms of “exploitation” from the perspective of microbial workers, pointing out their metabolic burden and sacrifices in the making of valuable substances for humans.

“None of these were equal. The bacteria doesn’t actually need plasmid to survive. It’s something that it did because we made it to do so. That’s one way of exploiting an organism where you’re forcing it to produce something that’s not relevant to its metabolism. And finally, at the end of the experiment, she had to kill all of her cells (to extract the plasmids they produce).” (Group 1)

Group 2 responded to the task with differentiation based on the species, with more appreciation towards mammals.

“Obviously there’s a lot of exploitation involved with these in vivo projects. [...] it becomes a much greater deal when you’re, you know, you’re working with [mammals].” (Group 2)

Regarding what can be done differently, the group identified limitations in current scientific structures.

“You can provide them with good food and hopefully like as little stress as possible within their short, three week to month long lives. But like I said, there’s only so much you can do. At the end of the day, scientific progress requires that these, quote, lesser animals get exploited. And I use less with some reservation but it requires them to be exploited. And like I said, just doing stuff like this makes you really appreciate the fact that they are in that situation.” (Group 2)

Group 3 expressed concern about the required task, thinking that considering microbial welfare would defy the progressiveness of transitioning from using components sourced continuously from several organisms to employing microbes to manufacturing them through recombination.

“If you know that production of insulin, we needed to use so many creatures and to extract (from them) and then now we shifted to the E. coli recombinant engineering. So I think this is a step ahead to move away from exploiting. So I think we shouldn’t be thinking about exploiting these bacteria for experiments.” (Group 3)

Group 4 found the task challenging, as they were not sure how organisms without complex neural systems could be mishandled.

“I don’t know how you could potentially exploit bacteria. I guess you couldn’t misuse it. Yeah. And you could release it through the environment or something. I don’t know how specifically you would exploit them because I don’t think they feel pain.” (Group 4)

The workshop demonstrated that labour provenance can serve as a valuable tool to discuss the ecologies of organisms implicated in biodesign experiments. Overall, participants went through a process of identifying labouring organisms at the centre of their experiments and slowly stretched out to more peripheral organisms, carrying out a deeper analysis of common lab tools. This process underscores how the visibility of organisms’ contribution is often conditioned by their structural roles within a design workflow. During the exercise of labour recognition and job title assignment, some of the participant responses showed an emerging awareness of such structural nuances. Examples can be seen in the response that recognises the organism-concealing effect of common tools, such as restriction enzymes, and the response that acknowledges and differentiates the labour of mice in the back and front stage of their experiments, recognising that they went through similar metabolic processes. The last exercise revealed multiple ways of looking at organisms’ welfare and that some forms of life are indeed deemed as belonging to different categories of value depending on one’s definition of ethical boundaries. From this, we found it useful to define a framework that delineates these structural nuances.

7 An analytical framework of more-than-human labourers in biodesign

Building on the case study, workshop findings, and the potential for labour analysis to generate reflection, we propose a framework that describes five types of labourers. This framework is intended to help designers analyse the structural roles of more-than-human labourers, from the centre to the periphery of biodesign practices. While the forms of labour (metabolic, resistance, sustenance) address the *capabilities* of the organisms, the proposed framework conceptualises their *job positions*, focusing on how these capabilities are harnessed for value creation. By situating organisms within specific positions and functions in design processes, the framework provides a means to 1) foreground all implicated labourers including peripheral ones, 2) clarify division of labour and interconnected relations, and 3) identify levels of control and intervention exerted on organisms by discussing their levels of subsumption. Below, we

elaborate on these types, their different characteristics, and the corresponding modes of subsumption discussed above. We use examples from biological HCI to expand its applicability within the CHI community.

- (1) **Primary biological labourers** Primary biological labourers perform the core function of a given project, they are the main experimental subjects or host organisms. Their labour is fully embodied and often highly standardised, such as the yeast and human cell lines in the case study. Within wider biodesign/HCI practices, examples include mycelium utilised in biomaterial fabrication [34], silkworms used in biofabrication projects [53, 88], bacteria for film plates [117], etc. Uprooted from their natural environments, organisms can undergo real subsumption, where every aspect of their living process is optimised and directed towards production, making them highly dependent on specialist human intervention and unlikely to survive outside of these productive activities. In many instances, their resistance is turned into an essential driver of productivity. Primary labourers are the most visible labourers. When belonging to the animal kingdom, and indeed when they are mammals, their contributions can be acknowledged by ethical lab protocols (e.g. [98, 105]) and animal rights movements [38].
- (2) **Specific skills labourers** Specific skills labourers provide specialised biological functions, raw materials or traits without directly performing the main task. These organisms or their components are often harvested for specific purposes, such as bacteria and jellyfish that supplied functional DNA sequences for plasmid construction in our case study. Examples in the wider biodesign/HCI practices include bacteria that offer bioluminescence for digital silkscreen printing [100], and the microbes, fungi or insects needed to degrade or compost biodegradable materials [9]. While some skilled labourers undergo minimal interference, merely providing naturally occurring substances (formal subsumption), others are subjected to more intensive modifications to amplify their outputs (real subsumption). The latter can be seen in bacteria engineered to mass-produce specific resistance genes for plasmid construction. In contrast to the primary biological labourers, the contribution of specific skills labourers is less likely to be recognised.
- (3) **Tool-based labourers** Tool-based labourers are organisms or biological components that facilitate the control, manipulation or handling of primary and skilled labourers. They are integral to the biodesign workflow, facilitating precise organismal or environmental manipulation. For one-off contributors, they often undergo formal subsumption, where their naturally occurring substances are harnessed directly. Examples in biodesign/HCI include the oats that serve as a conditioning tool to guide slime mould behaviours in living computers [1], the rice plant or barley behind vinegar as a pH regulator in bioplastic fabrication [74], and, in our case study hot spring bacteria providing heat resistant polymerase for genetic assembly. Real subsumption often happens in constant producers, which are modified to optimise production of specific valuable ‘tools’. For example, polymerase enzymes

are often mass produced through recombinant bacteria. However, the common perception of tools and its often obscure nomenclature (serial numbers and barcodes) pose challenges in recognising its potential organismal source and labour.

- (4) **Support and sustenance providers** Support and sustenance providers are the often-overlooked labourers that supply the essential nutrients and life-conducive environments to maintain the primary and skilled labourers, ensuring ongoing viability of production. Tracing the network of sustenance is often an expansive exercise. As mentioned above, culture media often includes a range of animal-, plant- and microorganism-derived components, linking the reproduction of laboratory cell lines to the wider agricultural ecosystem. Substances such as peptone and yeast extract used in the case study are also widely used in biodesign/HCI practices for mycelium cultivation [13]. Formal subsumption occurs when these organisms are simply harvested for their natural outputs, while real subsumption involves significant modification to maximise production, such as intensively farmed oil palm or recombinant bacteria that mass-produce rBSA. The extensive extraction and repurposing of their metabolic labour highlight how many biotechnological processes are fundamentally fuelled by their ‘reproductive labour’.
- (5) **Evaluation and feedback labourers** Evaluation and feedback labourers provide crucial responses and data that inform and refine experimental or design decisions. The visibility of feedback labourers depends on their role in the experiment. In the case study, it took a rather unassuming form, such as bacteria and viruses that supply DNA sequences for gene ladders used in gel electrophoresis. When testing is the main goal of the experiment, the feedback labourers become the primary labourers, examples can be seen in rabbits historically used for pregnancy tests, and horseshoe crab used in vaccine tests. In the wider biodesign practice, we can see feedback labourers mostly in forms of biosensing, such as bacteria engineered to signal environmental change [18]. In this case, real subsumption involves the modification of these organisms’ genome or entire living conditions to enhance their feedback capabilities.

8 Discussion

8.1 Revealing more-than-human ecologies

As we browse through catalogues of biological resources², we learn about what organisms, cells and biological components can do for a biodesign experiment and research. We learn that certain types of bacteria can change or gain vivid colours under particular circumstances, that, under certain conditions, mycelium spores can grow into a designated shape, and that the DNA of yeast cells can be modified with the help of certain substances to encode particular information. Detached from their context, there is a tendency for designers to not think about what could have driven these organisms to behave this way: what kinds of physical pressures they have endured and what kind of environmental interactions they became accustomed to in order to sharpen or gain these features.

²Such as Carolina.com, atcc.org, neb.com, etc.

This detachment hides the first level of labour these organisms have performed in order to achieve what we now deem valuable for a particular design: the bodily work that underlies their quest for survival.

As we uncover the hidden layers of living organisms that existed behind disembodied laboratory components, we also uncover their histories and recognise their interconnections with the wider world. The multitude of roles organisms play in laboratory practices (from primary production to serving as tools to manipulate other organisms) reflects a deeper reality: we are not merely co-opting individual organisms and their productive capabilities but also appropriating a network of relationships in the more-than-human world - from the antibiotic resistance race carried out by different types of bacteria and the flows of sustenance from microbes to animals, to the llama's immunological aptness against surrounding pathogens. Within our framework, we can recognise that life is interconnected and exists as much in a virus quasi cell as in the colours of sea anemone, and fetal serum of the calf that will never be. Indeed, we can understand our experiment as effectively establishing a wholly new ecology across humans, animals, plants, microbes and viruses - an ecology mediated by some humans in western industrialised countries (that is, us, and the many others that contributed to mass-produce biolab tools and components) and which would probably never have existed outside of this mediation. This new ecology, however, is still dependent on the original ecologies which these organisms have evolved into, and which created the features that allowed our experiment to take place. What our labour provenance approach does is to reveal these interdependencies, placing them within a noninnocent [25] perspective of utilitarianism, value creation, and/or capitalist production, a perspective that is prominent in our compromised existence [103] and which is increasingly stretching to all corners of the world.

The detachment created by the transformation of the living into laboratory components prevents us from acknowledging and celebrating the many ways in which these organisms support the sustenance, tools and primary production that enable our practices to take place. It leads us to seeing our practice as a combination of biological products and features rather than an intervention into, and creation of, new ecologies. The labour provenance lens gives us tools to reflect, evaluate and question these new ecologies within a wider context, emphasising the many forms of interconnected labour that more-than-humans perform, and the extent to which each individual organism is contributing to essential design processes through metabolic, resistance and/or sustenance labour, regardless of their species, or whether they provide an one-off or a continuous contribution.

In our labour provenance map, viruses, bacteria, mammals and plants all play a role within new and existing ecologies. While there might be a temptation to place more emphasis on the work of specific animals - and research shows that humans tend to more readily empathise with and consider the ethical implications of beings that are more similar to them or more present in their daily lives [76] - we argue that the more distant species are from our direct empathic sensibilities, the more important it becomes for us to apply conceptual theories to rehabilitate the recognition of their value. This approach is crucial because the emotional proximity between specific organisms and humans doesn't necessarily correlate with

the extent to which they are interconnected. In other words, the danger of overlooking 'less-appealing' organisms is that it prevents us from identifying the crucial interdependent relations between charismatic and less charismatic species, and indeed humanity's own interdependencies with these often-overlooked lifeforms.

In HCI, there is a significant amount of work done with bacteria [60, 83, 121], fungi [34, 62, 114], and plants [16, 46, 47, 54], alongside wild and domestic animals in Animal-Computer Interaction (ACI) [45, 71, 72]. Recent research has started to explore critical approaches to engaging microorganisms in research, including with focus on microbial temporality [8], unmaking [7] and non-participation [17]. These demographics of more-than-human organisms involved in design and HCI practices demand a more holistic approach in labour analysis that focuses on interconnections [36] rather than individual species.

They also invite new ways of honouring the contribution of these organisms. As Despret discusses in *Are any species killable?* [26], the way of "honouring" the labour and sacrifice of lab organisms "remains to be invented", particularly within western lab conventions. Other cultural practices, such as Japan's longstanding memorial services for lab animals (*Ireisai*) [51] and more recently, synthetic cells [52], point to existing ritualistic approaches that celebrate more-than-human contributions to research. Although predominantly focusing on primary contributors, these practices lay an important moral foundation for future forms of labour recognition that include a broader acknowledgement of the myriad shadow organism labourers and their ecologies.

8.2 Expanding notions of 'sustainability' in biodesign

Sustainability in biodesign is often framed as a natural outcome of working with living organisms, leveraging their capability to self-generate, adapt to different environments, and eventually biodegrade. Indeed, while it may appear that biodesign inherently aligns with sustainable principles due to its use of "natural" components, the reality is that it not only can replicate unsustainable patterns seen in traditional design and production, but also render itself more controversial, in the extent that it appropriates other organisms' capacities. The reproduction, maintenance, and growth of living systems in biodesign rely on extensive ecological networks and on living and non-living inputs, many of which are themselves products of industrial processes with significant environmental impact and/or extraction from an array of organismal labour. The complexity and multitude of more-than-human labour and its associated modes of production shown in this paper reveals that the sustainability of biodesign is inherently contingent on its wide ecologies of more-than-human labour and on its level of integration into industrial systems.

In her opening keynote at CHI 2024, Kate Crawford reiterated the need to focus on the materiality of artificial intelligence (AI) [23]. Through tracing the significant material cost behind the development of large language models (from environmental degradation to underpaid crowd labour), she redefines the impact scale of the seemingly ephemeral concept of AI. In particular, she mentions the mutually reinforcing methods of '*abstraction*', '*distraction*'

and 'extraction' of AI - that is, the abstracted images and disembodied analogies associated with AI, which remove it from the '*earthly resources needed to produce it*', and distract people from the power structures it originates from and thus reinforces. As such, abstraction and distraction lead to a sense of ignorance and further smoothes and exacerbates AI's associated resource and labour extraction.

Similarly, we contend that applications and methods of biological HCI can become an abstraction, distraction and extraction of the actual labour performed by different organisms involved in the research and production process. The abstraction of life through labelled components can distract researchers from the actual life-cost to produce them and exacerbate extraction of value from their bodily works and the wider labour ecologies that they are entangled with.

By providing a case study on labour provenance, we call for a more expansive perspective on sustainability - one that goes beyond visible and charismatic organisms to include all entities and the broader ecological implications of design. This approach calls for a holistic view that scrutinises every component and process involved in sustaining life, including the substances sourced to sustain biodesign practices and the environmental toll of lab operations. Only by accounting for these interconnected costs can we move towards genuinely sustainable practices that do not merely reinscribe the extractive logics from conventional anthropocentric design.

8.3 Labour as a lens for discussing more-than-human design ethics

Applying a labour provenance lens allows us to critically expand the boundaries of what can be seen and critically analysed in biodesign. As the discussion in the workshop regarding 'how to be a better boss for more-than-human labourers' reveals, there is often a struggle in conceiving of ethical treatments in certain types of organisms. As mentioned above, humans tend to more readily empathise with species that can be seen as having human traits, and traditional ethical frameworks often rely on biological traits such as pain perception or cognitive complexities as guard rails of moral relevance [95, 104], naturally leading to a focus on mammals. In contrast, environmental humanities, and posthumanist discourse suggest alternative approaches, emphasising the possibilities to establish ethical relevance through roles and contribution in ecosystems [27], interdependencies [92] and/or care relations [25, 28]. Viewed from the latter frameworks, the discovery of interconnected forms of labour in biodesign practices possesses significant ethical implications.

By evaluating the levels of subsumption exerted on organisms, we can assess the involvement of organisms in the design process, acknowledging whether their contributions are justified within a spectrum of capitalist value production that could vary from no subsumption, to formal and finally real subsumption. No subsumption would mean a form of design outside capitalist modes - a relationship to the more-than-human that does not imply any reproduction, scaling, added value or commercialisation. Formal subsumption could be identified as design practices that attempt to reward organisms by giving them optimal environments to produce

valuable responses or substances, while real subsumption would take place when organisms' functions are changed, optimised or scaled up to sustain a particular design.

A great part of current HCI research into more-than-human or multispecies design seems to inhabit a space between no subsumption and formal subsumption. Such practices emphasise interdependency and the ethical imperative to meet the needs of the organisms, mostly considering the creation of non-commercial research value, including educational, artistic and discursive outcomes. However, in these cases, organisms may still be subjected to human-defined goals, even when efforts are made to balance the contribution of more-than-human organisms with care and coexistence. By applying the labour lenses, and indeed by simply calling their participation "labour", we allow for a different discussion to emerge - one that could stress conflicting goals and potentially implicit anthropocentric agendas, as well as reveal ways of improving organismal welfare. As environments become more controlled, and techniques more interventional, however, there is an increased potential to move towards real subsumption (such as in the case of microorganisms in the biolab practices described above, but also more advanced forms of biological HCI) potentially leaving little space for organisms' interest or resistance beyond designated value creation. In this case, the framework allows us to critically evaluate the extent to which a design activity or a biological experiment subsumes the living processes of more-than-human organisms and its ecological context for the benefit of production.

While our work focuses on living labour and its surrounding ecologies, it may also invite reflections on the non-living. As technology advances, distinctions between the living and the non-living become blurred: while living organisms become more "designed", machines become more autonomous, akin to living things. Here, we argue that the labour framework can help us shift the focus from simple notions of autonomy to what is underlying such behaviours. We could say that, while living organisms possess their own generative agendas – e.g. to stay alive, reproduce, resist dominance – that can be co-opted into systems of production, the agendas of non-living agents such as machines and algorithms, as discussed by Crawford [23], are intrinsically connected to human-defined functions and systems of power. This way, while living organisms move from autonomy to real subsumption, machines and algorithms that manifest elements of autonomy move from real subsumption to autonomy. As such, the labour carried out by living organisms (and the ethical implications of extracting value from this labour) can be considered as intrinsically different. Indeed, as we move towards more entangled forms of living and non-living labour, there is a need for further investigation into the wider ecologies of labour, materials, and sustenance, the forms of control to which these are subjected, and how they are embedded within system of production.

Furthermore, while the labour framework enriches our understanding of organismal contributions and structural positions within design, we must also acknowledge that it still only addresses part of organisms' identity, which may overlook wider ecological roles, intrinsic values, the relevance of these organisms beyond systems of production, and more complex entanglements with the non-living.

To fully unfold the implications of different modes of labour subsumption, we need to understand the origins and forms of work

that are being subsumed. In the human context, the shift from formal subsumption to real subsumption significantly changes socio-economic structures and workers' relations with their means of production. In the context of 'employing' living processes and embodied work, different modes of subsumption can directly alter more-than-human workers' ecological relations, bodies, metabolism and genomes. As biodesign practices increasingly harness and reshape the living processes of organisms, the identification of labouring or value-generating processes becomes the crux of unravelling the locus of productionist control and assessing the ethical dimensions of these interventions.

In sum, the labour provenance framework provides a way to interrogate the potential ethical implications of biodesign, asking if the level of control over organisms is commensurable to the consequential benefit, and what could be done to improve conditions within these practices, even if ways to interpret these questions can vary, as indeed is the case amongst the authors of this paper. Rather than a set of guidelines on how to proceed, it is a way to leverage reflection on the many expressions of life, their interdependences, and the mediation of these interdependencies within our created worlds.

9 Conclusion

In this paper we have applied 'labour provenance' as a lens to uncover the network of more-than-human organisms implicated in a biodesign case study. We translated this approach into a workshop to facilitate reflection on hidden organism labourers and the spectrum of inclination towards ethical reflection on organisms' contribution. The analysis and reflections led to the definition of a framework to help designers investigate and analyse more-than-human labourers and which can help us question underlying power dynamics beyond the immediate relationship between designer and primary organisms. We propose the concept of labour provenance as a way to foster a discussion on more ethical approaches to biodesign that can acknowledge all contributing life forms. The multitude of uncovered organisms problematise the inherent notion of sustainability in biodesign and calls for a view that situates practices within the wider interconnected ecosystems and industrial production. Ultimately, this expansive perspective challenges us to rethink what it means to engage with living systems in design and to strive for practices that honour the full complexity and interdependence of our more-than-human world.

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