HTBAA Homework #1 — A Living Inkblot for Bees

Andrea Abbatangelo · Committed Listener, London UK

1. What I want to biomanufacture, and why

I want to biomanufacture a living inkblot for bees: a genetically engineered flowering plant whose bilateral form and ultraviolet pattern develop from my *Inkblot for Bees* series (2023 – 2024), and whose nectar contains a chemically defined plant-derived compound selected for investigation in relation to pollinator learning and memory.

The long-term aim is to investigate whether floral morphology, pollinator-visible patterning and nectar chemistry can be redesigned together around the perceptual and cognitive capacities of bees.

This research began in 2021 during my MA Fine Art: Digital at Central Saint Martins. I worked with antique microscope slides of bee tongues and mouthparts to examine pesticide exposure through the anatomy of feeding. This became *New Observations on the History of Bees*, followed by *Inkblot for Bees*, developed through my 2023 residency at Atelierhaus LEW1 in Darmstadt and the laboratory of TU Darmstadt. The drypoint series adapted the bilateral structure of the Rorschach inkblot for a non-human visual system. It established the visual and conceptual language of the project, but remained an early stage of the investigation: an image constructed for a bee without yet becoming something a bee could perceive as part of a living floral encounter.

Through Alias Studio × Serpentine's Future Art Ecosystems programme in 2025, I developed *BeeVision Fragmenta* and *BioViscous Mask*. These works moved the research from representation towards computational perception and material intervention: first by modelling how visual information might be reorganised through a bee-centred system, and then by considering whether a manufactured membrane could intervene in the physical relationship between a pollinator and a chemically altered environment.

Biomanufacturing is the next stage of this progression. I want to investigate whether the inkblot can be encoded into the development of a living flower. This would involve identifying a bee-attractive plant chassis; studying the developmental pathways that govern floral symmetry and ultraviolet nectar guides; and investigating whether a selected phytochemical could be produced specifically in its nectar. Sage, rosemary and melissa provide the conceptual starting point because of their histories as European medicinal plants associated with cognition, but their relevance to pollinators cannot be assumed. The compounds involved, their presence in nectar and their effects on bees would first need to be identified and evaluated. Caffeine, which occurs naturally in some floral nectars and has already been studied in relation to honeybee memory, can provide a scientific comparator.

Within the timeframe of this course, I propose two connected levels of development. The first is a contained bacterial-cellulose feeding object that functions as an experimental proxy [fig 1]. It can be used to investigate the inkblot's ultraviolet geometry, material stability, liquid delivery and candidate nectar chemistry without genetically modifying a plant or exposing living bees. In parallel, I will develop the genetic and phenotypic design of the future flower by selecting a suitable plant chassis and mapping the developmental, pigment and nectary pathways that would need to be modified.



Fig 1

The cellulose object is therefore not the final living inkblot. It is the first biomanufactured test platform through which the optical and chemical specifications of the engineered flower can be established. The longer-term outcome would be a sterile, contained plant prototype. Neither the material prototype nor the engineered plant would be introduced into nature or presented to living pollinators until its organisms, compounds and finished material had been assessed as safe for wild pollinators.

2. What living system would make it

The proposal has one target system and one proxy system, running in parallel.

The target: an engineered flowering plant

Three engineered layers would be needed, and each rests on published biology.

Floral symmetry. CYCLOIDEA-like TCP transcription factors establish bilateral symmetry in flowers [Fig 2], characterised first in *Antirrhinum* and since across the asterids. Recent work links the same regulators to the formation of asymmetric nectar guides through control of flavonoid synthesis, which is unusually convenient here because symmetry and pattern share a regulatory route. An important limit: modifying a developmental regulator produces a phenotype the plant's own developmental system arrives at, so the result would be screened across many individuals instead of drawn to specification.

Ultraviolet pattern. Flavonoid biosynthesis, principally the flavonol glycosides that absorb in the near-UV, already produces the nectar guides many bee-visited flowers carry and we cannot see. Altering the spatial expression of that pathway is the route to a bilateral UV blot.

Nectar chemistry. Nectary-specific expression of a selected biosynthetic pathway, so the compound appears in nectar and nowhere else in the plant.



Fig 2

Chassis choice is a real trade-off. *Salvia officinalis* is conceptually exact, since it attracts bees, produces nectar, carries a bilateral corolla and belongs to the medicinal-herb history this project departs from, though it is a poor genetic model. *Antirrhinum majus* or *Mimulus* are far more tractable for symmetry work, with the cost that the chemistry would have to be imported from elsewhere. I would begin by mapping both routes and choose on the evidence.

On the herbs. Sage, rosemary and melissa give the project its conceptual origin. The human trial evidence stays exactly that, since it tested a combined oral ethanol extract in people, found no significant overall memory difference across all 44 participants and produced its positive delayed-recall result only in the under-63 subgroup. So the proposal identifies candidate metabolites associated with the reported activity, determines whether they occur in floral nectar and at what concentration, selects one chemically defined and measurable candidate, then asks whether its pathway could be expressed in nectary tissue. Caffeine serves as the known benchmark alongside this, since there is direct evidence that naturally occurring nectar caffeine strengthens honeybee memory.

The proxy: a contained bacterial-cellulose test platform

Komagataeibacter rhaeticus grows bacterial cellulose, and engineered strains have been made to produce pigment within the growing pellicle through tyrosinase expression, with optogenetic control of gene expression demonstrated in the same system. That combination lets a pattern be written with projected light while the material grows.

This object answers the questions that would otherwise be entangled inside one engineered plant: what the inkblot should look like to a bee, whether the pattern survives growth and handling, how a liquid reward is held and delivered, which compound and concentration merit consideration, and whether the system can be contained and rendered non-viable. The plant phase then asks a separate question, which is whether those selected visual and chemical functions can be encoded into the development and metabolism of a living flower.

One point of naming matters. If the cellulose is rendered non-viable before any handling outside containment, it is accurately described as a material grown by living organisms. The engineered plant would be the first genuinely living floral inkblot.

The compound module

Cell-free synthesis of caffeine from xanthosine runs through three S-adenosyl-methionine-dependent methyltransferases characterised in *Coffea arabica*. Three enzymes suits a cell-free reaction, and commercially characterised caffeine can serve as a reference control while the pathway is being developed.

Assumptions to test: that near-UV-absorbing pigment can be produced in *K. rhaeticus* the way melanin already is; that optogenetic patterning resolves at a scale a bee can discriminate; that cellulose holds a liquid reservoir without collapsing the pattern; and that a CYCLOIDEA-route modification yields a screenable range of phenotypes in a chassis that also produces nectar.

3. How automation would help

Three places, in descending order of how badly I need them.

Cell-free optimisation on a liquid-handling robot. A three-enzyme pathway has a large combinatorial space: relative enzyme ratios, xanthosine concentration, SAM supply and regeneration, temperature, reaction time. Exploring that by hand means weeks of pipetting and inconsistent replicates. A desktop Opentrons or a Cloud Lab run can set up a few hundred small reactions in parallel, with the plate reader or mass spectrometry step giving caffeine yield per condition. This is the step I would automate first, because it is the one where manual work adds error and adds nothing else.

Projected light as the patterning tool. This is the part I find most beautiful. Optogenetic control means the pattern is applied by a programmable projector shining onto the growing pellicle, so the image becomes an exposure schedule: which regions, at what intensity, for how long. My inkblots have always been made by a physical process I only partly control, first the drypoint needle and later a generative model. Here the drawing instrument is light and the plate is alive. The same file drives every replicate, which is what makes a controlled experiment possible at all.

Automated behavioural measurement. Proboscis extension reflex conditioning is the standard honeybee memory assay: a restrained bee learns to associate an odour or colour with a sucrose reward, and retention is scored hours or days later. Automated stimulus delivery and video scoring remove the experimenter bias that is hard to avoid when a human decides whether a proboscis extended.

The automation for the prototype and for the scale-up diverge sharply, and the assignment asks me to say so. Prototyping wants many small parallel reactions and precise measurement. Production wants continuous fermentation, large static culture trays and a patterning rig sized to square metres instead of Petri dishes.

4. How much, and how long

The complete project extends well beyond this course. My objective during the course is a contained proof of concept for the material system: grow a small bacterial-cellulose substrate, investigate whether a bilaterally symmetrical UV-absorbing pattern can be produced or incorporated, measure that pattern's stability through growth, drying, sterilisation and rehydration, and test whether the material holds a chemically defined nectar analogue. The pattern would be evaluated through spectral measurement and simulated bee-vision modelling. The caffeine pathway runs alongside as a parallel module, with an outcome ranging from pathway design to a quantified cell-free synthesis depending on available lab time. The plant-engineering work during the course is genetic and phenotypic design instead of transformation.

I define three scales below: what the course can produce, what a later behavioural study would need, and what a landscape deployment would need.

Tier 0: the course-scale prototype

Twelve to twenty patterned cellulose units, each roughly 8 cm across, for material characterisation. No bees.

> *20 units × 50 cm² =* ***0.1 m² of patterned cellulose***

Static bacterial cellulose culture yields a usable pellicle in roughly 10 to 14 days, and the duration is set by the culture instead of the area, so trays run in parallel. Within a twelve-week course: 4 weeks to establish the strain and the projection rig, 2 weeks of patterned growth, 2 weeks of stability and reservoir testing, 2 weeks of spectral and bee-vision modelling, with the cell-free module running throughout. **Feasible, with the patterning work as the item most likely to overrun.**

Tier 1: enough to answer the behavioural question (later phase)

This phase belongs after safety characterisation. The experiment crosses three binary variables: pattern present or absent, caffeine present or absent, pesticide exposure present or absent. That gives 8 groups. At n = 30 bees per group, plus roughly 25% attrition, the study needs about **300 bees** and **60 living inkblots** (8 groups × 6 replicate units, plus spares).

Material. Each unit is a disc of roughly 8 cm diameter, about 50 cm². Sixty units come to 3,000 cm², or **0.3 m²** of patterned bacterial cellulose.

Compound. Wright and colleagues used nectar-realistic caffeine in the region of 0.1 to 0.3 mM. Taking 0.2 mM and a caffeine molar mass of 194.19 g/mol:

> *0.2 mmol/L × 194.19 g/mol =* ***0.039 g/L***

Each unit holds a 500 µl reservoir, refreshed four times across the study, so 2 ml per unit. Sixty units need 120 ml of dosed solution:

> *0.120 L × 0.039 g/L =* ***0.0047 g, roughly 5 mg of caffeine***

Five milligrams. Less than a tenth of what is in an espresso. A single cell-free reaction at millilitre scale would cover the entire study, which tells me the compound is not the bottleneck at this tier.

Time. Static bacterial cellulose culture produces a usable pellicle in roughly 10 to 14 days, and the duration is set by the culture rather than the area, so trays run in parallel. Strain construction and validation is the long pole. A realistic prototype timeline: 8 weeks to build and validate the pigment and optogenetic constructs, 2 weeks of patterned growth, 2 weeks of cell-free optimisation running in parallel, 1 week to assemble units, 4 weeks of behavioural assays. **About 4 months.**

Tier 2: enough to matter in a landscape (future phase)

Define the meaningful scale as one hectare of foraging habitat, populated at one living inkblot per 10 m²:

> *10,000 m² ÷ 10 m² =* ***1,000 units per hectare***

Material. 1,000 × 50 cm² = 50,000 cm² = **5 m² of patterned cellulose per hectare**.

Compound. Each unit dispensing 200 µl per day across a 60-day foraging season gives 12 ml per unit, so 12 litres per hectare:

> *12 L × 0.039 g/L =* ***0.47 g of caffeine per hectare per season***

Under half a gram. The striking result of this calculation is that the active compound is almost free, and the whole engineering problem lives in the material and the pattern.

Time. Growing 5 m² in 1 m² trays means 5 trays over one 14-day culture cycle, or a single larger tray. Adding patterning, harvest, drying and assembly, **roughly 4 to 6 weeks per hectare** once the strain exists. Ten hectares would need either ten times the tray area or ten sequential cycles, which is where continuous or roll-to-roll production would replace static trays.

Two caveats I want to state plainly. These numbers assume the material and the pattern work, so they size a manufacturing problem and say nothing yet about whether the object affects a bee. And Tiers 1 and 2 describe later phases contingent on the safety findings set out below, with Tier 2 presupposing the engineered plant rather than the cellulose proxy.

5. What I do not know yet

Whether a bee can see the pattern as a pattern. Bee vision has poor spatial acuity compared with ours, on the order of a few degrees of visual angle, so fine detail disappears at any distance. An inkblot designed for a human eye may register to a bee as a single blur. I would need to establish the minimum feature size that survives at realistic approach distances, then redesign the blot around that constraint. This is the unknown I find most interesting, because it turns a question about bee optics into a compositional rule.

Whether caffeine restores impaired memory or only enhances intact memory. The 2013 result was obtained in healthy honeybees. Pesticide exposure and caffeine act on different targets, and a compound that strengthens consolidation in a healthy brain may do nothing for one whose cholinergic signalling has been disrupted. Testing this needs a sublethal exposure model and a comparison of caffeine's effect in exposed and unexposed bees. If the answer is no, the honest version of the project becomes a study of enhancement instead of repair, and I would want to say so rather than quietly redescribe it.

Whether the material holds the pattern through growth and use. Bacterial cellulose keeps growing while it is patterned, so an image written early could stretch, blur or drift as the pellicle thickens. The material then has to survive drying, rehydration and outdoor weather without losing its optical structure. My earlier work on hydrogel and mineral composites ran into exactly this question of whether a structure survives a drying and rehydration cycle, and it remains open.

6. Ethical boundaries and containment

These are design constraints of the proposal, and they shape what the first generation can be.

The first generation will stay out of any natural environment and will be presented to no living bees. Its purpose is to establish whether the material can be grown, patterned in the ultraviolet range, biologically contained and used to hold a chemically defined sugar solution.

During manufacture the engineered microorganism remains inside a controlled laboratory system. Before the material leaves containment or enters any exhibition context, it is rendered non-viable while the cellulose structure and the optical pattern are preserved. A material holding living bacteria is by definition unsterilised, so the precise formulation is that the organism is physically contained and reproductively controlled during development, then rendered non-viable after pattern formation. In that sense the first object is a material biomanufactured by a living system.

The reservoir would provide a measured nectar analogue and no pollen. It is therefore unsuited to imitating or replacing a flower, and it supplies no complete pollinator nutrition. Because a nectar-only object could still redirect foraging, attraction, competition or nutritional choice, no ecological claim follows until those effects have been investigated.

Any later experiment involving living bees constitutes a separate research phase. It would proceed after the material's chemical composition, microbial containment, stability, dosage and potential toxicity have been characterised, and after consultation with pollinator researchers, biosafety specialists and the relevant ethics or regulatory bodies. Initial evaluation uses material measurement and simulated bee-vision analysis. No living bees will be exposed to the inkblots until further research has demonstrated that the engineered organisms, the compounds they produce and the finished material present no unacceptable risk to wild pollinators.

The engineered plant carries its own version of these constraints: sterility, contained growth, and no release of a first generation.

AI use

AI clients: ChatGPT (OpenAI); Claude (Anthropic), September 2026.

Prompts used, in sequence:

- Asked what the course expects from Homework #1 and which node centres to list on the application form.
- Described the project idea in my own words: merging *Inkblot for Bees* with the biomanufacture of a living inkblot, drawing on research suggesting European culinary herbs affect memory. Asked whether it would require DNA editing and wet lab work.
- Was advised that the human sage, rosemary and melissa trial evidence was weak ground for a bee proposal, and redirected toward pollinator-specific literature on caffeine and memory.
- Chose to frame the project as a test of whether pattern plus compound changes bee memory, with the treatment application as a later scale-up goal.
- Asked for a first draft, which I am now editing.

The framing, the artistic motivation and the decision to test before treating are mine. The suggestion to use caffeine in place of rosmarinic acid, the bacterial cellulose chassis and the structure of the scale calculations came from the exchange above and were checked by me against the sources below.

References

- Wright, G. A., Baker, D. D., Palmer, M. J., Stabler, D., Mustard, J. A., Power, E. F., Borland, A. M., & Stevenson, P. C. (2013). Caffeine in floral nectar enhances a pollinator's memory of reward. *Science*, 339(6124), 1202–1204. doi:10.1126/science.1228806
- Walker, K., Goosens, C., et al. (2024). Self-pigmenting textiles grown from cellulose-producing bacteria with engineered tyrosinase expression. *Nature Biotechnology*. (Preprint: bioRxiv 2023.02.28.530172)
- Gilbert, C., et al. (2021). Living materials with programmable functionalities grown from engineered microbial co-cultures / bacterial cellulose spheroids as building blocks for patterned living materials. *Nature Communications*, 12, 5027.
- Perry, N. S. L., et al. (2018). A randomised double-blind placebo-controlled pilot trial of a combined extract of sage, rosemary and melissa on the enhancement of memory in normal healthy subjects. *Phytomedicine*, 39, 42–48. (Cited as the origin of the idea, with its subgroup limitation noted.)
- Karim, A. S., & Jewett, M. C. (2021). Toward sustainable, cell-free biomanufacturing. *Current Opinion in Biotechnology*, 69, 136–144. (Course reading.)
- Petzold, C. J., & Mukhopadhyay, A. (2025). From bench to biofactory: high-throughput technologies and automated workflows to accelerate biomanufacturing. *Current Opinion in Biotechnology*, 94, 103320. (Course reading.)

Full citations for the caffeine biosynthesis methyltransferases and for bee visual acuity still to be added.