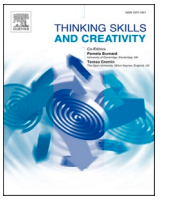
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Becoming a designer-scientist: A designer's journey into laboratory practice and material characterization as creative tools for biodesign with bacterial cellulose

Luis Quijano [a,b,c], Ziyuan Jing [d], Tiziana Ferrero-Regis [b], Laura Navone [a,c], Dmitri Golberg [a], Wenqing Zhang [d,*]

[a] Faculty of Science, Queensland University of Technology, Brisbane City QLD 4000, Australia
[b] Faculty of Creative Industries, Education and Social Justice, Queensland University of Technology, Kelvin Grove QLD 4059, Australia
[c] ARC Centre of Excellence in Synthetic Biology, Queensland University of Technology, Brisbane City QLD 4000, Australia
[d] School of Chemistry and Molecular Engineering, East China University of Science and Technology, Shanghai 200237, China

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ABSTRACT

With the integration of biotechnology into design practices (biodesign), designers are learning to navigate between the interfaces of design and science. However, for designers, the laboratory often remains an unfamiliar environment: structured, procedural, and often perceived as incompatible with creative practice. This study attempts to demystify laboratory practice and explores how laboratory practice can function as a creative methodology for designers through the reflection of the primary author's journey from designer to designer-scientist with an autoethnographic exploration of bacterial cellulose. Conducted within a chemistry laboratory, this study investigates how scientific protocols, tools, and material characterization techniques can inform design decisions and expand material design for designers. The findings show that engaging with laboratory methodologies allow designers to think through materials by observing transformation at both aesthetic and molecular levels, linking empirical data to creative decision-making. Reflecting on moments of uncertainty, adaption and learning, this study illustrates how laboratory practice reshapes the designer's practice and identity, fostering confidence and fluency across disciplinary boundaries. Ultimately, this study argues that the act of "becoming a designer-scientist" reframes biodesign as both an empirical and reflective practice, while opening new pathways for sustainable and transdisciplinary futures.

1. Introduction

The fashion industry is at the centre of an escalating environmental crisis, exacerbated by its reliance on synthetic fibres and unsustainable production models. Synthetic textiles primarily derived from fossil fuels, now account for 69% of global textile production, a figure projected to rise to 73% by 2030 (Changing Markets, 2024). Fashion is also responsible for significant greenhouse gas emissions, the depletion of finite water resources, and vast amounts of landfill waste (Niinimäki et al., 2020). Compounding these

* Corresponding author.
E-mail addresses: l.quijano@hdr.qut.edu.au (L. Quijano), jzy02200059@163.com (Z. Jing), tiziana.ferreroregis@qut.edu.au (T. Ferrero-Regis), laura.navone@qut.edu.au (L. Navone), dmitry.golberg@qut.edu.au (D. Golberg), zhwqing@ecust.edu.cn (W. Zhang).

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issues is the industry's linear production model, which prioritizes high volume and low cost at the expense of durability, repairability, and end-of-life recyclability. Addressing these systemic challenges requires urgent innovation to redefine material production, use, and disposal while reducing the fashion industry's use of fossil fuels (Changing Markets, 2024).

Biodesign and biotechnology have emerged as promising approaches for fashion sustainability, leveraging biological processes to create materials that are not only sustainable, but also capable of transforming the traditional fashion manufacturing model (Quijano et al., 2021). Biodesign represents a paradigm shift in material creation, where designers are no longer limited to traditional practices of crafting and prototyping, but are actively learning to 'grow' and 'modify' materials in diverse settings, including do-it-yourself (DIY) materials, artisanal makerspaces, and, more recently, professional laboratories (Pollini & Rognoli, 2024; Rognoli et al., 2015). Despite biodesign's potential, there are significant challenges for designers entering laboratory spaces. Designers frequently encounter barriers such as limited access to laboratories, insufficient scientific training, and significant differences in practices and terminology between the design and scientific communities (Quijano et al., 2024a). Transitioning from studio-based workflows or artisanal makerspaces to laboratories requires adapting to new tools and scientific protocols. Nevertheless, laboratories provide unparalleled platforms for designers to gain deeper insights into material properties and processes, enabling transformative practices that merge creativity and empirical rigor (Koskinen et al., 2011)

While biodesign has predominantly focused on repurposing biological materials for speculative, aesthetic, and exploratory applications (Scarpitti, 2022), advancing the field to create practical, scalable solutions demands that designers engage more deeply with the biological and material sciences underpinning their craft. One material at the forefront of this design-science convergence is bacterial cellulose, a biomaterial now embraced by both scientists in laboratory settings and designers in studios and makerspaces. Bacterial cellulose is a form of cellulose produced by bacteria and presents a promising avenue for biodesign due to its renewable and biodegradable properties (Quijano et al., 2025). Compared to plant cellulose, bacterial cellulose exhibits a higher purity of cellulose while lacking pectin, lignin and hemicelluloses (Qiu & Netravali, 2014). Material properties of bacterial cellulose include high crystallinity and degree of polymerization, material and tensile strength, and biodegradability (Qiu & Netravali, 2014). However, challenges remain in optimizing bacterial cellulose's productivity, treatment, and functionalization to meet the demands of various design and industrial applications (Pedroso-Roussado, 2024). Table 1 provides an overview of the discrepancies between current biodesign practices and the scientific norms of biotechnology, highlighting key challenges such as bacterial cellulose producer selection, genetic instability, and scaling up production.

The following study reflects upon the primary author's laboratory experience as a designer entering a chemistry laboratory from July 2024 to January 2025 through a self-reflective account (autoethnography), documenting the navigation of a designer to laboratory practice. Using natural dyes to alter bacterial cellulose's colouration as a case study, this research explores the opportunities and obstacles of laboratory experimentation as part of a designer's toolkit for material innovation. This study aims to provide designers

Table 1
Biodesign challenges for bacterial cellulose.

Challenge	Current biodesign practice	Problem	Solution	References
Choosing the right bacterial cellulose strain	Neglecting strains' specificities by using a symbiotic colony of bacteria and yeast (SCOBY).	SCOBY contains a mix of bacteria and yeast that vary geographically and regionally. Strains within the same species may have differing properties, making results inconsistent.	Incorporate microbial taxonomy to select and test specific strains based on desired outcomes. Partner with microbiologists to analyse the consortium for working with SCOBY or purchase a standardized known species strain from a biobank.	(Quijano et al., 2024b)
Choosing the right growth conditions	Using general recipes sourced from unrigorous references.	General recipes may fail to optimize growth for specific strains, resulting in low cellulose yield or inconsistent quality.	Read scientific literature to identify optimal growth conditions. Monitor parameters like pH, temperature, and nutrients for improved control microbial growth.	(Quijano et al., 2024b)
Genetic instability	Not addressed.	Cellulose synthase activity and production may vary due to genetic instability, leading to unpredictable outcomes.	Stabilize strains using genetic engineering or with synthetic biology. Consult synthetic biologists for tailored solutions.	(Malcı et al., 2024; Singh et al., 2020)
Equipment	Directly coupled with the end use (e.g. bacterial cellulose-sheets or more intricate moulds).	Growth methods tied to end-use applications limit yield and scalability, and equipment may not support consistent reproducibility and quality of material.	Decouple bacterial cellulose growth from end-use applications. Optimize production with scalable, standardized equipment. After the material has been grown, consider biofabrication strategies.	(Wang et al., 2019)
In and ex situ modifications	Exploratory and not fully addressed (impermeabilisation, coatings, adding technological features).	Lack of in situ/ex situ processes reduces durability and limits bacterial cellulose's use in advanced applications like textiles or electronics.	Incorporate chemical engineering and design techniques such as biofabrication or adding materials in and ex-situ to enhance bacterial cellulose's functional properties.	(Cazón & Vazquez, 2021; Lu et al., 2024;)
Scaling-up	Scaling production is often not considered in biodesign experiments.	Small-scale production limits bacterial cellulose's viability for industrial or commercial use.	Form interdisciplinary teams to address scaling, including biotechnologists, supply chain experts, and designers.	(Cruz et al., 2024)

Note. Adapted and modified from Pedroso-Roussado (2024)

with strategies for navigating laboratory environments and bridging disciplinary divides, with the following objectives:

1. To examine the challenges and opportunities of navigating laboratory practices as a designer, focusing on the integration of scientific protocols, tools, and workflows into design experimentation.
2. To reflect on the iterative interplay between design and science, identifying how laboratory experimentation informs creative material innovation and vice versa.

2. Literature Review

2.1. Laboratory practice

Laboratories are traditionally recognized as structured spaces of scientific production, where the complexity of the external world is transformed into controlled, reproducible experiments through precision, repeatability, and empirical validation (Latour, 1987). These controlled environments facilitate experimentation, data analysis, and interdisciplinary knowledge advancement (Koskinen et al., 2011). However, the scope of laboratories has evolved to embrace creative and exploratory practices such as biodesign, bioart, and sustainable material design innovation (Henninger et al., 2023; Willet, 2021). Laboratory practice entails the systematic application of techniques, tools, and protocols to investigate, manipulate, or develop materials and biological processes into measurable, repeatable results (Latour, 1987). Designers entering laboratory settings are reshaping design processes by integrating experimental and material-driven approaches. This reflects Latour's (1983) idea that scientific knowledge and experimentation are not merely objective processes, but are shaped by the continuous interplay of different actors, tools, and practices.

Laboratory practices vary depending on the scientific discipline and the focus of the research. For instance, biology and chemistry laboratories differ significantly in their methodology. Biology laboratories prioritize sterile environments for live cell manipulation using equipment such as incubators, autoclaves, biosafety cabinets, and microscopes. Conversely, chemistry laboratories emphasize reactions and material transformations, using instruments such as spectrometers, titration equipment, and fume hoods. For instance, bacterial cellulose cultivation in a biology lab involves maintaining sterile conditions, managing nutrient-rich media, and optimizing microbial growth (Quijano et al., 2024b). Meanwhile, post-treatment processes in chemistry labs, such as coating bacterial cellulose for water resistance or enhancing durability, utilize reactions to achieve functional goals (Cazón & Vazquez, 2021). Transitioning between these spaces provides adaptability in material design, as seen in the blending of biological growth processes with chemical modifications to create novel materials (Stefanova, 2021).

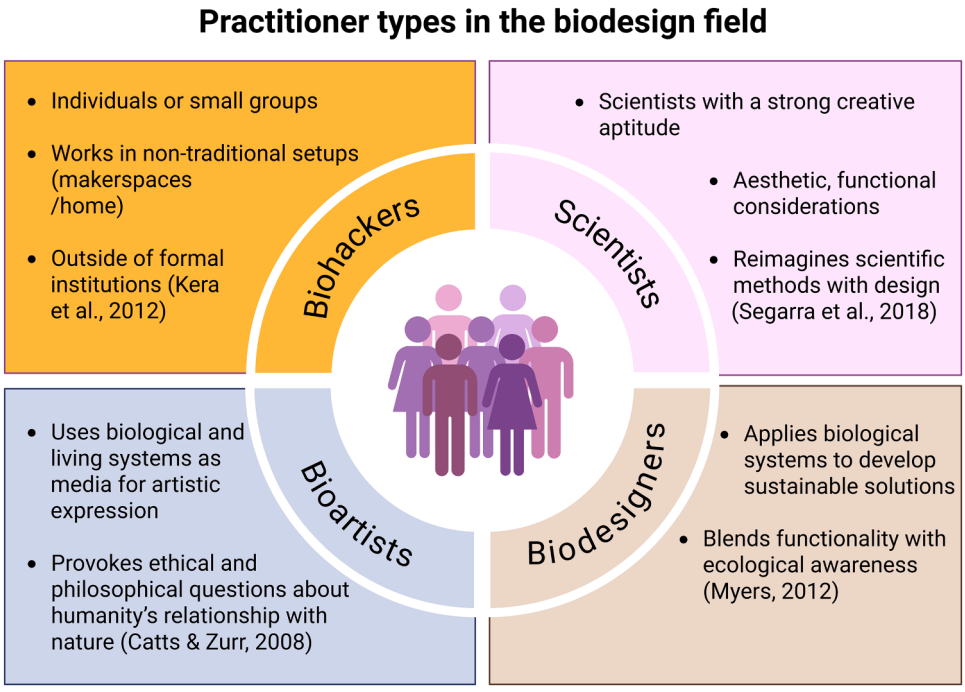


Fig. 1. Practitioner types in the biodesign field. Created with Biorender.com and adapted from Pollini (2024), Catts and Zurr (2008), Myers (2012) and Segarra et al. (2018).

2.2. Am I a designer or am I a scientist?

The emergence of biodesign has catalysed the development of hybrid professional identities that challenge traditional distinctions between creative and scientific practices. Pollini (2024) outlines, practitioners in this interdisciplinary space can be categorized into four emerging groups (biohackers, scientists with a strong creative aptitude, bioartists and biodesigners) shown in Fig. 1. Traditionally, designers in laboratories have been viewed as outsiders borrowing tools and methodologies to expand their creative practices (Willet, 2021). However, this shift toward hybrid professional identities is reflected in the rise of cross-disciplinary institutional initiatives. Recent examples of scientific laboratories in art and design spaces can be seen at the Royal College of Art where they established the Materials Science Research Centre to advance interdisciplinary material innovation; in 2024, they opened the Bio Lab and their first official project was to develop a series of protocols for practice revolving around bacterial cellulose (Royal College of Art, 2024). Similarly, in 2022, Imperial College London, a university predominantly known for its Science, Technology, Engineering, and Mathematics (STEM) research has partnered with Louis Vuitton Moët Hennessy, Fendi, and Central Saint Martins to develop lab-grown keratin-based fibres that mimic luxury materials such as fur (Mundell, 2022).

This proliferation of hybrid identities and of disciplines blurring boundaries are also evident in the growing number of interdisciplinary collaborations shaping material innovation across the globe. For instance, De Lara (2024) explores material-driven design approaches for knitted bacterial cellulose biocomposites in footwear, integrating low-tech fabrication with practice-led research to broaden access for designers outside traditional scientific environments. Biotecam in Brazil has developed and commercialized "Texticel"—a leather-like bacterial cellulose textile grown by *Acetobacter* and increasingly used by experimental fashion brands and researchers for sustainable garments (Jones, 2020). Current efforts at Biotecam focus on scaling up production and adding new properties, such as self-cleaning through nanotechnology (Monteiro et al., 2019). In the area of ecological restoration, Arredondo et al. (2022) documented a co-design process between material scientists and designers for morphing ceramic tiles (Blue Ceramics) to advance participatory nature-centred interventions. In "3D Corporate Tourism", collaborations crossed disciplines, geography, and institutional borders by inviting biologists, engineers, and designers to jointly prototype biomimetic materials in immersive settings to accelerate innovation in nanomaterials and sustainable product development (Gebeshuber & Majlis, 2011). These examples are part of a global movement in which hybrid teams consisting of designers, engineers, and scientists work together to create, functionalize, and apply biofabricated materials in both wearable and environmental contexts.

2.3. Studio vs laboratory

The studio and the laboratory represent two distinct, yet complementary spaces that shape how practitioners approach creativity and experimentation. In the fashion design studio, processes revolve around iterative and exploratory processes where practitioners

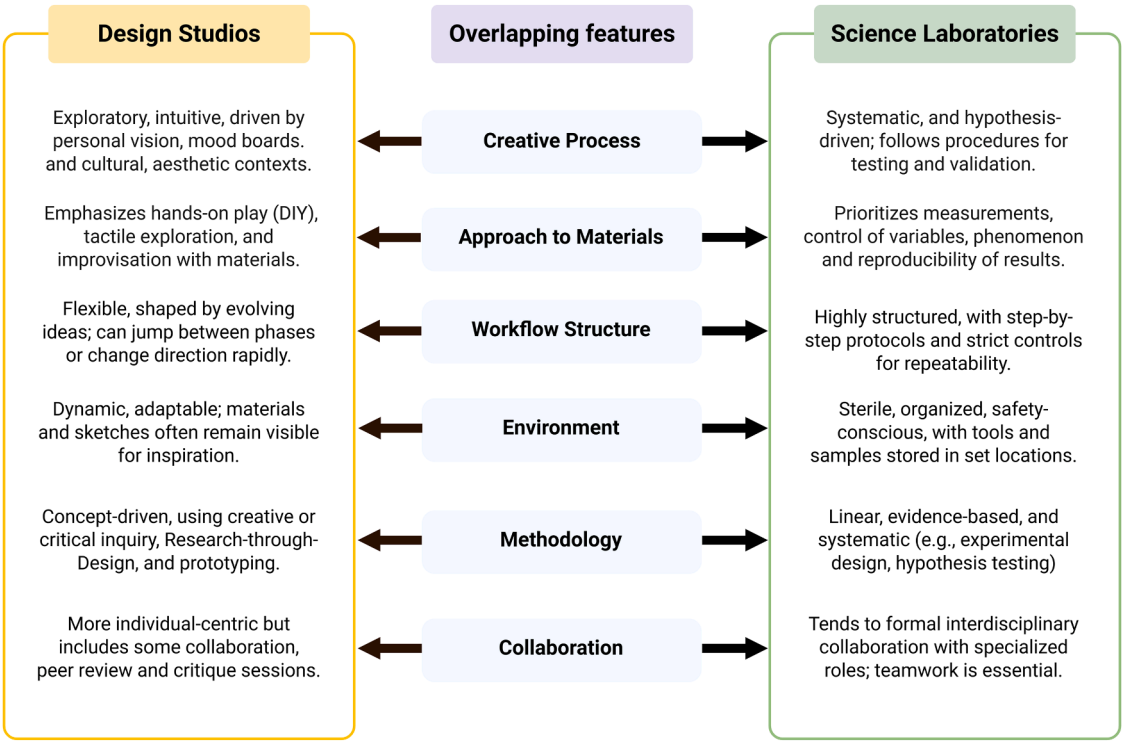


Fig. 2. Overlapping features between design studios and science laboratories. Created with BioRender.com.

engage with materials, tools, and conceptual frameworks. Studios are intentionally dynamic and unstructured, fostering creativity through hands-on engagement. Activities such as developing mood boards, sketching ideas, and conceptualizing collections are preparatory steps that set the creative direction (Rissanen & McQuillan, 2016). These preliminary stages culminate in a highly physical process where materials such as fabrics, threads, and tools are scattered across workstations as designers sew, drape, and experiment. The studio's messiness is not merely incidental but reflects the freedom and spontaneity that define design practices. The studio serves as a 'playground' for discovery, where designers are encouraged to think and act intuitively, producing one-of-a-kind outcomes (Lawson, 2006).

By contrast, laboratories are highly controlled spaces focused on precision, reproducibility, and empirical validation (Latour, 1987). The design of laboratories emphasizes order and sterility, with experiments taking place under specific environmental conditions such as temperature, pH, and humidity. Laboratories are equipped with specialized tools and protocols, such as analytical instruments and biosafety equipment, ensuring that experiments adhere to rigorous standards. Laboratory practices prioritize reproducibility to validate findings and ensure that they can be reliably applied to other contexts and other labs (Knorr-Cetina, 1999). For example, bacterial cellulose growth experiments must follow carefully defined parameters to produce consistent and analysable results (Wang et al., 2019). Despite these contrasts, studios and laboratories share several points of overlap that highlight their potential for interdisciplinary collaboration as shown in Fig. 2, including the use of creative processes, approaches to materials, workflow structures, environments (physical space), methodologies and collaboration.

3. Materials and methods

This materials and methods section, and the results section serve as a reflective case study documenting the primary author's journey as a designer-scientist navigating laboratory practice, experimenting with bacterial cellulose, and exploring its transformations through natural dyes. Bacterial cellulose was chosen as the material for this project as it not only exemplifies the spirit of biodesign as an accessible, renewable, and biodegradable resource, but also illustrates how materials can migrate fluidly between DIY biodesign contexts and advanced scientific research environments. As such, this study highlights the process of preparing and modifying bacterial cellulose for analysis focusing on the perspective of a designer in the laboratory, as well as the iterative methods employed to integrate scientific techniques into design practice. Since this study is both practice-led and reflective, the subsequent sections will transition from an objective third-person perspective to a first-person narrative to more directly capture experiences, insights, and challenges of primary author in this study. This shift allows for a more nuanced and personal discussion of how laboratory practices influenced my approach as a designer-scientist, bridging design and science.

3.1. Entering the laboratory as a designer

Prior to this study, my laboratory experience was limited to basic biology, specifically in fermentation processes and the cultivation of bacterial cellulose. I had no formal training in chemistry laboratories or exposure to advanced material characterization techniques. The motivation for venturing into this domain stemmed from the realization that while biological methods could modify bacterial cellulose or the organisms that produce it, analysing and quantifying these modifications for iterative practices required the methodologies and technology of chemistry and material science. As such, the goal of this project was to explore the interaction between bacterial cellulose and natural dyes, while reflecting on how laboratory practices particularly in chemistry and material science, could enhance my understanding of materiality as a designer-scientist. To supplement my laboratory practice, I also completed over 200 h of online chemistry tutoring throughout 2024-2025 to gain proficiency in general chemistry and material characterization for assessing bacterial cellulose modifications.

3.2. Designing experiments in the laboratory

As a designer-scientist entering a laboratory, my experiments began with a detailed plan, akin to a designer's sketchbook, where objectives, hypotheses, and proposed methods were outlined. These initial proposals were informed by a review of the literature. For instance, Costa et al. (2019) analysed the effects of natural dyes, such as *Clitoria ternatea L.* and *Hibiscus rosa-sinensis* pigments, on bacterial cellulose. The experimental plan underwent iterative refinement, drawing on the expertise of the co-authors, whose interdisciplinary contributions were integral to the study's development. Co-author 2, a graduate student in chemistry, taught and mentored me in the laboratory practices I needed to learn for my experiment. Co-author 3, an expert in fashion design, provided insights into material aesthetics, creative practice and user-centred design considerations. Co-author 4, specializing in biotechnology and synthetic biology, offered guidance on the cultivation and modification of bacterial cellulose from a biological perspective. Co-author 5, with a background in material science, contributed technical knowledge about the structural properties of bacterial cellulose, its functionalization, tensile testing and material characterization. Finally, co-author 6, an analytical chemist, played a critical role in refining protocols for advanced characterization techniques for textiles and providing me the laboratory space to conduct my experiment. Together, this diverse team provided a robust foundation for navigating the challenges of interdisciplinary research.

Pre-experiments were conducted to identify optimal parameters, including dye concentrations, soaking durations, and temperatures, while also familiarizing myself with laboratory protocols. These pre-experiments were crucial for bridging the gap between design and scientific methodologies, ensuring that the experiments aligned with both creative objectives and scientific standards. Feedback from co-authors and laboratory peers was instrumental throughout, with iterative improvements captured through detailed lab journals, email correspondence, photographs, and video documentation. These steps not only documented successes and failures

but also highlighted unexpected outcomes, reinforcing the importance of refining variables and adapting methods to achieve meaningful results.

3.3. Materials and Methods

The bacterial cellulose (BC-MA-1.5-L) used in the experiments was purchased from the Cellulose Lab, Canada. The pellicles were harvested, washed, and subjected to different drying methods (air-dried, oven-dried, and freeze-dried) to evaluate their impact on material properties. Lithospermum (*Lithospermum erythrorhizon*), was selected in consultation with the host laboratory group and purchased in ready-to-use form from Zisun Chinese Traditional Medicine. This laboratory group specializes in the historical preservation of textiles and sustainable dye practices, and their expertise provided valuable guidance. The choice to focus on lithospermum stemmed from my interest in understanding its applications both for fashion colouration and for potential functionalization. Lithospermum produces a purple-violet colour and is used both as a dye and for its bioactive properties (Yang et al., 2025).

The natural dyes were extracted by placing them directly into water at a proportion of 0.04 g/mL in a 1L solution, yielding a concentration of 40 g/L. The mixture was processed for 30 minutes in an ultrasonic bath (USC-502, Shanghai Jinghong Experimental Equipment Co., Ltd.) and extracted at 90°C using a constant temperature water bath (DK-S24, Shanghai Jinghong Experimental Equipment Co., Ltd.) for 1 hour. The solution was then filtered using a vacuum filtration system and Buchner funnel (Jiangsu Huida Medical Instrument Co., Ltd.) with a 1L capacity to remove any particulates using 11 cm qualitative filter paper (Fuyang Beimu, Hangzhou Fuyang Beimu Pulp & Paper Co., Ltd.).

Prepared dye solutions were then heated to 60°C or 90°C using a constant temperature water bath (DK-S24, Shanghai Jinghong Experimental Equipment Co., Ltd.). The samples were immersed in the dye bath and maintained at this temperature for 3 h, ensuring continuous agitation for uniform dyeing. After dyeing, all samples were rinsed with distilled water until the rinse water ran clear. Next, pellicles were oven-dried at 90°C for 4-6 h using an electric blast drying oven (Model DHG9123A, Shanghai Jinghong Laboratory Equipment Co., Ltd.). For advanced material characterization, samples were subsequently frozen overnight, then freeze-dried until fully dehydrated.

This study utilized three instruments (of which the methods will be discussed later in the paper): scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), and x-ray diffraction (XRD). SEM was selected to examine the surface morphology, microstructure, and changes in the fibre network resulting from dyeing and drying treatments, providing insights into both aesthetic and textural qualities, as well as underlying structural functionalization. FTIR was employed to identify chemical bonds, assess functional group changes, and reveal new interactions between the natural dyes and the cellulose substrate: information which is important for both a scientific understanding of material modification and subsequent adjustments in material design. XRD was used to assess the crystallinity and structural modifications of the cellulose matrix, clarifying how processing choices may influence key mechanical and optical properties relevant to fashion and textile purposes. Detailed step-by-step protocols for bacterial cellulose sample preparation are provided in Table 2, supporting transparency and reproducibility for both scientific and design-oriented readers.

4. Results

4.1. Learning lab practices: Physicality and building muscle memory

The first few weeks felt like learning a choreography in a language I had never heard before. I moved carefully among shelves and

Table 2
Weekly Laboratory Protocol for Bacterial Cellulose Processing and Analysis.

Day	Procedure
Monday	1. Prepare and handle bacterial cellulose materials (15 min) 2. Extract natural dyes (lithospermum) at 0.04g/mL in 1L distilled water, using an ultrasonic bath for 30 minutes followed by extraction at 90°C in a water bath (60 min) 3. Filter dye solution using a vacuum filtration system with a Büchner funnel and 11 cm filter paper 4. Dye bacterial cellulose samples in a constant temperature water bath preheated to 60°C or 90°C for 3 hours. 5. Wash and rinse dyed bacterial cellulose pellicles until the water runs clear; prepare for air drying overnight (30 min)
Tuesday	1a. Cut bacterial cellulose pellicles and blend for X-ray diffraction characterization (60 min) 1b. Place blended, bacterial cellulose pellicles in the freezer overnight so they can freeze. 2. Oven-dry the other bacterial cellulose pellicles at 80°C for 4–6 hours, with every half-hour monitoring. 3. Once the bacterial cellulose pellicles are oven-dried, keep them in a dry box environment.
Wednesday	1. Transfer frozen, blended bacterial cellulose and bacterial cellulose pellicles into a freeze-dryer; drying process requires 1-2 days. 2. Monitor the progress of freeze-drying.
Thursday	1. Check on freeze-dried bacterial cellulose materials in progress
Friday	1. Remove freeze-dried bacterial cellulose materials from the freeze-dryer.
	2. Re-blend the freeze-dried blended bacterial cellulose into a powder for analysis. 3. Organize and package bacterial cellulose into plastic bags or vials for upcoming analyses. 4. Schedule bacterial cellulose characterization appointments for the following week.

benches, mimicking what I saw my colleagues instructed me to do trying to look as though I belonged. In this process, I had to familiarize myself with laboratory tools and equipment commonly used in chemistry practices, each of which required mastering specific operating protocols. Fig. 3 illustrates the tools and equipment I engaged with. At first, the work felt mechanical. I followed procedures line by line, striving for perfection although my hands and body could not achieve this perfection right away. I remember once I spilled a beaker with lithospermum-extracted dye, and the liquid spread in slow motion across the counter onto the floor, gloves and sleeves. I remember stopping to stare at that spreading stain all over my lab jacket, realizing that mistakes in this environment left visible traces in the body of room. However, with patient repetition, the unfamiliar became routine. Pouring, stirring, rinsing, cleaning, extracting, these processes linked together in a meditative kind of rhythm for me.

My experience of gradual adjustment from mimicking to familiarity resembles what Zhang (2022) calls "the becoming of scientists, " a rite of passage facilitated by behavioural habituation and values imprinting. Each day I worked on my experiment in the laboratory, the lab's cultural norms translated into bodily knowledge. This process also reflected what Crawford (2023) describes as a typical "shadowing period," in which designers entering science labs learn through close observation and collaboration. Following the steps of senior researchers, watching how they measured or logged results, and then repeating those actions on my own formed the foundation of my learning during this stage.

4.2. *Learning lab practices: Planning and logistics*

Planning the rhythm of my experiments became as important as learning the procedures themselves. In a chemistry laboratory, every action demanded planning that extended beyond the immediate task at hand. I learned to map my days around the repeating

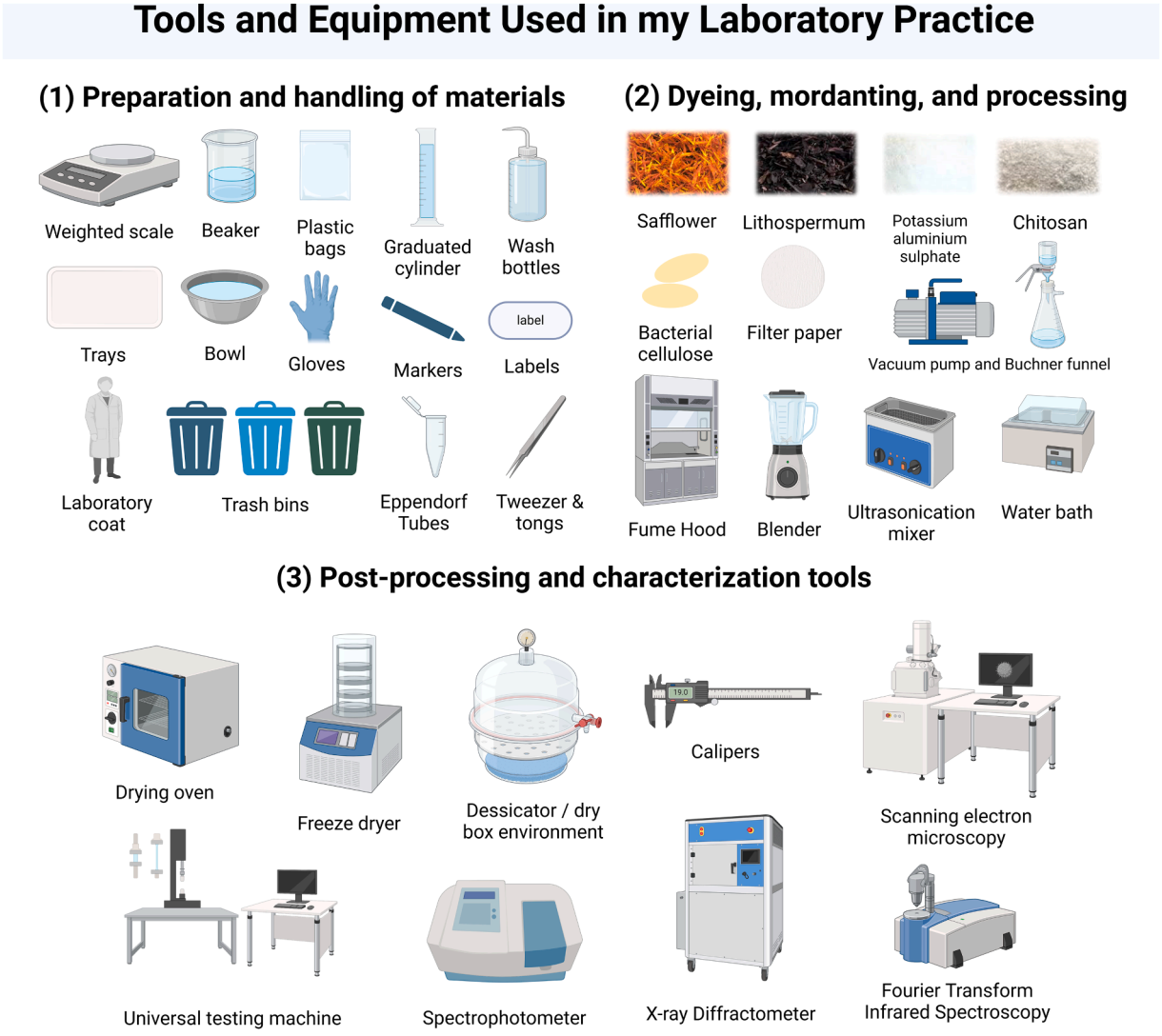


Fig. 3. Tools and equipment used in my laboratory practice. Created with Biorender.com.

cycles that were a part of my experiment such as extraction, filtration, absorption and drying. Table 2 showcases the optimized workflow I developed during this project. The work was rarely linear; steps overlapped and folded back on one another. Early on, I discovered that overworking and insufficient documentation were two key factors that could jeopardize the success of my experiments. When I skipped lunch by accident or worked throughout the day without pause, my accuracy would slip in tasks that demand precise timing and careful handling. Equally important was documentation. Forgetting to label bacterial cellulose samples or failing to record the precise dye variant used on a batch when working on multiple batches simultaneously could compromise an entire experiment. Laboratory notebooks and sticky notes became indispensable tools for tracking variables, recording observations, and ensuring that my experiments were reproducible. These shifting tempos mirrored what Hussey and Douglas-Jones (2024) describe as "laboratory times," the coexistence of multiple, overlapping temporalities created by experiments themselves.

4.3. Adapting to laboratory culture

Laboratory practice thrives on shared knowledge and teamwork. In the lab I worked in, it was customary for senior lab members to train and mentor juniors, fostering an environment of continuous learning. As a novice in chemistry, I was treated as one of the juniors and received hands-on guidance including mentorship and knowledge exchange, laboratory workflow and organization, hazardous material handling and disposal, and adherence to safety protocols areas. This mentorship dynamic was invaluable, providing me with the technical knowledge necessary to navigate their laboratory while enabling me to offer my own design-driven insights and perspectives. In time, the laboratory came to feel like its own society, one built on collective attentiveness.

A significant adjustment for me as a designer was adapting to laboratory workflow and organization. At first, I found it challenging to maintain order in my workspace. Pieces of bacterial cellulose were larger than anyone else's samples and disrupted the tidy geometry of the lab benches. My habits from the design studio where I would lay everything out where I could see it, clashed with the lab's expectation of surfaces wiped clean and materials neatly contained. However, I quickly realized the importance of real-time organization in the lab not only to optimize my workflow, but also to respect the shared nature of the space. Keeping my workspace orderly ensured that I worked efficiently while maintaining a structured and collaborative environment.

Another key aspect of laboratory culture was hazardous material handling and disposal. Unlike in a design studio, where waste disposal is often straightforward, laboratory work often requires careful management of chemicals and other substances. Proper disposal methods were strictly enforced to ensure environmental and personal safety, reinforcing the importance of responsibility when working with chemical substances. Finally, adapting to safety protocols was an essential part of integrating into laboratory practice. This included everything from wearing appropriate personal protective equipment (lab coat, goggles, gloves) to following precise procedures when operating laboratory instruments.

Over time, I developed what Crawford (2023) terms a "choreography of respect," where designers entering scientific spaces learn safety and order as practices of mutual regard. I learned to clean and organize my workspace after each step, ensuring that tools and materials were properly stored and ready for the next stage of experimentation. This structured approach mirrored the discipline required in laboratory research while still allowing room for creativity and exploration within the constraints of lab protocols.

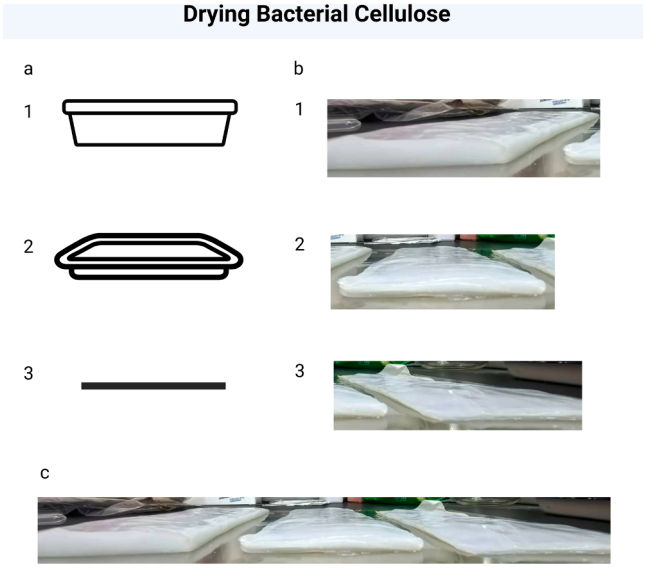


Fig. 4. A comparative analysis of the 3 trays tested for drying bacterial cellulose. None of these pellicles were dyed. (a) Three trays are pictured. (a1) Tray 1 was 4 cm in height; (a2) Tray 2 (middle) was 2 cm in height; (a3) Tray 3 (bottom) was 0 cm in height. (b) bacterial cellulose pellicles after drying. (b1) bacterial cellulose pellicle from tray 1; (b2) bacterial cellulose pellicle from tray 2; (b3) bacterial cellulose pellicle from tray 3. (c) A comparative photo of the bacterial cellulose pellicles from Tray 1 (left), Tray 2 (middle), and Tray 3 (right) after drying for 4 h in a drying oven at 80°C. Created with BioRender.com.

Creativity was maintained through my ability to experiment with different material formulations, adjust variables, and explore new methods of interaction with bacterial cellulose, all while adhering to the established scientific methods.

4.4. Iterative practices in experimentation: drying bacterial cellulose

Iteration is fundamental to both design and science, though the two disciplines approach it in distinct ways. In design, iteration is often tied to prototyping and creative exploration, with an emphasis on originality and adaptability. By contrast, scientific iteration prioritizes reproducibility and replicability, with iterative processes designed to validate results and refine methods to ensure consistency. This section reflects on the iterative approaches I employed during my experiments, emphasizing the processes of drying bacterial cellulose and refining dyeing parameters.

The main iterative challenge I encountered in the lab was determining the optimal method for drying bacterial cellulose. Up to 98% of the BC's weight can consist of water, so the process of removing this moisture to create a textile-like material requires significant time and experimentation (Qiu & Netravali, 2014). During my optimization of experimental variables, it became apparent that the height of the trays used for drying significantly influenced the material's properties. Fig. 4 illustrates the three types of trays I used during my bacterial cellulose experimentation. All bacterial cellulose materials discussed in this study were dried at a consistent temperature of 80°C for 4–6 h, depending on the thickness of the material. For the results I describe in this section, the results are based on a drying duration of 4 h and was done in triplicates. Tray 3, a flat sheet surface with no raised edges, facilitated the most uniform heat distribution and dried the bacterial cellulose faster under the same temperature and time conditions within the drying oven. In contrast, tray 1, which had edges 4 cm in height, did not contribute visually to decreasing bacterial cellulose thickness. Tray 2, with 2 cm-high edges, dried the material more slowly and led to uneven moisture distribution. These observations underscored the critical role of tray height in optimizing airflow and heat exposure during drying.

Additionally, the bacterial cellulose pellicles I worked with were larger than the typical samples used in small scale laboratory experiments, which often involve smaller material volumes. This difference in scale presented unique challenges, such as uneven drying during my initial trials in the drying oven. Thicker pellicles required extended drying times; however, over-drying could cause brittleness or lead to portions of the material adhering to the tray surface. I also observed that drying bacterial cellulose in a single, continuous session produced the most consistent results. Removing samples midway through the drying process one day and reintroducing them to the oven on the next day often resulted in aesthetic inconsistencies, illustrated in Fig. 5a and 5b. Fig. 5a shows a bacterial cellulose-lithospermum dyed pellicle that underwent an interrupted drying process: initially oven-dried, left to air-dry overnight, and then reintroduced to the oven for further drying the following day. This discontinuous process led to uneven drying patterns, as visible in the intermediate drying stage. In particular, the upper section of the pellicle dried significantly faster than the lower portion, which retained noticeable water and moisture, creating a distinct demarcation in colour intensity and texture. Upon completing the drying process (5b), the material exhibited variations in texture and colour intensity, particularly along the edges. Notably, the edges of the bacterial cellulose pellicle consistently dried faster than the central regions, retaining a darker colour compared to the interior. This edge-drying effect suggests that thinner and outer sections of larger, bacterial cellulose pellicles may be more prone to rapid dehydration, which can impact both material uniformity and final aesthetic properties. Additionally, prolonged drying caused some sections to adhere to the tray surface, making removal difficult without damaging the material. This issue



Fig. 5. An example of drying bacterial cellulose inconsistencies during laboratory experimentation. (a) Interrupted drying process of oven and air drying, and (b) finished drying (oven + air + oven) process. Created with BioRender.com.

underscores the importance of adjusting drying parameters based on sample thickness and ensuring even airflow distribution to prevent localized moisture retention.

4.5. Transformation of bacterial cellulose

4.5.1. Exploring new materialities

Preparing bacterial cellulose for material characterization revealed unexpected insights into its materiality and expanded my understanding of its potential applications. Preparing bacterial cellulose samples for techniques such as SEM, FTIR, and XRD involved cutting, blending, drying, gluing, and taping the material to fit into specialized machines. Beyond the traditional forms of bacterial cellulose, I was working with in the dyeing experiment, I also experimented with bacterial cellulose in a pulverised and foam form. Fig. 6, 7 and Video 1 showcase part of that material exploration.

For pulverised bacterial cellulose, I began by cutting a piece of the wet bacterial cellulose pellicle into smaller sections (6a) and blending it with a small amount of water to create a uniform slurry (6b). To ensure even consistency, I blended the mixture twice, allowing it to cool between blending cycles (6c). Once the slurry was fully prepared, I froze it overnight to stabilize the material before the next phase (6d). The frozen bacterial cellulose slurry was then placed into a freeze-dryer, where all moisture was removed, transforming the material into a lightweight, brittle structure (6e). Following freeze-drying, the dried material was blended once more, breaking it down into a fine, uniform powder (6f, 6g). Finally, the pulverised bacterial cellulose was carefully stored in small Eppendorf tubes to maintain its integrity and facilitate transport for XRD analysis.

In contrast to the methodical process of pulverising bacterial cellulose, foam bacterial cellulose accidentally emerged during an early freeze-drying experiment (Fig. 7 and Video 1). While learning to use the freeze-dryer, I tested placing a wet, untreated bacterial cellulose pellicle directly into the machine without freezing it beforehand. This deviation from the standard protocol resulted in a flexible, foam-like structure, revealing an alternative material transformation that may warrant further exploration. Unlike the dried sheets, which lose most of their water weight and become rigid, the foam bacterial cellulose retained a surprising level of flexibility, and a softer, squishy texture. The material's unexpected structural transformation suggests that freeze-drying bacterial cellulose in its wet state alters its internal architecture, potentially creating a porous, aerated structure. This warrants further exploration, as such a structure could offer new applications for bacterial cellulose beyond textiles, perhaps in biomedical scaffolding, packaging, or cushioning materials.

4.5.2. Presenting preliminary data and its role in design practice

The data generated from analytical techniques like SEM, FTIR, and XRD provided critical insights into bacterial cellulose's transformations, bridging the gap between material analysis and design. Collaboration with technicians proved essential in this process. Their expertise in operating advanced equipment and interpreting preliminary results served as a foundation for understanding bacterial cellulose's unique material properties. For instance, the SEM technician advised me on optimizing sample preparation techniques, which reduced distortions and improved the clarity of the resulting images. Similarly, the FTIR technician demonstrated how the analysis process works, offering real-time feedback on my samples, ensuring I was better prepared for future submissions. Initially, I submitted dried bacterial cellulose pellicles for XRD analysis, only to learn from the technician that converting

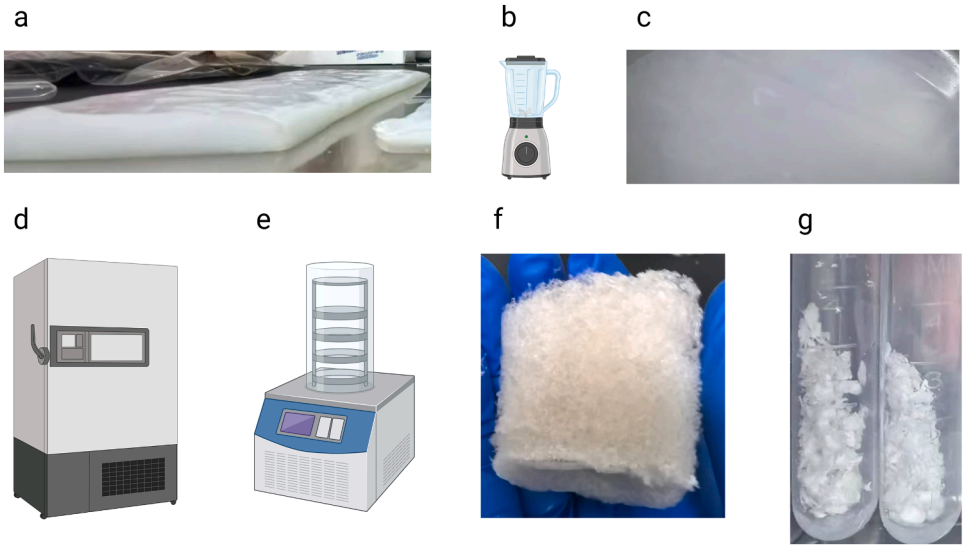


Fig. 6. The visual process of pulverising bacterial cellulose. Created with Biorender.com. (a) Bacterial cellulose pellicle. (b) Blending the pellicle into a slurry. (c) Bacterial cellulose slurry. (d) Freezing the slurry. (e) Freeze-drying the frozen slurry. (f) Freeze-dried bacterial cellulose. (g) Pulverised bacterial cellulose after blending the freeze-dried material.



Fig. 7. An image of foam bacterial cellulose dyed with lithospermum. This accidental emergence occurred during experimentation.

the material into powder form would yield more reliable results. These collaborative exchanges not only enhanced the quality of the data but also underscored the importance of cross-disciplinary learning, enabling me to navigate the complexities of laboratory practices more effectively.

SEM revealed bacterial cellulose's surface morphology at high resolution. Both images 8a and 8b were taken at 10,000x magnification, with samples gold-sputtered for 30 seconds to ensure adequate conductivity. In panel 8a, the undyed BC pellicle [BC-NM-ND] is shown. In panel 8b, we see a lithospermum-dyed BC pellicle, also undyed at 90°C [LT-NM-90]. BC-NM-ND shows a clear, fibrous structure. In contrast, the LT-NM-90 appears coated with a semi-consistent layer surrounding the fibres, suggesting the dye's interaction with and adhesion to the material's surface.

FTIR provided molecular-level insights into the chemical changes induced by dyeing. In panel 8c, the hydroxyl region (3400–3200 cm^{-1}) showed reduced intensity and a slight shift in the dyed sample, indicating hydrogen bonding between lithospermum and cellulose. Similarly, changes in the carbonyl region (1730 cm^{-1}) suggest interactions with ester or carbonyl groups introduced by the dye. The fingerprint region (1200–900 cm^{-1}) further revealed structural modifications, with broader and less distinct peaks in LT-NM-90 compared to BC-NM-ND.

XRD is a technique used to analyse the crystalline structure of materials by measuring the diffraction patterns produced when X-rays interact with the sample. XRD highlighted the crystalline structure of bacterial cellulose and the changes introduced by dyeing. The XRD peaks for the bacterial cellulose pellicles [BC-NM-ND] and [LT-NM-90] are displayed in Fig. 8d. Both BC-NM-ND and LT-NM-90 samples displayed characteristic peaks at 14.7°, 17.0°, and 22.7°, corresponding to the crystalline planes of cellulose I. LT-NM-90 shows a significant increase in peak intensity at all major positions, indicating an enhancement in crystallinity upon dye interaction. The enhancement suggests that the dyeing process with lithospermum potentially reorganizes the cellulose molecules, promoting better alignment and packing. Such changes could improve material strength, durability, and transparency, features that can enhance its usability in both functional and decorative applications.

For designers, this level of molecular insight offers the potential to manipulate the material's mechanical and optical properties, opening doors for innovative applications. These scientific insights were not isolated observations, but rather iterative inputs into my design practice. The SEM, FTIR, and XRD data became creative tools that informed the development of my materials and workflows. For instance, the textural and structural data from SEM guided adjustments in future dyeing experiments, while spectral data from FTIR and XRD influenced future decisions about dye formulations and treatment conditions. This integration of scientific analysis and design thinking allowed for a holistic exploration of bacterial cellulose as a dynamic and versatile material, empowered by the quantitative data that can be derived from laboratory practice and material characterization.

4.6. How material characterization informs design choices

The data obtained from SEM, FTIR, and XRD not only confirmed initial hypotheses I had as a designer, but also played a significant role in how I shaped my subsequent design choices. For example, the SEM images revealed that the lithospermum dye forms a coating on the bacterial cellulose surface. However, that coating appeared uneven and patchy; this directly correlated with the slightly patchy coloration I observed visually but was unsure without any kind of quantifiable data. Similarly, the FTIR analysis showed only minor changes in the chemical bonds between the dye and the cellulose. This indicates that the interactions between the dye and material were relatively weak. The material data obtained from SEM and FTIR led me to decide that I needed to modify the initial dyeing process, either by incorporating additives such as mordants so that the chemical bonds between the dye and material can become stronger, or by changing the way the dye is absorbed into the material to achieve greater dye uptake and colouration. XRD data also

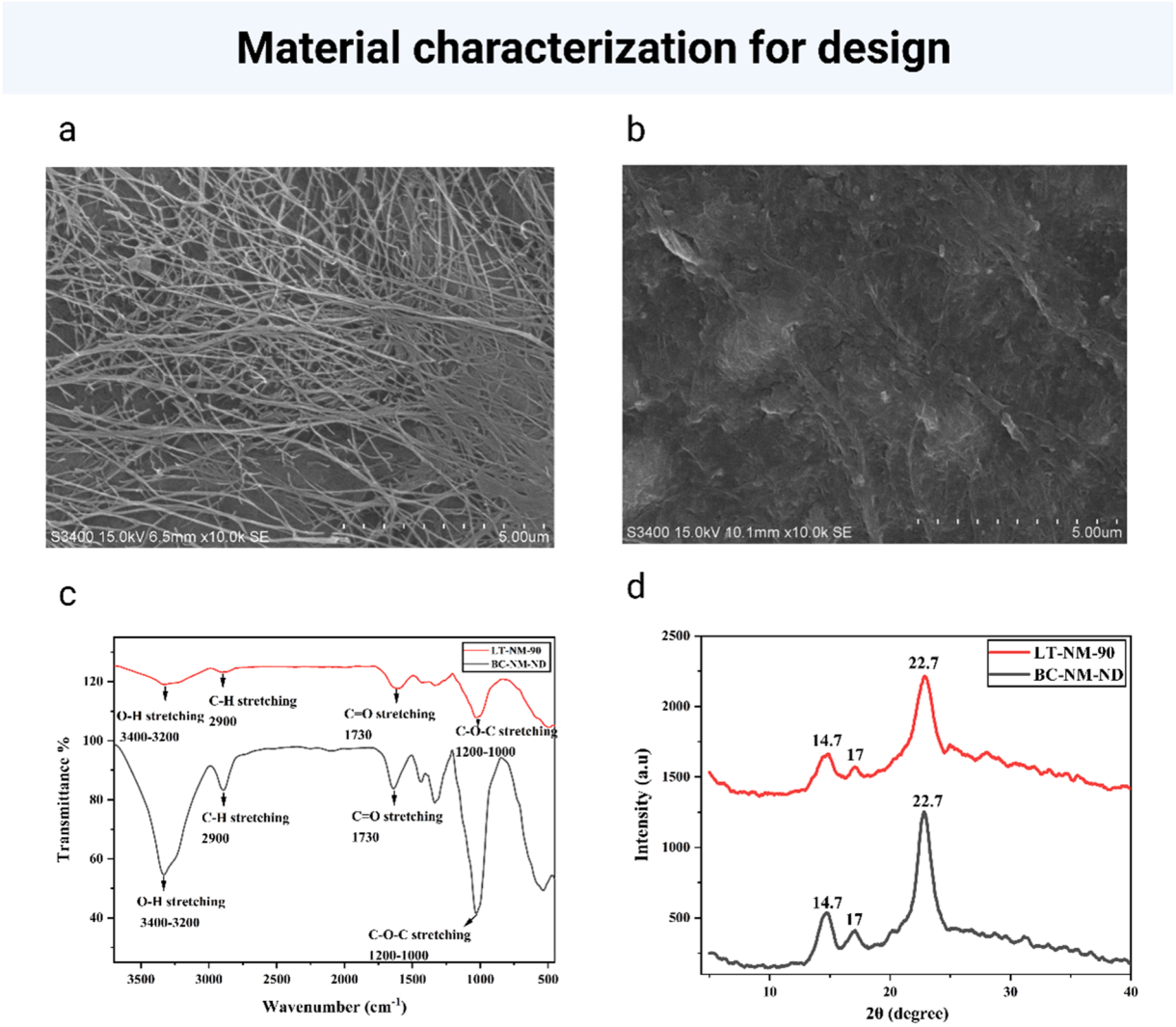


Fig. 8. Material characterization for design showcasing SEM images of (a) Bacterial Cellulose-Never Mordanted-Never Dyed (BC-NM-ND) and (b) and bacterial cellulose dyed with Lithospermum-Not Mordanted-at 90°Celsius (LT-NM-90) (c) FTIR graph for both BC-NM-ND and LT-NM-90 and (d) XRD graph for BC-NM-ND and LT-NM-90. Created with BioRender.com.

provided information about the underlying structure of the cellulose itself. After dyeing, the cellulose showed an increase in crystallinity, a change that could make the material stronger. In summary, each type of material analysis offered practical feedback that informed the next set of design and experimental choices. This ongoing exchange between laboratory data and creative decisions demonstrates the value of combining scientific and design approaches when developing new, sustainable materials for both scientists and designers alike.

5. Discussion

5.1. Designer-scientists and the changing landscape of biodesign

Biodesign represents a paradigm shift where the boundaries between science and design are increasingly fluid. Traditionally, designers have approached the laboratory as outsiders, while scientists viewed creative practice as separate from empirical research. However, the rise of hybrid lab/design spaces and technological advances in fields such as biodesign and synthetic biology require new kinds of practitioners, those who are comfortable in both domains. Equipping design students with scientific training early in their education could greatly enhance their ability to engage with laboratory-based materials and innovation. To achieve this, foundational lab skills, scientific literacy and familiarity with materials could be introduced into the design curricula. This is also particularly relevant in fashion, where biodesign offers a sustainable alternative to conventional material production, drawing from biotechnology, biomimicry, and biofabrication to create textiles that merge nature, science, and creativity (Myers, 2012; Cogdell, 2017). Such a shift

can be challenging, especially for students used to the studio environment, however, exposure to both modes of inquiry enables students to develop creative strategies that are grounded in empirical evidence.

The advantages of becoming a hybrid practitioner are becoming increasingly apparent as biodesign continues to flourish. Many interdisciplinary teams face recurring hurdles: gaps in terminology, differences in risk tolerance and study aims, varying ways of collecting data and practice, and contrasting attitudes of what counts as failure versus iteration. That said, a designer-scientist can move more seamlessly between concepts and prototypes, communicate more effectively across disciplines, and independently translate their ideas into material practice. These qualities create a greater potential for generating original solutions that neither field might reach in isolation. Fig. 9 shows what designer-scientists and their integration of approaches may look like in practice.

5.2. *The role of laboratories in fashion biodesign*

For designers working with biotechnology-driven materials such as bacterial cellulose or mycelium, laboratories serve not only as spaces of experimentation but also as potential sites for future education and collaboration. Traditionally, design education has been studio-centric, prioritizing craftsmanship and material exploration through tactile engagement (Rissanen & McQuillan, 2016). As biodesign advances, it is important for design education to integrate laboratory training, equipping practitioners with scientific literacy, laboratory protocols, and material characterization techniques. Quijano et al. (2024a) suggest that emerging fashion biodesign laboratories should not be one-off experimental spaces, but embedded within interdisciplinary programs, where designers and scientists work collaboratively and consistently rather than remaining on the periphery. The increasing role of biomaterials and technologies in fashion requires dedicated biodesign courses that foster long-term partnerships between scientists and designers.

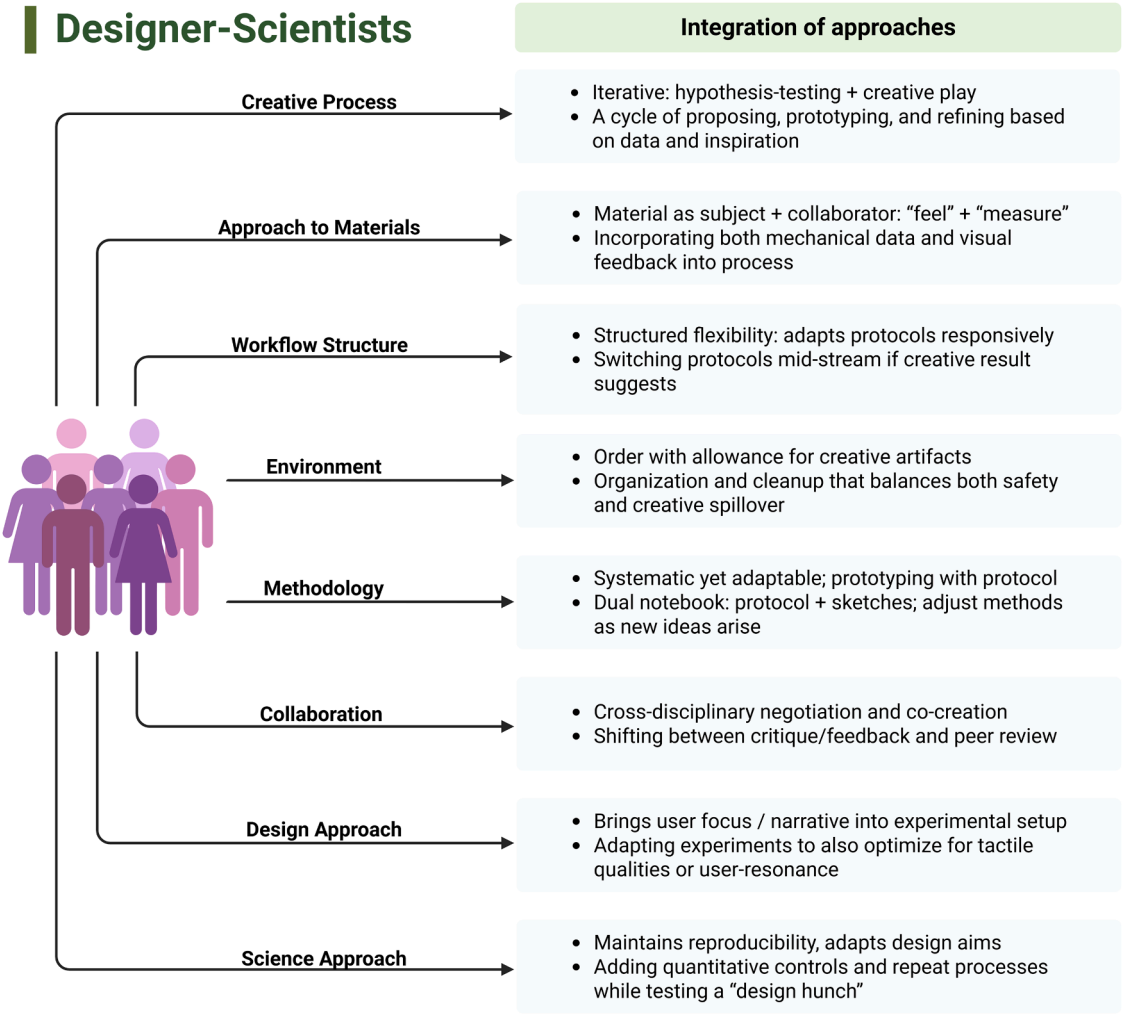


Fig. 9. Designer-scientists and their integration of design and science approaches. Created with BioRender.com.

5.3. Challenges and limitations

This research underscores the transformative potential of interdisciplinary work, but also highlights important challenges. One major limitation is the accessibility of laboratory spaces, as most design students lack opportunities to engage with laboratories due to institutional barriers or resource constraints. The lack of structured pathways for design students to gain laboratory experience presents a significant barrier to advancing biodesign research and practice. Additionally, the steep learning curve associated with acquiring scientific skills such as operating instruments, designing experiments and interpreting data can be daunting for designers without prior scientific training. With respect to this study, the observations of drying efficiency and uniformity presented in section 4.4 relied primarily on visual analysis and were not supported by statistical or quantitative measurements. This approach, while practical for an exploratory study, limits the precision and reproducibility of the findings in that section. Future research should incorporate quantitative analysis, such as measuring moisture content, thickness uniformity, or mechanical properties after drying, particularly when scaling up to larger sheet formats or industrial applications.

6. Conclusion

By bridging the gap between design and science, this research underscores how laboratory practices and scientific methodologies can inform and enhance design approaches, creating new pathways for material innovation. This study demonstrates that engaging with laboratory practices is not restricted to scientists; with the right training, anyone including designers can learn and adopt the methodologies of scientific inquiry, unlocking new opportunities for experimentation and creativity. Analytical tools such as SEM, FTIR, and XRD, can provide designers with data that informs material design decisions. For the fashion industry, where innovation increasingly requires balancing creativity with sustainability, integrating scientific processes into design workflows is essential. As the field of biodesign grows, fashion designers will increasingly occupy hybrid roles that require scientific literacy, technical expertise, and creative vision. By equipping future designers with these skills, educational institutions can prepare them to navigate and lead the intersection of design, science, and sustainability.

Disclosure statement

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Ethical approval

Ethical approval was not needed for this study.

CRediT authorship contribution statement

Luis Quijano: Writing – original draft, Visualization, Methodology, Investigation, Conceptualization. **Ziyuan Jing:** Methodology, Investigation. **Tiziana Ferrero-Regis:** Writing – review & editing, Methodology, Conceptualization. **Laura Navone:** Writing – review & editing, Supervision. **Dmitri Golberg:** Writing – review & editing, Methodology. **Wenqing Zhang:** Writing – review & editing, Supervision, Methodology.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.tsc.2025.102125.

Data availability

Data will be made available on request.

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