Before Arsenic: Recovering a Forgotten Indian Technique of Painting with Indigo and its Implications for Knowledge Transfer

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ABSTRACT: This article challenges the prevailing historiography, which asserts that painting with indigo on cotton was technically impossible until the British innovation with arsenic trisulphide in the 1730s. By reconstructing the Indian indigo painting process from the Beaulieu manuscript, the study demonstrates that European dismissal of fermented coconut sap as a viable technique stemmed from a lack of understanding and its incompatibility of the Indian technique with capital-intensive production models. The findings emphasize that painting with indigo was not a technical impossibility but an economic and artisanal problem, requiring specialized knowledge of fermented coconut sap's properties. The study argues that successful knowledge transfer depends on adaptability to environmental and structural conditions, advancing a broader definition of "useful knowledge" in global economic and technological history—one not limited by immediate economic applicability.

KEYWORDS: useful knowledge; knowledge transfer; indigo; calico printing; labor-intensive industrialization

Introduction

Historiography typically credits British printers with pioneering uses of arsenic trisulphide to paint indigo on cotton in the 1730s.[1] However, material evidence suggests that Indian printers had been

[1] Floud, "The English Contribution to the Early History of Indigo Printing in England."

painting indigo on cloth since at least the twelfth century.[2] What methods did they employ, and what do these tell us about the concept of useful knowledge, knowledge transfer, and the discrepancies between historiography and material evidence? This study reconstructs Indian methods for producing chintz with indigo, based on a historic recipe recorded in the Beaulieu manuscript (1726–29), which documented Indian calico-printing techniques for application in Europe. Empirical analysis, including solvency tests, colorimetry, and polarized light microscopy, reveal that Indian artisans achieved vibrant blue hues in specific parts of their patterns by pretreating cotton cloth with local fermented coconut sap as an assistive agent. The scholarship has largely overlooked the significance of fermented coconut sap, often omitting its reference in the original Beaulieu manuscript. This omission has perpetuated an erroneous historiography, disregarding the environmentally specific, labor-intensive and skill-driven techniques central to Indian chintz production.

This article argues that the local environment not only shaped the existing knowledge base in Europe but also played a crucial role in absorbing new knowledge, as well as in forming technical responses to production challenges in the early modern period. Knowledge transfer was therefore structurally constrained, resulting in the misreading of a labor-intensive manufacturing process and the underappreciation of skill-intensive knowledge unsuited for seamless adaptation to capital-intensive production modes. To fully understand the value of knowledge within diverse

[2] Gittinger, *Master Dyers to the World: Technique and Trade in Early Indian Dyed Cotton Textiles*, 33, 56; Greene, *Wearable Prints 1760–1860*, 83; Barnes, Cohen, and Crill, *Trade, Temple and Court*, 64; Gittinger, “Indigenous Techniques in Early Indian Dyed Cotton”; Barnes, *Indian Block-Printed Cotton Fragments in the Kelsey Museum*, 29, 85.

ecological contexts, its usefulness must be analyzed independently from its economic viability. While the introduction of new knowledge may not inherently affect its usefulness or reliability, it is interpreted or gatekept through the lens of a preexisting knowledge base, filtering its adoption and impact.

History of Useful and Reliable Knowledge

Useful knowledge occupies a central place within theories of economic growth, bringing global and artisanal perspectives to explanations of long-term economic development. Historian Joel Mokyr's *Gifts of Athena* sought to define knowledge, identify who accessed it, and understand how it was utilized and transferred to those who did not previously possess it.[3] He deployed Simon Kuznets's idea of useful knowledge as the foundation of modern growth, evaluating potentially useful knowledge in economic production to determine what is known and useful. Wrestling with the variability of "usefulness" and the temporal nature of testing usefulness, Mokyr connected practical knowledge to material welfare, linking usefulness with economic value.[4] He defined technology as the "manipulation of nature for human material gain," framing useful knowledge as that of practitioners who collected, interpreted, understood, codified, or applied it for economic gain. For Mokyr, the West's ascendency stemmed from a "knowledge revolution" unparalleled elsewhere, making the West richer because it "knew" more.[5]

This Eurocentric view of technological growth and useful knowledge as precursors to

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[3] Mokyr, *Gifts of Athena: Historical Origins of the Knowledge Economy*, 2–3.

[4] Mokyr, *Gifts of Athena*, 2–3.

[5] Mokyr, "Intellectual Origins of Modern Economic Growth," 285–351.

economic gains has faced sustained challenges, refinements, and modifications from economic, global, and science and technology historians. While Mokyr's idea of useful knowledge anchors discussions of the West's "knowledge revolution," the mere transfer and application of useful knowledge does not fully explain the motivations behind this revolution. Conversely, empirical knowledge of materials and processes developed in the East—and coveted globally—provides a necessary framework for understanding a knowledge revolution founded on investigative techniques, leading in turn to a scientific revolution in the West.[6]

Contextualizing useful knowledge and its transfer across regions remains a key challenge. British historian Maxine Berg highlights Asia's influence on Western technological thinking and product quality improvement, driven by competition with imported Asian products.[7] Juxtaposing Mokyr's emphasis on codification by engineers and inventors with Liliane Hilaire-Pérez's view of artisanal connections fostering shared and improved knowledge through "open techniques," Berg locates useful knowledge within objects and their production processes. For Berg, innovation arose from learning through observation, examination, and reverse engineering products of Eastern goods.[8] Accordingly, as I have shown elsewhere, Indian cloth embedded the knowledge required for its imitation and British cotton quality evolved to converge toward Indian benchmarks, with the help of sequential mechanization of cotton spinning during the eighteenth and nineteenth centuries.[9]

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[6] Raman, "Learning from the Muse: Indian Cotton Textiles and British Industrialisation."

[7] Berg, "Useful Knowledge, Industrial Enlightenment and the Place of India."

[8] Berg, "The Genesis of Useful Knowledge."

[9] Raman, "Indian Cotton Textiles and British Industrialization: Evidence of Comparative

Berg also highlights the uncertainties and obstacles in transferring useful knowledge. She cites the British state and the English East India Company (EIC) as enterprises filtering the knowledge that traveled from India to Britain. Berg references Anton Hoves and Benjamin Heynes, who attempted to gather local manufacturing knowledge within India, but this knowledge never reached Britain. Through these examples, Berg demonstrates the significance of the "culture of savants" in both financing knowledge acquisition expeditions and in determining the perceived value of specific knowledge.[10] She describes how the EIC savant Joseph Banks criticized Hove's attempts to document Indian cotton varieties and spinning-weaving processes. Banks dismissed this knowledge as unworthy of the high costs involved, effectively deciding on behalf of the British public that it lacked utility.[11]

Similarly, Ian Inkster argues that the institutions responsible for diffusing and testing useful knowledge critically shaped its adoption in Europe.[12] Karel Davids underlines the role of gatekeepers of knowledge—experts at universities, learned societies, and state or privately owned entities—in validating, testing, and interpreting the legitimacy and usefulness of new knowledge.[13]

Learning in the British Cotton Industry in the Eighteenth and Nineteenth Centuries"; Raman, "From Hand to Machine: How Indian Cloth Quality Shaped British Cotton Spinning Technology."

[10] Berg, "Useful Knowledge."

[11] Berg, "Useful Knowledge," 131–32.

[12] Inkster, "Potentially Global: 'Useful and Reliable Knowledge' and Material Progress in Europe, 1474–1914."

[13] Davids, "Gatekeeping: Who Defined Useful Knowledge in Early Modern Times?"

Hilaire-Pérez and Catherine Verna argue that gatekeepers adapted and translated techniques before dissemination, shaping how knowledge was received locally.[14] Londa Schiebinger illustrates this dynamic by highlighting the West Indian peacock flower's abortion-inducing properties, which were ignored due to prevailing social norms.[15] Furthermore, American historian Nina Lerman points out that science, as opposed to "non-science," is associated with maleness, whiteness, and middle-class upward mobility in American society.[16] Simona Valeriani demonstrates that despite the growing culture of scientific observations, preexisting artisanal and religious notions and practices routinely impacted how useful knowledge was understood, interpreted, and applied in Britain.[17]

Through "artisanal literacy," American historian of science Pamela Smith locates knowledge within artisans, manufacturers, and traders, showing how experimentation with materials and new knowledge overlapped with disciplines that would morph into sciences like chemistry and botany.[18] Paola Bertucci demonstrates the failed transfer of silk-reeling technology from Piedmont, Italy, to Georgia, United States, showing that knowledge resides within both

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[14] Hilaire-Pérez and Verna, "Dissemination of Technical Knowledge in the Middle Ages and the Early Modern Era: New Approaches and Methodological Issues," 536–65.

[15] Schiebinger, *Plants and Empire: Colonial Bioprospecting in the Atlantic World*, 226, 230.

[16] Lerman, "The Uses of Useful Knowledge: Science, Technology and Social Boundaries in an Industrialising City," 39–59.

[17] Valeriani, "Grasping the Body: Physicians, Tailors and Holy People," 467–93.

[18] Smith, *The Body of the Artisan: Art and Experience in the Scientific Revolution*, 15–64.

human practitioners and the immovable environment, shaped by natural and institutional factors.[19] These findings complicate the usefulness and transferability of knowledge across contexts.

Blurring the boundaries between borrowing and innovation, William McNeill positions diffusion at the heart of human history.[20] Israeli geographer Avinoam Meir, however, calls for examining the "personal/cultural complex" of adopters, noting that mere knowledge transfer is insufficient for adoption.[21] Torstern Hägerstrand exposes the "shadow-side of innovations," i.e., denovations and exnovations.[22] In his groundbreaking work, Everett Rogers demonstrates how diffusion networks and social systems shape knowledge adoption.[23] Echoing these views, Liliane Hilaire-Pérez and Catherine Verna caution against generalizations, emphasizing that knowledge transfer evolves in specific social, cultural, and ecological contexts, making it inapplicable or unviable in others.[24]

Such a rationale evokes Japanese economic historian Kaoru Sugihara's idea of plural paths to economic growth, which, based on factor ratios, challenges the West-centric narrative of the road to economic growth. His concept emphasizes labor-intensive industrialization in the East as

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[19] Bertucci, "Spinners' Hands, Imperial Minds: Migrant Labor, Embodied Expertise and the Failed Transfer of Silk Technology across the Atlantic," 1003–31.

[20] McNeill, "Diffusion in History," 75–90.

[21] Meir, "Adoption Environment and Environmental Diffusion," 233–47.

[22] Hägerstrand, "Some Unexplored Problems in the Modeling of Culture Transfer and Transformation," 217–32.

[23] Rogers, *Diffusion of Innovations*, 5–38, 300–401.

[24] Hilaire-Pérez and Verna, "Dissemination of Technical Knowledge," 536–65.

a viable alternative to the West's capital-intensive model, highlighting distinct non-Western pathways to knowledge diffusion, skill development, and industrialization. He argues that local conditions in the East, shaped by unique combinations of factor and resource endowments, fostered labor-intensive industrialization, a trajectory typically reliant on highly skilled labor, locally sourced raw materials, and export-oriented manufacturing.[25]

In a comprehensive review of the many perspectives on useful knowledge, knowledge transfer, and technological change within economic history, the history of technology, and global history, Dagmar Schäfer and Simona Valeriani observe that Patrick O'Brien's call to study how useful knowledge differed within regions and over time has led to research into regional cultures of knowledge development as well as the origins of "European expansion."[26] Both pathways leave scope for interpreting how knowledge from one region might be absorbed or rejected in another. Hilaire-Pérez frames this issue in the language of codification: Who codifies knowledge, and under what conditions? For Hilaire-Pérez, bureaucracy's role in codifying useful knowledge within merchant economies significantly influenced technological change and the rise of the sciences.[27] For Bertucci, a failed transfer of knowledge is equally, if not more, insightful in understanding how knowledge does, or does not, transfer.

[25] Sugihara, "Labour-Intensive Industrialisation in Global History: An Interpretation of East Asian Experiences," 20–64; Sugihara, "Varieties of Industrialisation: An Asian Regional Perspective," 249–69.

[26] Valeriani and Schäfer, "Technology Is Global: The Useful and Reliable Debate," 327–47.

[27] Hilaire-Pérez, "The Codification of Techniques: Between Bureaucracy and the Markets in Early Modern Europe from a Global Perspective," 442–66.

Within the vast scholarship on useful knowledge, its generation, and transfer, analyses of products and specific production techniques have been largely overlooked. This knowledge, relating to products suitable for global markets, is key to expanding our understanding of its creation, transfer, and usability. The material evidence provided by such knowledge is considerably valuable but not adequately incorporated within global history. Cotton textile products and printing-dyeing techniques used to produce their distinctive imprints are at the heart of this useful knowledge debate. In line with Hilaire-Pérez and Bertucci, this article attempts to understand the processes of knowledge transfer and codification from the perspective of a failed transfer of technique from India to Europe. It views the categorization of knowledge as useful only if it has economic value as an overly narrow framework, largely responsible for editing out specific knowledge from the East when not adopted in the West. This framework also contributes to perpetuating the narrative of the West as evolving on a pathway of science-backed economic development that remains disconnected from the East.

The Historical Context of Indigo

The interest in Indian printed cottons and ensuing experiments to replicate the many vibrant colors produced by Indian craftspeople on cotton cloth led to the development of innovative techniques worldwide, where Indian cloth was imitated.[28] One such technique involved penciling indigo

[28] A large body of literature discusses the introduction of Indian cotton textiles into seventeenth-century Europe, which spurred consumption and replication: Lemire, *Fashion's Favourite: The Cotton Trade and the Consumer in Britain, 1660–1800*; Parthasarathi, *Why Europe Grew Rich and Asia Did Not: Global Economic Divergence, 1600–1850*; Raman, "Indian Cotton Textiles";

mixed with arsenic trisulphide directly on small parts of the cloth with a brush, hence called the "pencil blue" technique. Another was the China blue technique, which mixed reduced indigo with gum to thicken its consistency, enabling block printing. Scholarship traditionally credits British printers as the first to achieve both: printing directly on cloth with indigo and using thickened dyestuff with a resinous substance for block printing.[29] However, newly discovered historical evidence in the Roques manuscript challenges part of this narrative, showing that premodern Indian printers routinely used resinous additives to thicken dyes for easier block printing.[30] Similarly, analysis of surviving textiles disputes long-held views on the first direct painting with indigo on cloth, with evidence suggesting that Indian printers were painting indigo directly on cloth as early as the twelfth century.[31]

According to historical accounts, indigo is a complex dye to process, requiring specialized techniques. In India, specialist indigo dyers were responsible for applying this color to cloth because indigo, in its normal form, is insoluble in water.[32] To dye cloth, indigo must be "reduced" to its deoxidized or "white" state, allowing it to bond mechanically, rather than chemically, with

Raman, "From Hand to Machine"; Berg, "From Imitation to Invention: Creating Commodities in Eighteenth-Century Britain"; Irwin and Brett, *Origins of Chintz*.

[29] Floud, "The Origins of English Calico Printing," 278; Floud, "English Contribution," 344–49.

[30] Roques Manuscript, 4–9.

[31] Gittinger, *Master Dyers*, 33, 56; Greene, *Wearable Prints*, 183; Barnes, Cohen, and Crill, *Trade, Temple and Court*, 64; Gittinger, "Indigenous Techniques," 4–15; Barnes, *Indian Block-Printed Cotton Fragments*, 29, 85; Raman, "Learning from the Muse," 163–71.

[32] Coeurdoux Letters, 108.

the cloth. The "reduction" process involves introducing an alkaline medium to convert indigo into "leuco indigo," an acid form that attaches to cloth. Traditionally, the simplest way to dye cloth blue with indigo was to dip it into a vat of reduced indigo. As the cloth was removed, the indigo reoxidized upon contact with air, transforming from leuco indigo to blue indigotin.[33]

Painting indigo directly on small areas of cloth poses a difficulty, as the dye re-oxidizes rapidly, often before it can be applied. This feature explains why most historical indigo textiles are white on blue: The white areas resisted the dye while the cloth underwent vat-dyeing with reduced indigo. In the absence of direct references to indigo painting in India, historians have long assumed that the small blue details, like tiny leaves and strokes on the large textiles such as palampores and printed chintz bedspreads that were exported to Europe since the sixteenth century, were achieved by resisting over 90 percent of the fabric and vat-dyeing it.[34]

According to Peter Floud, British calico printers were the first to paint indigo directly on cloth successfully, using orpiment (arsenic trisulphide) as part of the pencil blue technique, to delay reoxidation while the dye was still on the painter's brush.[35] Other accounts suggest that Indian artisans may have learned this technique through reverse transfer of knowledge from England after the 1730s, when arsenic was first used.[36]

This narrative, however, fails to align with surviving material evidence. Twelfth-century

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[33] Cardon, *Natural Dyes: Sources, Tradition, Technology and Science*, 339–40.

[34] Floud, "English Contribution," 345.

[35] Floud, "English Contribution," 345.

[36] Greene, *Wearable Prints*, 31.

Indian textiles show evidence of indigo painted or applied directly on cloth.[37] This evidence calls into question the long-held historiography of dyestuffs and global textile history, which has traditionally overlooked earlier Indian innovations.

Forgotten French Clues

Three French manuscripts detailing Indian techniques have survived, offering historians today valuable insights into preindustrial Indian processes for dyeing cotton cloth. These include the Roques manuscript, compiled by Georges Roques between 1678 and 1680, documenting textile printing processes in Ahmedabad, Gujarat; the Beaulieu manuscript, compiled by Antoine Georges Nicolas de Beaulieu between 1726 and 1739, focusing on the Coromandel Coast; and the Coeurdoux manuscript, a series of letters by Père Coeurdoux, a Jesuit living in India between 1742 and 1747, which details printing and dyeing techniques on the Malabar Coast. The Calico Museum of Textiles in Ahmedabad published English translations of these French manuscripts in its *Journal of Indian Textile History* series (1955–67) under the guidance of John Irwin, keeper of the India Section, as it was then known, at the Victoria and Albert Museum.[38]

The Beaulieu manuscript provides two clear references to the direct application of reduced indigo on cloth. In the first instance, Beaulieu briefly mentions applying dye outside the vat. After the cloth is dipped in the vat, removed, and spread out, he notes that "*il a appliqué de cette liqueur*

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[37] Gittinger, *Master Dyers*, 33, 56; Greene, *Wearable Prints*, 183; Barnes, Cohen, and Crill, *Trade, Temple and Court*, 64; Gittinger, "Indigenous Techniques," 4–15; Barnes, *Indian Block-Printed Cotton Fragments*, 29, 85.

[38] Beaulieu Manuscript, 5–23; Roques Manuscript, 4–9.

sur les endroits qu'il a jugé n'en avoir pas assez pris." P. R. Schwartz translates this as "he applied the liquid to the parts that in his opinion had not taken sufficiently."

The second reference details techniques for creating small marks with different dyes to produce various colors. The manuscript curiously notes the direct application of blue dye as practiced along the Coromandel Coast: "*Pour panacher les fleurs il a tiré de petits traits dont ceux qui doivent être blancs ont été faits avec de la cire fondue, ceux qui doivent être rouges avec de la liqueur faite avec le bois de Japon et ceux qui doivent être bleus ou verts d'abord avec du Chouris et ensuite avec de la liqueur propre à teindre en bleu*."[39] Schwartz translates this: "To streak the flowers with different colours he drew small lines, the ones to be white were done with molten wax, the ones to be red with liquor made from Sapan wood and the ones to be blue or green first with *Chouris* and then with liquid blue dye. Beaulieu then adds *"C'est alors qu'on a coupé le 7éme morceau. Il n'y a point dans ce dessin de ces traits bleus ou verts*." Schwartz reads this as, "At that point the seventh piece was cut. This drawing shows no traces of blue or green."[40]

These passages highlight the direct application of indigo to cloth, distinct from vat-dyeing. The second example refers to preapplying *chouris*. Beaulieu describes chouris as a liquid tapped from coconut trees: *"Chouris c'est une liqueur qu'on tire par incision du tronc des cocotiers*."[41] Southern India, rich in coconut palms, has a long tradition of using coconut tree sap for culinary purposes. Once collected, coconut sap ferments naturally from lactic to acetic acid, potentially

[39] Irwin and Schwartz, *Studies in Indo-European History*, 84–85.

[40] Irwin and Schwartz, *Studies in Indo-European History*, 84–85.

[41] Irwin and Schwartz, *Studies in Indo-European History*, 80–85.

making it a suitable substance for aiding the application of indigo to cloth.[42] Beaulieu's sequence suggests that areas intended to be blue or green were "streaked" first with *chouris* then with liquid blue dye, implying a role for chouris in enhancing the adhesion of leuco indigo to pretreated areas.

Irwin and Schwartz, however, dismiss Beaulieu's reference to using *chouris* for direct indigo painting as incorrect, arguing that it was technically impossible—but without providing a clear explanation. They instead rely on Querelles's interpretation of the manuscript from his 1760 treatise on cotton printing, which omits any mention of *chouris* or direct indigo painting and assert that Querelles's account is undoubtedly correct.[43] By prioritizing Querelles's interpretation, they effectively excluded references to innovative Indian techniques, shaping the foundation of the current historiography of dyestuffs. Is it possible that both Querelles's interpretation of the manuscript as well as Irwin and Schwartz's reliance on Querelles as the trustworthy source on the matter are flawed?

The scholarship's perspective depends on whether historians regard the original manuscript as the authoritative source on dyeing techniques in premodern India or accept Querelles's interpretation of the manuscript. Irwin and Schwartz take Querelles's account as authoritative, claiming that he had "additional information," even though this claim is neither clarified nor substantiated.[44] This choice of one source over another has critical implications, as it entirely omits references to *chouris* and Indian artisans painting directly with indigo, thereby paving the way for

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[42] Atputharajah, Widanapathirana, and Samarajeewa, "Microbiology and Biochemistry of Natural Fermentation of Coconut Palm Sap," 273–80.

[43] Irwin and Schwartz, *Studies in Indo-European History*, 84.

[44] Irwin and Schwartz, *Studies in Indo-European History*, 78.

the assertion that the British were the first to paint on cloth with indigo. The clear reference to a substance indigenous to India's coastal regions—rich in natural sugars and prone to rapid natural fermentation—merits consideration as a legitimate contender in aiding the direct application of indigo.

Empirical Investigations and Methodology

In the summer of 2019, with the help of curators, conservators, and scientists at the Winterthur Museum and its laboratories, I conducted three distinct investigations into suspected indigo painting on Indian cotton cloth. First, Raman spectrometry confirmed that the blue observed on Indian textiles was indeed indigo. Second, X-ray fluorescence (XRF) tested for the presence of arsenic to evaluate the hypothesis of reverse knowledge transfer. The results were negative, with no traces of arsenic detected. Third, gas chromatography-mass spectrometry (GC-MS) tested for residual substances that may have acted as reoxidation-reducing agents, such as lime, honey, egg white, or fish glue. However, the GC-MS results were inconclusive. Post experiment discussions emphasized the repetitive washing involved in Indian printing and dyeing processes, suggesting that any applied organic matter may have been washed away, leaving no discernible traces.[45] This finding also suggests that current scientific techniques are insufficient for investigating direct indigo application to cloth in premodern India.

While Indian textiles from as early as the twelfth century housed in collections around the world also display evidence of indigo painted on cotton cloth,[46] the material evidence (ME) used

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[45] Raman, "Learning from the Muse," 163–71.

[46] Gittinger, *Master Dyers*, 33, 56; Greene, *Wearable Prints*, 183; Barnes, Cohen, and Crill,

for this investigation of painted indigo consists of select high-end luxury eighteenth-century Indian printed and painted textiles from the Winterthur Museum's textile collections (see figure 1).

ME1 is a quilt made from a whole cloth palampore, printed and painted on southern India's Coromandel Coast between 1750 and 1790. The palampore bears a United East India Company stamp on the lower right corner, indicating that it was custom made for the Company. This palampore is significant to the investigation because its pattern displays two distinct shades of blue in close proximity. The blue on the leaves, presumably intended as a blue-green with some yellow layered on top or underneath to depict foliage—referred to here as blue 1—appears frequently on seventeenth- and eighteenth-century Indian printed textiles. Blue 1 is predominantly found in parts of the design where shading or gradation of color is not required. The blue on the outermost layer of the flower, presumed to represent sepals or outer petals, is a clearer, fresher sky blue, referred to here as blue 2.

Trade, Temple and Court, 64; Gittinger, "Indigenous Techniques," 4–15; Barnes, *Indian Block-Printed Cotton Fragments*, 29, 85.

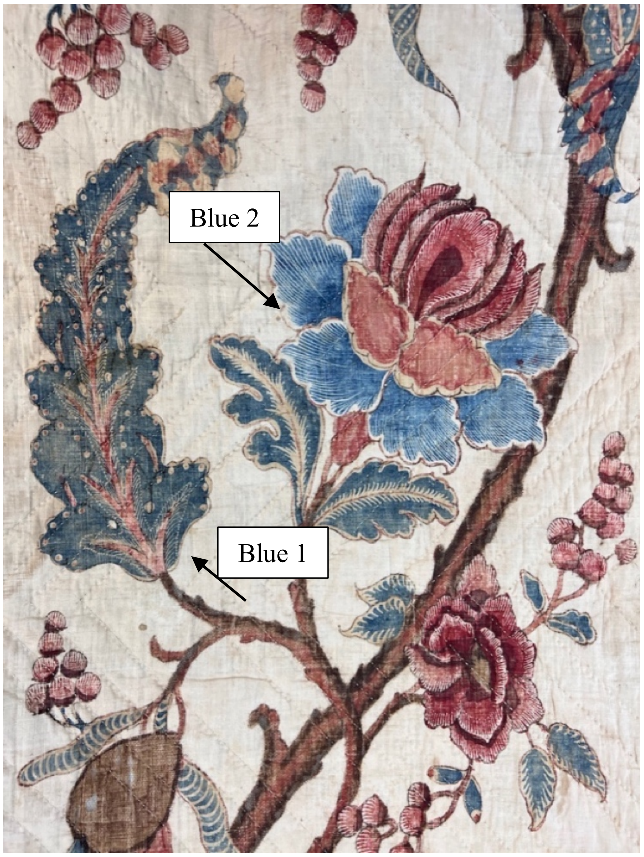

FIG.1: Quilt object: Palampore 1960.0780, 18th century, Winterthur Museum

ME2 and ME3 are also eighteenth-century Indian printed and painted textiles. ME2 is an offcut of a larger high-quality textile, dated between 1775 and 1800. It is a mordanted and painted piece with visible brushstrokes throughout. XRF analysis revealed no arsenic residues, confirming that the blue could not have been applied using the pencil blue technique involving a reverse transfer of technology from England, as is sometimes claimed in the literature.[47] ME3 is a large bedcover made of a high-quality custom-made printed and painted cotton textile from India. Stray brushstrokes of blue 2 on ME3, along with its application inside flower patterns, confirm that blue 2 was applied using a brush or brush like instrument (see figure 2).

[47] Greene, *Wearable Prints*, 31.

FIG. 2: Textile sample, 1952.0072.011, 18th century, Winterthur Museum.

FIG. 3: Bedcover, 1957.1290, 18th century, Winterthur Museum

Blue 1 and blue 2 represent two distinct shades of the color blue within the ME. Blue 1 was achieved through vat-dyeing with indigo over significant myrobalan deposits on the base cloth. Blue 2, in contrast, was achieved by removing myrobalan and milk deposits in specific areas using fermented coconut sap or *chouris* (see figure 3).

Having exhausted current scientific laboratory-based methods for investigating direct indigo application to cloth, this study adopts a historical reconstruction approach. The methods and processes detailed in the Beaulieu manuscript were recreated to test the feasibility of direct indigo painting. The investigation included various analyses, such as visual and applicability analysis, solvency test, colorimetry, and polarized light microscopy on the dyed and painted textile samples.[48]

Indian handspun and handwoven cotton fabric of 100 count was sourced online from Maiwa, along with *Indigofera tinctoria* and calcium hydroxide. Natural fruit sugars (banana, peach, and dates) were used to prepare natural sugar vats. All reconstruction and analyses were conducted in the Paintings and Textile Conservation Laboratories and the Scientific Research and Analysis Lab (SRAL) at Winterthur Museum, Delaware.

Historical Reconstruction

Is painting indigo directly on cloth impossible without arsenic, as the literature contends? Did Indian artisans use *chouris* to facilitate indigo painting, possibly as an agent enabling different shades of blue in small designs elements? To answer these questions, indigo painting was reconstructed with and without *chouris*, based on the sequential process described in the Beaulieu manuscript.

Any historical reconstruction grapples with the sheer impossibility of replicating past activities. Recreating the printing-painting process faces many obstacles. For instance, South India artisans historically established their printing-dyeing workshops near rivers. The composition of river water—rich in organic and inorganic matter and influenced by distinct geological strata—

[48] The following works served as guides and cross-reference sources for making indigo sugar vats: Cardon, *Natural Dyes*; Boutrup and Ellis, *The Art and Science of Natural Dyes: Principles, Experiments and Results*; Mohanty, Chandramouli, and Naik, *Natural Dyeing Processes of India*.

differs vastly from the tap or ionized water in laboratories. Similarly, environmental factors like sunshine, humidity, and even dust in the air cannot be reproduced in modern laboratories. Furthermore, reconstruction might not be possible where the process developed historically, due to the lack of suitable venues for scientific experiments.[49]

Other significant limitations arise from historical measurements and their modern equivalents. For instance, Beaulieu documented that his printer-dyer added thirty grains of powdered myrobalan to two pots of water to kickstart cloth printing. There is no way of knowing the size of the pots or the volume of water used in this preparatory step. The reconstruction, therefore, relied on rational guesstimates, aided by modern assessments of natural dyeing processes. The reconstruction used two tablespoons of myrobalan powder in two liters of water for this initial step.

A key material for this investigation is *chouris* or coconut sap, harvested from coconut blossoms through "tapping," where a cut in the blossom's stem allows sap to drip into a previously attached container. Once collected, the sap ferments instantaneously, undergoing lactic, alcoholic, and acetic acid fermentation sequentially. The fermented sap, known as toddy (*todi* or *tadi* in South India and Sri Lanka), is a milky white liquid containing 6–7 percent alcohol and live microorganisms. Toddy is consumed directly, used in cooking, or distilled into the alcoholic beverage *arrack*.[50]

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[49] A laboratory setting is ideal for this experiment as it enables precise measurement and recording of findings. The key materials—indigo, cotton fiber, and *chouris*—are expected to behave consistently regardless of location, whether in southern India or in a U.S. laboratory.

[50] Atputharajah, Widanapathirana, and Samarajeewa, "Microbiology and Biochemistry," 273–80.

As fresh coconut sap or toddy could not be sourced from India or within the United States, a substitute toddy was prepared in the laboratory. Toddy was achieved by fermenting fresh tender coconut water with yeast, following a traditional South Indian method. The lab-made toddy underwent a twenty-four-hour fermentation process, resulting in a milky white toddy similar to a naturally tapped toddy.

Despite such limitations warranting reasonable adjustments, historical reconstruction offers a resourceful approach to our understanding of past techniques. In 1961, Thomas Settle reconstructed Galileo's experiments on naturally accelerated motion, demonstrating their technical feasibility and providing insights into Galileo's intended outcomes.[51] Similarly, Pamela Smith's "Making and Knowing Project" at Columbia University reconstructs materials and processes from a French Renaissance "book of secrets," yielding greater understanding of historical terminologies, skills, and techniques.[52]

Reconstruction provides forms of insight into materials and techniques that literary historical records alone cannot offer. While a historian can analyze a dye recipe and theoretically interpret the knowledge contained in the sequence of instructions, the written medium cannot fully convey tacit, experiential, or locational knowledge assumed in the text. Through reconstruction, the historian can break down these elements by closely recreating the process and documenting its prerequisites and assumptions. This approach bridges the gap between tacit and codified knowledge, allowing the historian to gain an insider's perspective. By identifying and explaining

[51] Settle, "An Experiment in the History of Science," 19–23.

[52] Smith, "Historians in the Laboratory: Reconstruction of Renaissance Art and Technology in the Making and Knowing Project," 210–33.

the nuances of the process, the historian develops experiential knowledge, enhancing the comprehension and interpretation of historical practices.

To approximate historical Indian indigo-dyeing materials, indigo, calcium hydroxide, and unbleached cotton textiles were sourced from Maiwa in Canada.[53] Natural sugars (organic dates, bananas, and peaches), full-fat organic milk, organic myrobalan powder (*Terminalia chebula*), and lab-made organic rice starch (prepared by boiling rice in water) were used. Indigo was reduced using natural sugar methods and applied sequentially, as described in the Beaulieu manuscript. Two types of cloth were prepared for the experiment: prepared cloth 1 (PC1) was pretreated with myrobalan as a tannin, using the technique described by Beaulieu. Prepared cloth 2 (PC2) was prepared using the same technique but without the pre-treatment with myrobalan.

Indigo in different states was applied to leaf motifs on the cloths using a brush and toddy and water as base. Applicability and visual assessments showed that indigo adhered to the cloth in every state, but leuco indigo yielded the darkest shade when applied on a toddy base.[54] Tests showed that toddy acted as a solvent, dispersing milk-myrobalan deposits and enabling a clearer shade of blue where indigo was applied. The colorimetry results confirmed that leuco indigo applied on a toddy base produced shades closer to those achieved on PC2, where no myrobalan was present, confirming the hypothesis that toddy removed the milk-myrobalan deposits to help

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[53] Maiwa sources its indigo and cotton from India: https://maiwa.com.

[54] The toddy, containing natural sugars, may facilitate the delayed reoxidation of leuco-indigo and help remove the oily milk-myrobalan coating on the cloth's surface. It might also enable leuco-indigo to re-reduce upon contact with the sugars, enhancing indigo attachment to the fibers. However, this cannot be conclusively determined with the current examination tools.

achieve a clearer blue. Polarized light microscopy showed that the most efficient indigo attachment occurred via vat-dyeing, followed by single or repeated applications of leuco indigo on a toddy base.[55] For darker colors, washing and reapplication were necessary across all methods—vat-dyed or manual.

The results of the reconstruction demonstrate that, contrary to prior assumptions about technical issues, it is feasible to apply reduced indigo directly on cotton cloth using a brush or a wad of cloth as a sponge. The process requires skill, dexterity, and speed. Historical Indian textiles provide several examples of indigo painted or dabbed directly on cloth. Indian artisans' use of *chouris* or toddy represents an additional step to enhance designs by creating nuanced shades of blue in small areas.[56]

An Economic Problem

The historical reconstruction of painting indigo on cotton using fermented coconut sap as a solvent demonstrates that it is a relatively uncomplicated process, albeit one that is time, labor, and raw material intensive. Evidence confirms that indigo was applied directly in preindustrial India, and *chouris* played a technical role, as noted by Beaulieu and substantiated through scientific analysis.

Historically, indigo has been an expensive dye due to the high costs associated with its production. Dominique Cardon notes that the yield for *Indigofera tinctoria* in India was 10–13 per hectare per year, producing 22–55 kg of indigo cakes per hectare.[57] Jenny Dean estimates that

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[55] All indigo, whether in vat or with a brush, attaches mechanically to fibers.

[56] All results of the historical reconstruction can be seen in the Appendix.

[57] Cardon, *Natural Dyes*, 358.

about 20,320 kg of indigo leaves are required to produce 45 kg of dye.[58] Prices in Britain ranged between 3 shillings and 6 pence to 7 shillings per pound weight of natural indigo in 1897.[59] According to Prakash Kumar, indigo cultivation in India was highly labor intensive, requiring nearly three times more labor than any other crops.[60] Historian Ghulam Nadri notes that indigo production in India was erratic, heavily dependent on soil quality, rainfall, water brackishness, and the practical knowledge of manufacturers converting green leaves into blue dye. An overabundant monsoon, insufficient rain, or inexperience or carelessness in the manufacturing process could result in low-quality indigo, making its production both costly and risky.[61]

While indigo leaves can be used for dyeing without processing, the low concentration of indigotin in them produces lighter shades of blue.[62] Processed indigo remained the foremost source of natural blue, with the most common global methods involving reducing the dye in vats for dip-dyeing plain fabrics or resist-dyeing for patterns. Despite its low yield and high costs, indigo, alongside madder, was the most important textile dye from 1700 to 1892.[63]

Compared to vat-dyeing, painting with indigo incurred additional costs, not only due to the

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[58] Dean, *Wild Colour: How to Make and Use Natural Dyes*, 99.

[59] Kumar, "Scientific Experiments in British India: Scientists, Indigo-Planters and the State, 1890–1930," 253.

[60] Kumar, "Scientific Experiments in British India," 256.

[61] Nadri, *The Political Economy of Indigo in India, 1580–1930: A Global Perspective*, 12–60.

[62] Cardon, *Natural Dyes*, 341–44.

[63] Engel, "Colouring Markets: The Industrial Transformation of the Dyestuffs Business Revisited," 10–29.

concentrated use of the expensive dyestuff but also accruing from higher labor costs for the time spent on each textile item and each dyeing phase. The *chouris* method is particularly time-consuming and material, as well as labor, intensive. After applying a coat of *chouris*, a streak of concentrated leuco indigo had to be applied swiftly by skilled hands.[64] Achieving darker colors required further steps, including washing, drying, and reapplying additional coats of leuco indigo. Unsurprisingly, the historical Indian textiles where indigo appears to be hand-painted, rather than resist- or vat-dyed, are the high-end luxury items, likely custom made to absorb the higher labor and material costs.

The process of painting cotton textiles with indigo aligns with Kaoru Sugihara's description of labor-intensive industrialization. This method highlights the significance of geographically specific raw materials and the aggregate technical knowledge developed over time by local communities. The *chouris* method, for example, would have been inconceivable outside tropical regions with deep historical knowledge of coconut plants and the skills and application involved in using every part of the coconut tree. This geographically specific technique, aided by the labor-intensive factor ratio, enabled the development of critical skills and expertise for producing differentiated, high-quality hand-painted textile products.

Painting with indigo also illustrates the inherent limits to transferring traditional techniques developed in one setting to another, despite the traceability of knowledge transfer. These limits arise from a population's prior learning, which acts as a filter, determining which knowledge is absorbed or excluded. This prior knowledge, shaped by the local geography—including the availability and familiarity with specific raw materials—fits within the framework of "plural

[64] Painting likely required a concentrated vat with higher indigo content.

paths" to long-term economic development.[65] While our understanding of labor-intensive industrialization stems from institutional and technological responses to production organization based on factor endowments, the knowledge transfer of indigo painting shows that geography also played a crucial role in shaping technical responses to production challenges in the pre-modern period. The reference to *chouris* reflects the broader transfer of knowledge from one type of production system to another—specifically, from a labor-intensive model in South India to a capital-intensive system in Europe. The labor-intensive utility of *chouris* was misaligned with Europe's capital-intensive manufacturing framework, rendering it seemingly irrelevant, assessed as incorrect, and ultimately dismissed.

Gatekeeping and the Transfer of Knowledge

The evidence presents a unique problem: How do we explain a flawed historiography that has persisted over time and filtered into our collective narratives of the past? Why was the knowledge about *chouris* dismissed in Europe? The Beaulieu manuscript, written by a French observer for a Western intellectual audience, documents what Beaulieu observed happening in India. He clearly and precisely described the use of *chouris* in the dyeing-painting sequence. However, the misrepresentation of Beaulieu's account began in France, perpetuated by savants who had never witnessed the printing-dyeing process. While these savants possessed experiential and empirical knowledge of European printing-dyeing techniques, their understanding of Indian processes was experimental and lacked direct exposure to the raw material in question—fermented coconut sap

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[65] Austin, "The Developmental State and Labour-Intensive Industrialisation: Late Development Reconsidered," 51–74.

or *chouris*—and its many local uses in southern India.

It is unclear whether Querrelles experimented with *chouris* and found it unsuitable or dismissed it outright without adequate investigation. He likely omitted references to *chouris* because he could not obtain it. What is certain is that his gatekeeping—omitting *chouris* from the printing-dyeing process—excluded the material from subsequent historiography, paving the way for erroneous interpretations.

Later writers had access to material evidence that could corroborate or challenge Querrelles's decision to exclude chouris from his transcription of the Beaulieu manuscript. However, intellectual path dependence on arsenic as a reoxidation-delaying agent led historians to overlook *chouris* and its potential uses in indigo painting and to seek potential Indian uses of arsenic or other reoxidation-delaying agents.[66] The main problem was that leuco indigo had to be skillfully and quickly applied to cloth before it re-oxidized on the brush or wad. The European focus, therefore, was on finding a reoxidation-reducing agent rather than on acknowledging India's development of artisanal speed and skill. Beaulieu's step-by-step account of the process, including his specific references to the use of *chouris*, was dismissed by Irwin and Schwartz, who reinforced the entrenched view that painting with leuco indigo was primarily a technical challenge. Although Irwin and Schwartz had the opportunity to reintroduce this knowledge to an academic audience, path dependency of viewing the issue as a technical problem had already become firmly entrenched, perpetuating an erroneous historiography. The prevailing assumption among savants seemed to be that if *chouris* could not function as a reoxidation-reducing agent, it served no meaningful purpose in the printing or painting process. Consequently, its inclusion in the Beaulieu

[66] Greene, *Wearable Prints*, 31.

manuscript was deemed erroneous and dismissed.

The usefulness of *chouris* accentuates the challenge of the diffusion of knowledge about a local tropical raw material into a temperate ecology where the population was entirely unfamiliar with the material, its properties, and its common applications. While the environment in South India generated specific in-situ knowledge about *chouris*, it also constrained the absorption of this knowledge in temperate Europe. Equally, the limits of knowledge transfer underscore the pivotal role of experts and savants, whose past knowledge paradigms shape how new knowledge is interpreted and integrated. New knowledge must first pass through these expert gatekeepers, who verify, corroborate, authorize, or reject it based on their established knowledge structures. This process determines whether the knowledge is allowed to percolate into the wider population. The introduction of new knowledge often necessitates scientific investigations, fostering the development of observation and analysis techniques, contributing to the growth of a "scientific culture."

The decision in Britain to pursue a reoxidation-reducing agent found in arsenic is also noteworthy. The development of the pencil blue technique, which used arsenic as the reoxidation-reducing agent, indicates the necessity for a method of applying indigo to small areas of a design without having to resist large parts of the fabric. Peter Floud identifies three reasons for the technique's unsatisfactory performance: First, the use of arsenic was dangerous to the men, women, and children routinely employed for such small jobs in printing workshops. Second, the results were "messy and uneven," likely due to the reliance on unskilled low-cost labor (see figure 4). Third, and most significantly, the pencil blue technique was inadequate since the arsenic's reoxidation reduction did not last long enough to be viable for block printing.[67] The focus on pencil blue for block printing indicates a drive toward increasing productivity and standardization of printing outcomes, despite the technique's ultimate failure. In the capital-intensive textile printing and dyeing workshops around eighteenth-century London, adopting the labor- and skill-intensive technique of painting with indigo using coconut sap was unlikely, even if the method had been understood and correctly interpreted.

FIG. 4: Textile sample, 1969.3254, mid-eighteenth century, WM

The pencil blue technique represents a key development in the history of printing and dyeing in Britain, as well as an example of scientific knowledge intersecting industrial application. Although there is no precise date for its development, Floud places it in the 1730s.[68] The China blue technique followed in the 1740s in England, enabling block printing with indigo by printing

[67] Floud, "English Contribution," 346.

[68] Floud, "English Contribution," 346.

with unreduced indigo on cloth and then reducing it directly on the cloth.[69] Despite these innovations, Floud explains that the problem of painting with indigo was regarded as unsolved even after 1800 owing to dissatisfactory outcomes. Floud credits British chemists and printers with developing these techniques, indicating the overlap between commercial industrial pursuits and the growth of chemistry as a distinct scientific discipline.[70] This case of developing new scientific knowledge to enable commercially oriented process innovations highlights the role of science to overcome specific material challenges, such as those involving indigo. The misunderstanding of, and mismatch with, a process developed in India spurred an alternative trajectory of innovations in indigo printing and dyeing in the West. These innovations were rooted in the advancement of science and scientific culture, stimulated by the introduction of new textile products containing material knowledge from India.

The practice of painting with indigo corroborates Hilaire-Pérez's emphasis on the role of the interpreters who codified new knowledge and deemed it useful or useless. It also aligns with Bertucci's notion that knowledge was not only embodied within the artisan but also in the immovable environment. While the environment and local production systems facilitate the development of organically grown knowledge, they can also limit the comprehension and absorption of new knowledge if it does not align with existing local paradigms developed in specific ecological systems. Notably, no local substitute was sought for *chouris* in Europe, unlike the substitution of chay root with madder for red dye. There are two possible explanations: First, *chouris* was so alien to how Querelles as the first gatekeeper of this knowledge understood the

[69] Floud, "English Contribution," 347.

[70] Floud, "English Contribution," 347–48.

process of dyeing with indigo that he decisively dismissed it. Second, Querelles did not intentionally discard *chouris* but failed to mention it in his transcription of the Beaulieu manuscript because he could not corroborate its usefulness. His error lay not in his inability to verify the role of *chouris* but in omitting to acknowledge that he had been unable to do so.

The sequence of events demonstrates that useful knowledge of the use of *chouris* was dismissed twice within the history of dyestuffs. First, Querelles excluded it from his transcription. Later, Irwin and Schwartz missed the opportunity to reassess the material and technical validity of *chouris* in whether Querelles had made an error of judgment. Their omission allowed Floud to assert that over 90 percent of a chintz pattern was resisted by Indian artisans to achieve blue in small areas, perpetuating an incomplete understanding of historical dyeing techniques.

Conclusion

The case of direct painting with indigo on cloth provides significant new insights into useful knowledge, knowledge transfer, and the role of the environment as well as the intermediaries in determining the absorption or rejection of new knowledge within global history. It demonstrates that defining useful knowledge solely by its economic applicability is limiting, as it undervalues or discards knowledge that may lack immediate economic viability, especially when transferred from a skill-intensive to a capital-intensive setting.

Painting with indigo has been misrepresented as a technical problem due to the tendency to view useful knowledge through the lens of economic utility. Historical reconstruction, based on a well-documented but previously dismissed Indian method of indigo painting, shows that the process is relatively simple, though time, labor, and material intensive. It requires the artisan's skill and familiarity with the properties of fermented coconut sap. Far from being a technical issue, this article argues that painting indigo on cotton was primarily an economic challenge. Recreating the chintz-making process detailed in the Beaulieu manuscript demonstrates that Indian artisans successfully integrated indigo painting into the wider, multilayered production of chintzes. The colorful early modern Indian chintzes, which shaped global textile consumption and production patterns, utilized specialist techniques—such as the use of coconut sap for indigo painting—to achieve diverse hues and colors. This diversity was deeply rooted in the synergy between local environment, raw materials, and artisanal skills, all shaped by the region's ecology.

The reconstruction demonstrates that past knowledge in any socioeconomic environment not only shaped the local knowledge base but also influenced the absorption or rejection of external knowledge. New knowledge did not enter new socioeconomic systems seamlessly; its adoption was mediated by biases, blind spots, and preexisting knowledge systems. Gatekeepers of knowledge tested, verified, and interpreted new ideas, often through the framework of a "scientific culture," leading to either validation or rejection. These gatekeepers' academic and experiential backgrounds often colored their interpretations, as seen in the rejection of indigo painting techniques as impractical or irrelevant. In the case of indigo, preexisting paradigms led to the summary dismissal of an unfamiliar technique without adequate verification. This case study thus highlights the enduring influence of path-dependent knowledge systems, emphasizing the need for critical reassessment of historical narratives to better understand the interplay of environment, expertise, and innovation in global history.

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