Bridging Biocultural Conservation and Education: An Integrated Pedagogical Framework in a Museum Setting

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Conservation science education often emphasizes decontextualized technical knowledge, leaving graduates ill-prepared for real-world situations where ecological needs intersect with culture, social values, and policy. This paper presents an integrated pedagogical framework designed for conceptual and practical application in biocultural conservation education that repositions a cultural heritage museum as a dynamic learning environment for biocultural conservation training. Using the Hainan Intangible Cultural Heritage Museum and traditional bark cloth production from *Antiaris toxicaria* as a case, the museum is treated as a living laboratory that combines material authenticity, cultural context, and engagement with indigenous knowledge holders. Grounded in experiential, place-based, and transformative learning theories, the scaffolded curriculum progresses from ethnobotanical knowledge comparison and sustainable resource management to interdisciplinary policy synthesis and innovation. Through artifact-based learning, workshops with substitute materials, case discussions, and mentored research, the framework promotes respect and balance between conservation objectives and traditional resource use. It cultivates boundary-crossing competence and hybrid technical-ethical skills, demonstrating how museums can serve as hubs for culturally responsive and equitable conservation education within an interdisciplinary and replicable model.

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INTRODUCTION

Contemporary conservation science education has made substantial advances in training students in ecological theory, biodiversity assessment, and quantitative modeling (Osagiede and Alordiah 2024; Bermudez and Krell 2025). However, an increasing body of scholarship highlights a persistent disconnect between disciplinary training and the realities of conservation practice, particularly in socio-ecologically complex landscapes where biodiversity conservation intersects with cultural traditions, livelihood needs, and governance constraints (Bennett and Dearden 2014). Graduates of conservation-related programs often demonstrate strong analytical capacity in population ecology, species distribution modeling, and ecosystem assessment. However, they are frequently underprepared to engage with conservation challenges characterized by value conflicts, culturally embedded resource use, and competing policy objectives. This gap reflects a broader "abstraction problem" in conservation education, whereby conservation is framed primarily as a technical and biological enterprise, largely detached from its social and cultural context (Sterling *et al.* 2017).

Such limitations have tangible consequences for conservation outcomes. Technocratically driven interventions—designed with limited attention to social legitimacy or cultural relevance—have repeatedly elicited resistance, poor compliance, or long-term failure, despite grounding in sound ecological science (Adams *et al.* 2004; Sullivan *et al.* 2022). In response, conservation science has increasingly embraced interdisciplinary and transdisciplinary approaches, emphasizing that effective biodiversity protection requires not only ecological knowledge but also an understanding of social systems, cultural practices, and ethical trade-offs (Díaz *et al.* 2019; Winkler-Schor *et al.* 2024). Nevertheless, this paradigm shift has not been fully reflected in conservation education, which remains largely organized along disciplinary lines and dominated by classroom-based instruction and biologically oriented field training.

The need to integrate the biological and cultural dimensions of conservation is particularly evident in the growing recognition of biocultural diversity—the intertwined diversity of life and culture shaped through long-term human–environment interactions (Franco 2022; Nemogá *et al.* 2022). Traditional Ecological Knowledge (TEK), developed through cumulative observation, practice, and adaptive management, has been shown to contribute valuable insights into species ecology, sustainable resource use, and ecosystem dynamics (Robinson *et al.* 2021). Despite this recognition, conservation education frequently treats TEK as marginal, supplementary or anecdotal, rather than as a knowledge system that can be critically examined, compared, and integrated with scientific data. At the same time, programs focused on cultural heritage and anthropology often lack ecological frameworks to assess conservation effectiveness or biological sustainability (Lindholm and Ekblom 2019). This persistent disciplinary bifurcation represents a critical educational gap: future conservation professionals are rarely trained to systematically evaluate conservation dilemmas in which biological protection and cultural continuity are simultaneously at stake.

Despite the considerable appeal of experiential and museum-based learning approaches, it is important to acknowledge that these pedagogical modes are not without critics. Some scholars argue that unstructured or insufficiently scaffolded experiential learning can be less efficient than well-designed traditional lecture-based instruction in conveying foundational disciplinary knowledge and ensuring competency in core skills (Kirschner *et al.* 2006; Hmelo-Silver *et al.* 2007). Critics contend that the time devoted to facilitated experiences may reduce opportunities for systematic instruction in ecological theory, taxonomic identification, and quantitative methods that remain central to conservation science training. These concerns are legitimate and should not be dismissed. However, a growing body of evidence suggests that when experiential learning is carefully scaffolded—as in the modular, progressively complex framework proposed here—it can complement rather than displace foundational instruction, promoting deeper conceptual understanding, transferable problem-solving capacities, and affective engagement that persist beyond the classroom (Prince 2004; Freeman *et al.* 2014). The challenge for conservation educators is therefore not to choose between experiential and conventional instruction, but to design integrated curricula in which each approach reinforces the other.

Museums offer an underexplored opportunity to address this gap from a natural science education perspective. Traditionally viewed as repositories of specimens and artifacts, museums are increasingly recognized as active learning environments that support inquiry-based, experiential, and interdisciplinary education (Kreuzer and Dreesmann 2017; Todino and Campitiello 2025). Natural history museums have long played a crucial role in taxonomic training and biodiversity documentation. However, cultural heritage museums—particularly those documenting practices linked to biological resources—remain marginal in formal conservation science curricula (Bennett *et al.* 2017). Recent studies suggest that museums can function as "contact zones" where different epistemologies, including scientific and indigenous knowledge systems, are made visible and open to critical comparison (Onciul 2018; Todino and Campitiello 2025). Empirical studies on museum-based learning have documented significant gains in students' conceptual understanding, scientific inquiry skills, and affective engagement with course material compared to classroom-only instruction (Kisiel 2005; Martin *et al*. 2016). However, empirical frameworks demonstrating how such spaces can be systematically integrated into conservation science training, rather than used as peripheral educational supplements, remain scarce.

This study addresses a specific and underexamined research gap at the intersection of conservation science education, biocultural conservation, and museum-based learning. While previous work has advocated for interdisciplinary conservation education (Marsh 2017; Sterling *et al.* 2017) and highlighted the importance of biocultural approaches in practice (Díaz *et al.* 2019; Lukawiecki *et al.* 2022), few studies have translated these principles into operational pedagogical models grounded in concrete conservation conflicts. Moreover, existing educational frameworks rarely address cases in which legally protected species are directly implicated in culturally significant practices, despite the prevalence of such conflicts in biodiversity-rich regions.

To address this gap, the authors develop and present an integrated pedagogical framework that reconceptualizes the Hainan Intangible Cultural Heritage Museum as a functional learning laboratory for biocultural conservation training. The framework is offered as a theoretically grounded curriculum design model, with the understanding that systematic empirical evaluation of student learning outcomes constitutes an important direction for future research. The framework is anchored in a focal case involving the traditional bark cloth (tapa) production practiced by the Li ethnic minority using *Antiaris toxicaria* Lesch. (bark cloth tree, 见血封喉树) in the Mulberry family (Moraceae). It is a large tree native to the tropical and subtropical regions of South and Southwest China. Its thick bark has relatively long, fine, strong and pliable fibers that some minority mountain people have used to make bark cloth, which can be crafted into garments and mattresses. Due to habitat degradation and loss, the species is protected under national regulations in China (Lu *et al.* 2021). This case represents a prototypical biocultural conservation dilemma: a nationally recognized intangible cultural heritage practice depends on the extraction of bark from a biologically protected species, creating inherent tensions between biodiversity conservation objectives and cultural preservation mandates. Such conflicts are widely reported across conservation contexts but remain underrepresented in formal conservation science education (Fredriksson 2021).

The Hainan Intangible Cultural Heritage Museum provides an unusually comprehensive and scientifically relevant setting for examining this dilemma (Li 2025). The museum curates physical bark cloth artifacts, visual documentation of production processes, living specimens of *A. toxicaria*, and long-term collaborations with elder practitioners who retain detailed process knowledge. Together, these elements enable students to analyze conservation challenges using multiple lines of evidence, including ethnobotanical documentation, species-level ecological traits, regulatory frameworks, and stakeholder perspectives. Importantly, the museum context allows these diverse multidisciplinary components to be examined simultaneously, rather than sequentially or in isolation, thereby approximating the complexity of real-world conservation decision-making.

The pedagogical framework proposed here is grounded in experiential learning theory, place-based education, and transformative learning, but is explicitly structured to meet the analytical standards of conservation science training. Learning modules progress from biological and ethnobotanical characterization of the focal species, through assessments of resource-use sustainability and conservation status, to an interdisciplinary evaluation of policy instruments and management alternatives. Hands-on activities employ ecologically appropriate substitute materials to explore craft techniques without compromising conservation ethics. At the same time, case-based seminars and mentored research projects require students to synthesize ecological data with cultural and institutional analysis. In this configuration, the museum functions as a "third space" that facilitates the production of hybrid knowledge integrating ecological rigor with cultural and ethical reasoning (Du and Cui 2021).

By bridging biological science education, biocultural conservation theory, and museum-based learning, this study contributes to ongoing efforts to reform conservation education toward more integrative, socially grounded, and practically effective models. The framework provides a transferable template for regions where traditional practices intersect with conservation priorities. It offers a pathway for cultivating conservation professionals capable of navigating the complex socio-ecological landscapes of twenty-first-century biodiversity management.

STEPS TO PEDAGOGICAL DEVELOPMENT

Educational Setting and Participants

The proposed framework is conceptualized as a modular, scaffolded curriculum for implementation at the Hainan Intangible Cultural Heritage Museum, a specialized institution dedicated to the preservation of Li ethnic minority cultural practices, including traditional bark cloth production from *A. toxicaria*. This curriculum comprises three sequential learning modules: ethnobotanical knowledge comparison, sustainable resource management, and interdisciplinary policy synthesis. They are operationalized through four core activity types: guided museum interpretation, hands-on workshops using substitute materials, case study seminars, and mentored research projects.

As a theoretically grounded curriculum design model, this paper focuses on the conceptual development of the framework rather than the results of an empirical intervention; consequently, no experimental cohort was recruited for the present study. The intended target participants include undergraduate or graduate students in fields such as conservation biology, ethnobotany, environmental education, or biocultural conservation. While these students typically possess foundational biological knowledge, the framework specifically addresses their often limited exposure to the socio-cultural dimensions of conservation.

Designed to accommodate cohorts of 15 to 30 students over a single academic semester, the framework relies on strategic partnerships with museum staff, ethnobotanists, and traditional knowledge holders to ensure reciprocal learning and adherence to ethical protocols (*e.g.*, utilizing substitute plant materials to protect endangered species). While a more detailed account of this structure is provided in the following section, empirical pilot testing and formal outcome assessments are scheduled for subsequent research phases.

Pedagogical Design and Framework Structure

The framework integrates principles from experiential learning theory (Warners *et al.* 2026), place-based education (Cruz *et al.* 2021), and transformative learning theory (Collins *et al.* 2022), positioning the museum as a "third space" for the development of boundary-crossing competence. It is structured as a modular, scaffolded curriculum with progressive complexity, following the principles of spiral curriculum design (Grant 2010).

The course is organized into three sequential modules, each building on prior learning outcomes (Fig. 1).

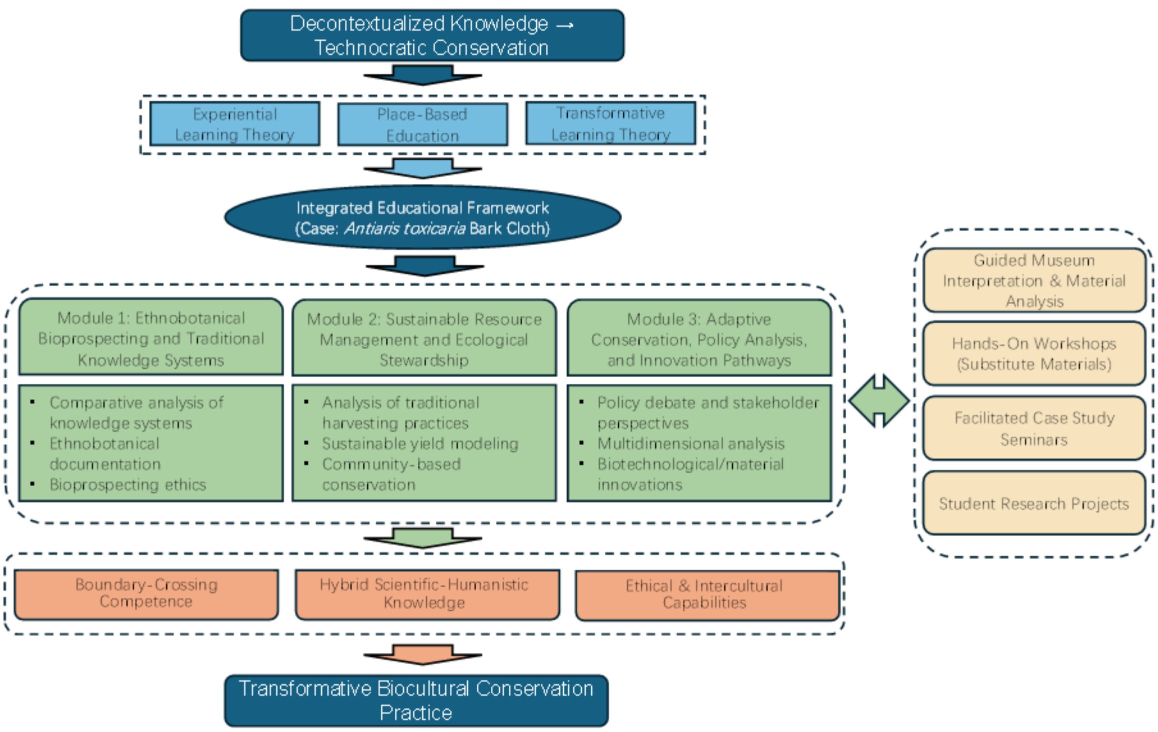

Fig. 1. Flowchart of the integrated museum-based biocultural pedagogy framework, showing the theoretical foundations, modular progression, and implementation activities

Module 1: Ethnobotanical bioprospecting and traditional knowledge systems

Focus: Comparative analysis of scientific and traditional ethnobotanical knowledge using *A. toxicaria* as a case study. Activities include systematic species identification (using scientific taxonomic keys rather than traditional classification methods), ethnobotanical documentation methods (such as interviews and participant observation), and critical examination of bioprospecting ethics.

Module 2: Sustainable resource management and ecological stewardship

Focus: Application of ecological principles to traditional Li harvesting practices. Activities involve analyzing harvest protocols (*e.g.*, seasonal timing, and partial stripping), designing sustainable yield models, and evaluating community-based conservation using common property theory (Agrawal 2007).

Module 3: Adaptive conservation, policy analysis, and innovation pathways

Focus: Synthesis and interdisciplinary problem-solving of the *A. toxicaria* conservation paradox. Activities include stakeholder role-playing debates, multidimensional policy analysis (considering biological, cultural, economic, and ethical criteria), and exploration of biotechnological innovations (*e.g.*, tissue culture propagation, and substitute material testing).

Implementation Procedures and Activity Types

Implementation follows a mixed-methods pedagogical approach emphasizing inquiry-based, experiential, and collaborative learning. Four primary activity types are integrated across modules.

Guided museum interpretation and material analysis

This component is primarily implemented through guided visits to the museum, during which students learn directly from curated exhibitions and on-site interpretation. Under the guidance of museum educators and invited specialists, including ethnobotanists, conservation biologists, and Li craftspeople, participants are introduced to the cultural and ecological background of bark cloth production. Learning activities emphasize close observation of exhibited artifacts, interpretive discussions of raw materials and production processes, and reflective dialogue on the relationships between traditional practices and biodiversity conservation. Through this museum-based learning experience, students develop a contextual understanding of traditional material use and its conservation implications, forming a foundation for subsequent scientific and interdisciplinary analysis.

Beyond formal educational sessions, there is significant potential to expand the reach of this museum-based learning model by developing multimedia resources. They include narrated video presentations documenting the bark cloth production process, interviews with Li master craftspeople, and visual overviews of the conservation dilemma. Many contemporary museums have established dedicated small-scale media spaces—studio alcoves or screening rooms—where visitors can engage with curated video content at their own pace, thereby gaining contextual orientation before exploring exhibits in greater depth (Xu *et al*. 2025). Once produced, such multimedia resources would enable repeated and scalable dissemination to museum visitors and remote learners alike, greatly amplifying the educational impact of the framework beyond enrolled course participants.

Hands-on workshops with substitute materials

Embodied learning *via* bark cloth production is conducted using non-protected species (*e.g.*, *Broussonetia papyrifera* or *Ficus* spp.). Facilitated by Li craftspeople, sessions cover full production sequences (harvesting, retting, and beating). Participants maintain reflective process journals to document the acquisition of tacit knowledge, challenges, and comparative insights into material authenticity versus substitutes.

Facilitated case study seminars

Problem-based learning centered on the *A. toxicaria* conservation-*versus*-utilization dilemma. Participants apply analytical frameworks from multiple disciplines to primary sources (*e.g.*, conservation assessments, policy documents, and stakeholder testimonies). Structured discussions use evidence-based argumentation protocols, culminating in multi-criteria evaluation of policy proposals.

Student research projects

Mentored small-team inquiries can span chemical or biochemical analysis (*e.g.*, detoxification experiments), materials science testing (*e.g.*, mechanical properties), or ethnographic documentation (*e.g.*, interviews with practitioners). Projects incorporate community review protocols for ethical reciprocity and cultural sensitivity.

Materials and Ethical Considerations

Materials: Museum collections (artifacts, specimens); substitute plant materials compliant with conservation laws; analytical tools (portable microscopy, tensile strength testing equipment); documentation resources (interview guides, journals).

Ethical Protocols: Adherence to principles of free, prior, and informed consent with traditional knowledge holders; reciprocal benefits (*e.g.*, archival resources for community use); compliance with Chinese wildlife protection and cultural heritage laws. Research projects that involve human subjects require institutional ethics approval.

RESULTS AND DISCUSSION

Pedagogical Rationale: Reconceptualizing the Museum-as-Laboratory

The conceptualization of museums as educational laboratories has evolved considerably beyond earlier models that positioned museums primarily as venues for informal public science communication or supplementary enrichment experiences peripheral to formal academic curricula (Kreps 2015; Abd El Wareath 2022). Contemporary museum education scholarship recognizes cultural institutions as sites possessing unique pedagogical affordances—material, spatial, and social characteristics that enable forms of learning difficult or impossible to replicate in conventional classroom settings (Kristinsdóttir 2017). The Hainan Intangible Cultural Heritage Museum exemplifies these affordances through several distinctive features that make it an ideal setting for biocultural conservation education (Fig. 2).

In Fig. 2, the main content written on the exhibition board is (A): Before using hemp and cotton for weaving, the ancestors of Hainan Island experienced a long period of "no weaving". In the mountainous areas of the Li ethnic group, where the trees were abundant, the Li ancestors used the bark of trees such as the *A. toxicaria* and the willow tree, through processes such as soaking, repeated rinsing, and beating, to process it into non-woven fabric, which was used to make clothes, bedding, *etc*., for warmth and protection. In the Qing Dynasty, Zhang Qingchang wrote "The Chronicles of Li Qi", in which it was recorded: "During the cold winter in the Li ethnic area, they collected the bark, pounded it soft, and used it to cover their bodies. At night, they would use it as a substitute for a quilt. The tree was called tapa, and it was a product of the Li people." Bark cloth was the earliest non-woven fabric made by humans using plant fibers, and it is even older than the Li ethnic weaving technique.

First, the museum provides material authenticity—direct access to actual authentic artifacts, specimens, and documentation produced through traditional practices, rather than mediated representations such as photographs, diagrams, or verbal descriptions. For biological science students accustomed to examining preserved specimens in university collections or standardized samples in laboratory settings, engagement with culturally significant materials—bark samples at various processing stages, tools bearing the patina of decades of use, finished textiles that embody the accumulated skill of master craftspeople—creates what phenomenological learning theorists describe as “authentic encounter”.

Fig. 2. Li bark cloth craftsmanship exhibited at the Hainan Intangible Cultural Heritage Museum. (A) An overview of the traditional bark cloth making technique that predates textile weaving using cotton and hemp, and a master practitioner. (B) The eight-stage production sequence: material selection, bark stripping and preparation, soaking, degumming, beating and rinsing, drying, sheet formation, and garment making. (C) Completed bark cloth products. All images were taken at the Museum.

The reality encounter denotes a form of engagement that stimulates multisensory observation, emotional response, and recognition of materiality in ways that fundamentally differ from abstract conceptual learning (Ghigi *et al.* 2025). Students examining the progressive transformation of *A. toxicaria* bark from rigid, toxic tissue to supple, safe fabric can observe changes in fiber structure at multiple scales, assess alterations of material properties through tactile examination, and directly apprehend the relationship between processing techniques and material outcomes. The acquisition of experiential knowledge can complement but cannot fully replace the theoretical understanding of polymer degradation or fiber mechanics.

Second, the museum offers cultural contextualization (Mao and Fu 2022) — the integration of biological specimens and ecological knowledge into cultural meaning systems, use contexts, and knowledge traditions. Natural history museums typically present plants and animals as taxonomic specimens or ecological types abstracted from human relationships. In contrast, intangible cultural heritage museums explicitly foreground these relationships, displaying *A. toxicaria* bark not merely as botanical material but as a culturally constructed resource situated within complex networks of traditional knowledge, craft technique, social organization, and cultural identity. This vivid contextualization enables what anthropological learning theory terms "thick description learning" — engagement with knowledge systems in their full complexity rather than as simplified, discrete, and decontextualized facts (Haggis 2008). Students do not encounter isolated biological information (such as plant morphology, toxin chemistry, and fiber properties). Instead, they are exposed to an integrated and comprehensive biocultural knowledge system in which botanical knowledge, material processing techniques, ecological management practices, and cultural values constitute mutually reinforcing elements of a coherent worldview.

Third, the museum facilitates engagement with knowledge holders, involving direct interactions between students and traditional practitioners who serve as living repositories of embodied knowledge and cultural perspectives that cannot be fully captured in written documentation or artifact collections. The presence of Li master craftspeople as educators fundamentally transforms the pedagogical dynamic from conventional expert-to-novice knowledge transmission to what intercultural education scholars describe as "reciprocal learning partnerships". The alliance involves academic students and traditional knowledge holders jointly engaging as co-learners, each possessing specialized forms of expertise that interact, complement and challenge one another (Gugulethu 2025). Through dialogue, demonstration, and collaborative inquiry, students gain appreciation for the epistemic sophistication of TEK systems. They embrace a rich repertoire of internal logic, empirical foundations, and systematic approaches to observation and experimentation. Meanwhile, practitioners gain exposure to scientific frameworks, analytical tools, and policy contexts that may inform their advocacy efforts for cultural heritage protection and sustainable resource access.

This museum-as-laboratory model enables living and lively pedagogical connections that are difficult to achieve through conventional disciplinary education structures (McNichol 2010). The framework explicitly bridges multiple knowledge domains that are typically segregated in university curricula. For instance, botanical systematics (plant identification, morphological analysis, and phylogenetic relationships) integrates with ethnobotany (cultural plant use patterns, traditional nomenclature systems, and indigenous ecological classifications). Forest ecology (community structure, species interactions, and ecosystem processes) connects with conservation policy (protected area designation, species recovery planning, and regulatory frameworks). Biochemistry (secondary metabolite function, enzymatic degradation pathways, and polymer chemistry) links with material science (fiber microstructure, mechanical properties, and textile engineering). By situating learning at these disciplinary interfaces, the museum environment cultivates what educational theorists term "boundary-crossing competence" (Oonk *et al.* 2022). Students can learn to navigate among different knowledge systems, translate concepts across disciplinary languages, synthesize insights from multiple perspectives to address complex problems, and hybridize disparate knowledge realms to build a holistic and thorough understanding.

Structured Learning Architecture: Module Design and Pedagogical Progression

The educational framework is organized as a sequence of three interconnected modules, each targeting specific learning objectives and progressively building toward a comprehensive understanding of biocultural conservation challenges and solution pathways. This modular architecture reflects the adoption of two educational design principles. First, scaffolding involves structuring learning experiences in a developmental sequence that moves from foundational knowledge and skills toward increasingly complex analysis and application. Second, the spiral curriculum design revisits core themes at progressively deeper levels of sophistication (Campbell *et al.* 2022).

Module 1: Ethnobotanical Bioprospecting and Traditional Knowledge Systems establishes a foundational understanding of how Traditional Ecological Knowledge operates as a legitimate form of empirical inquiry and a systematic knowledge-generation process. Students engage intensively in the botanical and cultural dimensions of *A. toxicaria* and related species used in Li material culture. They develop competencies in systematic species identification using both scientific taxonomic keys and traditional morphological classification systems. Key learning outcomes include the ability to document plant uses through ethnobotanical interviews, apply participant observation methods, and recognize the empirical basis underlying traditional knowledge claims. Cases in point include how harvest timing recommendations reflect observations of phenological patterns, how detoxification procedures encode an understanding of toxin chemistry (Reyes-García 2010; Robinson *et al.* 2021), and critical analysis of the concept of "bioprospecting". The cultural history and anthropology of bark cloth, an ancient human invention, and its convergent innovations in different places, times and among different peoples, can be explored in the context of human ingenuity in bioprospecting (Nyabongo 1944; Leonard and Terrell 1980; Kotilainen 1990). These activities examine the potential value of discovering useful biological resources, as well as the problematic history of the appropriation of indigenous knowledge and inequitable benefit-sharing.

Pedagogically, this module employs comparative analysis of knowledge systems, coaching students to examine how scientific botany and traditional ethnobotany approach similar questions. They include species identification, plant property characterization, and assessment of potential resource use, employing different methodological frameworks and epistemic assumptions. Students analyze specific case examples where TEK provided insights that triggered and accelerated scientific discovery or informed conservation planning. Moreover, cases where scientific analysis reveals limitations or inaccuracies in traditional knowledge can foster a nuanced understanding, thereby avoiding both the romanticization of TEK as infallible wisdom and the dismissal of traditional knowledge as unscientific folklore. Such studies underscore the need for conservation science to adopt an ethical, empathetic and critical approach toward the management of indigenous lands and peoples as well as their constituent cultures, knowledge and livelihoods (Jessen *et al.* 2022). This balanced, objective and deepened perspective is essential for effective biocultural conservation practice, which requires respectful engagement with traditional knowledge holders while maintaining critical analytical capacity. Enlightened understanding can resolve the ingrained conflicts and contradictions between modern conservation practice and traditional bioresource utilization.

Module 2: Sustainable Resource Management and Ecological Stewardship advances student learning into the application domain. It examines how traditional harvesting practices embody principles of sustainability and adaptive management that contemporary conservation science has only recently formalized. Students analyze in detail the Li bark-harvesting protocols, including seasonal timing, tree selection criteria, partial stripping techniques, and rotation patterns across forest areas. Whereupon, they develop an understanding of how these time-honored practices function as informal yet effective conservation strategies that maintain population viability while enabling ongoing resource use. Key learning outcomes include interpreting the indigenous wisdom and capacity to design ecologically sustainable harvesting protocols through the lens of modern science.

They include assessment of species life history, population dynamics, and regeneration ecology; application of ecological concepts (including maximum sustainable yield, population growth rate, recruitment limitation, and disturbance ecology) to evaluate traditional resource management systems; and critical reflection on the relationship between resource security, cultural incentives for conservation, and effective biodiversity protection.

This module directly challenges the fortress conservation paradigm by demonstrating, through empirical case analysis, that human use and ecological sustainability are not inherently contradictory (Knox 2025). Instead, the association can be complementary when use patterns are embedded within cultural systems that constrain overexploitation through social norms, ritual restrictions, or traditional tenure systems (Nguyen 2019). Students can engage with the literature on common property theory, tragedy of the commons, community-based conservation, and indigenous resource management to examine the conditions under which sustainable traditional use may succeed or fail. The failure of modern fortress conservation, which displaces and dispossesses indigenous people in creating protected areas, can be critically assessed based on enlightened IUCN guidelines (Stevens *et al.* 2024). Practical exercises involve designing monitoring protocols to assess the impacts of harvest on target tree species and associated ecosystems, evaluating the changing ecological footprint of bioresource extraction, calculating sustainable yield levels based on demographic data, and developing adaptive management frameworks to inform harvest level adjustments in response to population monitoring results. These technical skills are taught explicitly within the context of collaborating with traditional resource users rather than imposing external management regimes. This approach emphasizes the importance of incorporating local knowledge into management planning and ensuring that conservation interventions align with rather than contradict community livelihood needs and cultural values (Sene-Harper *et al.* 2019).

Module 3: Adaptive Conservation, Policy Analysis, and Innovation Pathways represents the culminating synthesis module in which students integrate knowledge and skills from previous modules to engage directly with the *A. toxicaria* conservation paradox. It is analyzed as a complex, real-world policy dilemma requiring interdisciplinary analysis and creative problem-solving. Students examine critical and controversial issues, such as records and trends of bark harvesting, biological justifications for the designation of protected species, reasons for harvest exclusion in protected areas, and the cultural impacts of harvesting prohibitions. The studies can extend to the administrative regime, including the legal frameworks governing wildlife protection and cultural heritage preservation in China, as well as the institutional barriers to developing flexible governance approaches that accommodate traditional uses. Key learning outcomes include the ability to conduct multidimensional analyses of conservation policies from biological, social, cultural, economic, and ethical perspectives; the critical evaluation of trade-offs inherent in conservation decision-making under uncertainty; and the development of innovative solutions employing technological approaches, policy reforms, or institutional reforms to address conservation-heritage conflicts.

Central to this module is the structured policy debate in which student teams represent different stakeholder perspectives. They include government conservation agencies, traditional knowledge holders, cultural heritage organizations, botanical gardens, research institutions, tourism and economic development interests. Collaboratively, these interested parties can confer and consult to hammer out compromise policy proposals that balance competing expectations and objectives. Furthermore, the team can translate the policies into an actionable plan to apply knowledge in the real world. This deliberative reality-learning process is grounded in structured case study analysis and role-playing pedagogy, which have been increasingly adopted in conservation and sustainability education to simulate in-depth and inclusive exploration of complex, real-life decision-making contexts (Chen and Martin 2014). Through guided discussions and scenario enactment, students develop perspective-taking capacities and gain a deeper understanding of how different stakeholders work in concert to frame conservation problems and develop solutions despite divergent values, knowledge systems, and priorities (Frank and Schäffler 2019). Collectively, these activities strengthen students' competencies in collaborative governance, including negotiation, dialogue, co-production of knowledge, and the translation of ideas into policies and actions, which are widely recognized as core features of contemporary conservation practice (Wyborn *et al.* 2019).

The module also introduces students to biotechnological and materials science innovations that may offer pathways for reconciling conservation and cultural preservation objectives. Students explore the potential of in vitro propagation and tissue culture techniques for producing *A. toxicaria* plant material outside natural populations, examining both the technical feasibility and the cultural acceptability of cultivated alternatives. Materials science approaches to fiber analysis enable comparative studies of bark properties from different plant species, helping to evaluate whether non-protected alternatives can serve as functional substitutes. The prospect of modernizing bark cloth production technology and manufacturing garments for the environmentally friendly eco-fashion market, thereby providing a new lease of life and a new source of income from a prehistoric craft, can be critically assessed (Robertson 2014; Venkatraman *et al.* 2020). Students are afforded opportunities to apply analytical techniques (microscopic examination of fiber microstructure, length, and thickness, tensile strength and pliability testing, and chemical composition analysis) to ethnobotanically significant materials. These explorations emphasize that technological innovation, while valuable, cannot substitute for addressing underlying policy and governance challenges; solutions must ultimately be socially and culturally appropriate to succeed.

Implementation Strategies: Translating Pedagogical Theory into Practice

The translation of this educational framework from theoretical design to effective implementation requires careful attention to pedagogical methods, assessment strategies, and institutional partnerships that enable sustained, high-quality learning experiences. Implementation proceeds through four integrated activity types, each employing specific pedagogical techniques that are aligned with the learning outcomes.

Guided museum interpretation and material analysis sessions offer structured engagement with museum collections through interpretive tours led by ethnobotanists, conservation biologists, and Li master craftspeople who serve as co-educators. Unlike conventional museum tours that emphasize passive information reception, these sessions employ inquiry-based learning methods in which students actively investigate artifacts and specimens as primary sources, formulate questions, make detailed observations, and develop interpretive hypotheses that are then discussed and refined through dialogue with educators (Rapanta and Felton 2022). Students document fiber microstructure at different processing stages using portable digital microscopy, analyze tool morphology to infer use techniques, and examine finished textiles to assess quality variation related to material properties and processing methods. These observations generate data that students later analyze using scientific methods, creating explicit connections between traditional material culture and contemporary analytical approaches (Walker *et al.* 2019). The co-educator model, in which scientific and traditional experts provide complementary forms of expertise, models the integrative thinking that biocultural conservation requires while demonstrating respect for different knowledge systems.

Hands-on workshops employing substitute materials enable embodied learning through direct participation in bark cloth production processes using non-protected plant species such as *B. papyrifera* (paper mulberry) or locally available *Ficus* species that do not contravene harvesting restrictions. These workshops, facilitated by Li craftspeople with support from an ethnobotanist, guide students through the complete production sequence: bark harvest and preparation, retting under controlled conditions with documentation of microbial activity and fiber separation progression, and beating techniques that transform processed bark into coherent fabric. This experiential engagement provides students with a tacit understanding of process complexity, material variability (Zandvliet and Rotinsulu 2025), and skilled judgment that cannot be conveyed through verbal descriptions or observing demonstrations alone. Students maintain detailed process journals documenting their observations, proactive production practices, encountered challenges, and problem-solving strategies, which later become the basis for reflection and analysis.

Critically, the use of substitute materials serves dual pedagogical functions. First, it enables practice-based learning while respecting conservation regulations and demonstrating a commitment to legal compliance, thereby modeling the ethical considerations that students as future conservation professionals must embody. Second, it creates an empirical foundation for comparative analysis. Students directly experience the functional differences between substitute species and traditional materials, gaining a visceral understanding of why material authenticity matters for the integrity of cultural practice. Simultaneously, they recognize that alternative materials may serve important functions for cultural transmission and demonstration purposes (Jones and Yarrow 2013). This experiential comparison generates a rich discussion of questions central to biocultural conservation: What constitutes authentic cultural practice? How do material substitutions transform practices even when techniques remain similar? Under what circumstances are substitutes culturally acceptable versus culturally problematic?

Facilitated case study seminars employ problem-based learning pedagogy, in which the *A. toxicaria* conservation dilemma serves as a complex, ill-structured problem that students must analyze from multiple disciplinary and stakeholder perspectives (O'Brien *et al.* 2013). Seminars are structured around analytical frameworks from conservation biology, environmental ethics, policy analysis, and anthropology, with students applying these lenses systematically to dissect the case's multiple and intertwined dimensions. Students examine primary source materials, including conservation status assessments, traditional knowledge documentation, policy texts, and stakeholder testimonies. They learn to critically evaluate the quality of evidence, identify the implicit assumptions and values underlying different positions, and recognize how problem framing influences the possibilities for solutions.

Discussion protocols emphasize argumentation and evidence-based reasoning (Siverling *et al.* 2021), requiring students to articulate positions clearly, support claims with specific evidence, acknowledge counterarguments and limitations, and engage respectfully with perspectives they may find unconvincing. These intellectual habits and protocols, fundamental to scientific inquiry, are applied to normative questions about conservation priorities, cultural rights, and policy design—domains where technical expertise must integrate with the human dimension of ethical reasoning and stakeholder engagement. Students develop and debate alternative policy proposals, which are evaluated using multi-criteria decision analysis frameworks that explicitly consider biological effectiveness, cultural acceptability, economic feasibility, institutional implementability, and alignment with principles of justice and equity (Banda *et al.* 2024).

Student research projects provide opportunities for in-depth exploration of specific topics aligned with individual interests, while contributing to a collective understanding of the bark cloth tradition and its associated conservation challenges. Research projects are designed as mentored inquiry experiences in which students work in small teams under the guidance of university faculty, museum staff, and traditional knowledge holders to address focused research questions. Project options encompass a range of approaches, each emphasizing different methodological competencies while maintaining a connection to the overarching educational themes.

The relevant materials and processes can be used to develop practical exercises for students. Chemical and biochemical analysis projects investigate the detoxification and degumming processes through controlled experiments that vary retting conditions (temperature, pH, microbial inoculation, rinsing repetitions, soaking duration, and mallet pounding skill). These experiments quantify toxin reduction, pectin degradation, and lignin solubilization using analytical chemistry techniques. These projects enable students to apply laboratory skills to better understand traditional processes, potentially generating insights valuable for optimizing cultivation-based production systems. Materials science projects employ mechanical testing (tensile strength, elongation at break, and tear resistance), microscopy (fiber diameter, length, surface morphology, and interlocking patterns), and comparative analysis of bark properties across plant species to characterize material attributes underlying textile functionality. Results inform the evaluation of the suitability of substitute material and the documentation of traditional material qualities that cultivation programs should aim to achieve. Ethnographic documentation projects employ qualitative research methods—such as semi-structured interviews, participant observation, and visual documentation—to systematically record traditional knowledge held by elder practitioners. At the same time, the results should be kept in an accessible repository, creating archival resources for future research and cultural revitalization efforts.

These diverse project types cater to heterogeneous student interests and career trajectories. Some students may pursue laboratory-based conservation research, whereas others may engage in community-based conservation that requires ethnographic approaches. Still others may focus on policy analysis or conservation education. Despite these divergent orientations, all project types share common learning outcomes. They include integrating an interdisciplinary approach and conducting ethical research when working with traditional knowledge holders, as well as a commitment to research that advances scientific understanding while addressing community interests and concerns.

Assessment of Learning Outcomes and Future Evaluation Directions

A critical consideration for any proposed educational framework is the capacity to document and evaluate learning outcomes in ways that satisfy both scholarly and institutional accountability requirements. Although the present study offers a theoretically grounded curriculum design rather than an empirical evaluation report, we recognize that funders, institutional partners, and educational researchers will rightly expect evidence of the framework's effectiveness. Accordingly, we outline here a set of assessment approaches that can be systematically integrated into future implementation.

Student learning outcomes can be assessed at multiple levels using a combination of formative and summative tools. Pre- and post-module knowledge assessments, employing structured questionnaires or concept-mapping tasks, can quantify gains in understanding of ecological, ethnobotanical, and policy dimensions of biocultural conservation. The boundary-crossing competence central to the framework's objectives can be operationalized and assessed through analytical essay assignments that require students to synthesize perspectives from at least two disciplinary domains, evaluated using validated rubrics for interdisciplinary reasoning (Mansilla *et al*. 2009). Reflective journals maintained throughout hands-on workshops provide a longitudinal record of tacit knowledge acquisition and attitudinal development amenable to qualitative content analysis. Stakeholder role-play debates can be assessed using argumentation quality rubrics that evaluate evidence use, perspective-taking, and reasoning coherence (Siverling *et al.* 2021). Finally, mentored research projects can be evaluated using standard academic criteria, with additional assessment of ethical research conduct and the quality of community engagement.

Longer-term outcome tracking, such as follow-up surveys of graduates employed in conservation-related fields, can provide evidence of whether the competencies developed through this framework translate into professional practice. A pilot implementation with a cohort of 15 to 30 students, combined with these assessment approaches, would provide the empirical foundation needed to validate, refine, and scale the proposed curriculum.

CONCLUSIONS

1. The proposed integrated educational framework effectively addresses the abstraction problem in conservation science education by repositioning the Hainan Intangible Cultural Heritage Museum as a dynamic laboratory that integrates material authenticity, cultural contextualization, and direct engagement with traditional knowledge holders, thereby fostering the development of transdisciplinary knowledge fusion and boundary-crossing competence essential for biocultural conservation practice.
2. Through its modular structure and diverse pedagogical activities—guided material analysis, hands-on workshops with substitute materials, case study seminars, and mentored research projects—the framework successfully bridges otherwise segregated knowledge domains, enabling students to acquire hybrid scientific-humanistic competencies that combine technical proficiency with ethical reasoning and intercultural sensitivity.
3. The museum-based approach demonstrates that cultural institutions can serve as central sites for transformative interdisciplinary training, moving beyond conventional supplementary roles to provide replicable models for place-based, experiential, and transformative and reality learning in biocultural conservation contexts.
4. By grounding learning in the real-world tensions exemplified by the *Antiaris toxicaria* conservation paradox, the framework equips students to navigate complex dilemmas involving competing biological, cultural, and policy imperatives, promoting more nuanced, integrative and collaborative approaches that transcend the entrenched binary protection-versus-use confrontational paradigms.

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Author Contributions

XC and LH conceived and designed the research; XC, ZY and LH performed research; XC wrote the original draft; JCY reviewed and edited. All authors had read and agreed to the published version of the manuscript.

Conflict of Interest

The authors have no relevant financial or non-financial interests to disclose.

Use of Generative AI

The authors declare that generative AI was used only for limited language polishing of parts of the manuscript. Specifically, DeepSeek was employed to improve grammar, clarity, and academic expression without altering the scientific content, interpretations, or conclusions. No AI tools were used for data analysis, study design, idea generation, reference collation, or preparation of images, figures, graphs, or diagrams. All substantive content remains the original work and responsibility of the authors.

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