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Review Article

Ethno-Pedagogical Module: A Theoretical Exploration of Knowledge Transmission in Ethnobiological Systems

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Abstract

The vertical transmission of ethnobiological knowledge across generations is crucial in preserving biodiversity and sustaining biocultural diversity. However, the mechanisms underpinning this process remain insufficiently studied. This paper introduces the "ethno-pedagogical module" as a novel interdisciplinary framework for analyzing and enhancing the understanding of traditional ecological knowledge (TEK) transmission. The module integrates perspectives from cultural anthropology, education theory, and ethnobiology. Cultural anthropology contributes insights into the role of rituals, oral traditions, and communal practices in knowledge dissemination. Education theory offers methodologies for understanding experiential and participatory learning processes essential to TEK. Ethnobiology provides the foundation for examining the practical and symbolic human-environment relationships embedded in traditional practices. This framework facilitates the disaggregation of TEK systems and enables cross-cultural comparisons, revealing how diverse communities sustain biocultural diversity through unique adaptive practices and learning processes. It also offers practical applications by guiding the integration of TEK into formal and informal education systems to foster environmental stewardship and cultural resilience among younger generations. By addressing the complexities of TEK transmission, the ethno-pedagogical module presents a structured approach for preserving traditional knowledge amidst global environmental and cultural changes. The module bridges traditional ecological practices with contemporary educational strategies, promoting resilience and innovation in sustaining biocultural diversity. This interdisciplinary approach underscores the importance of collaboration in safeguarding cultural heritage and biodiversity in an increasingly interconnected and rapidly changing world.

Keywords: Adaptive Learning; Traditional Ecological Knowledge; Learning Systems; Social Cognitive.

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1. INTRODUCTION

Ethnobiology is a multidisciplinary field that explores the intricate relationships between human societies, biological systems, and the environment [1], [2]. Among the many definitions proposed, Svanberg and Łuczaj [3] offer a particularly encompassing perspective, defining it as the scientific study of biocultural domains that emerge from the dynamic interplay between humans, biota, and landscapes, spanning historical and contemporary contexts. This definition highlights the ecological and cultural dimensions of these relationships, as well as the critical processes through which ethnobiological knowledge is acquired, maintained, and transmitted across generations.

Ethnobiology has evolved into a multidisciplinary field encompassing various subfields, each contributing unique perspectives to our understanding of human-nature interactions. Among the most prominent subfields are ethnobotany, ethnomedicine, ethnozoology, and ethnoecology, which together explore the intricate ways in which communities interact with their environments [4]–[16] Ethnobotany, for instance, investigates the cultural, medicinal, and nutritional uses of plants, revealing how communities manage plant resources for both practical and symbolic

purposes [17]–[21]. This subfield often intersects with ethnomedicine, which focuses on traditional healing practices and the use of natural resources to maintain health and well-being [8]. These studies document valuable traditional knowledge and provide insights into the potential applications of these practices in modern medicine and sustainable resource management.

Ethnozoology and ethnoecology further expand the scope of ethnobiology by exploring human relationships with animals and ecosystems. Ethnozoology delves into the cultural and ecological roles of animals, examining their significance in subsistence strategies, rituals, and symbolic systems [5], [22]–[25]. The domestication of animals and their roles in spiritual or ceremonial contexts highlights the complex interplay between cultural values and ecological practices. Meanwhile, ethnoecology offers a holistic view of how communities perceive and sustainably manage their ecosystems, emphasizing adaptive practices that foster environmental resilience [26]–[28]. By studying these practices, ethnoecology sheds light on traditional ecological knowledge systems that balance human needs with ecosystem health, offering valuable lessons for addressing contemporary challenges such as biodiversity loss and climate change. Collectively, these subfields enhance our understanding of traditional knowledge and underscore its relevance in promoting sustainability and environmental stewardship.

Despite its diverse and interdisciplinary domains, ethnobiology has predominantly focused on documenting Indigenous knowledge systems, particularly the use of plants and animals for medicinal, agricultural, and other utilitarian purposes [29]–[31]. While such documentation is invaluable for preserving traditional ecological knowledge (TEK), a deeper exploration of the pedagogical processes involved in the transmission of this knowledge is equally critical [32], [33]. These processes shape how knowledge is passed between generations and determine the adaptability of TEK to evolving socio-environmental contexts.

Understanding knowledge transfer mechanisms, such as storytelling, apprenticeships, and rituals, can offer valuable insights into how Traditional Ecological Knowledge (TEK) adapts and persists despite pressures from globalization, technological advancements, and cultural homogenization. Moreover, attention to these processes is vital for fostering the resilience and sustainability of TEK systems. By highlighting the role of pedagogy in TEK, researchers can uncover strategies that communities employ to preserve their ecological heritage amidst global environmental challenges, such as climate change, habitat loss, and shifting cultural identities [34]–[36].

Recent studies highlight the importance of understanding the cultural, social, and cognitive mechanisms that facilitate the retention and dissemination of ethnobiological knowledge. Oral traditions, experiential learning, and communal practices are crucial in transmitting knowledge across generations within many Indigenous communities [37]–[41]. These traditional methods are deeply rooted in the communities' lived experiences and ecological contexts, ensuring the knowledge remains relevant and adaptive.

Integrating ethnobiological knowledge into modern education systems offers a powerful pathway to both preserve and revitalize traditional knowledge. Such integration safeguards these cultural assets and encourages environmental stewardship and ecological consciousness among younger generations. By bridging traditional practices with contemporary educational approaches, communities can inspire a new generation of custodians who appreciate the value of biodiversity and sustainability [42]–[45]. This approach serves as a dual-purpose strategy: reinforcing cultural identity while addressing pressing global environmental challenges.

This study aims to address the gap in the literature by focusing on the ethno-pedagogical processes that underpin the learning and sharing of ethnobiological knowledge. The study aims to contribute to a deeper understanding of the dynamics of cultural and ecological sustainability by analyzing how this knowledge is transmitted. Drawing on interdisciplinary frameworks in ethnobiology, education, and cognitive science, this work highlights the importance of these processes for the continuity of traditional environmental knowledge and their role in promoting biodiversity conservation and cultural resilience.

This ethno-pedagogical module aims to contribute to the theoretical research discourse of understanding the transmission of ethnobiological knowledge. More precisely, this module conceptualizes the learning-teaching mechanisms within ethnobiological systems as a distinct unit of analysis, providing theoretical clarity on the dynamics of knowledge transfer. Through the lens of the ethno-pedagogical module, we examine how cultural practices, environmental interactions, and cognitive strategies facilitate the retention and adaptation of traditional knowledge.

2. EXPLANATION OF THE MODULE

Ethno-pedagogy refers to the systematic study and generalization of the educational traditions, practices, and experiences of specific ethnic groups. It encompasses analyzing how these communities transmit knowledge, values, and skills, often rooted in their unique ecological, cultural, and historical contexts. Within this framework, the ethno-pedagogical module is a structured approach to understanding the processes, methods, and environments through which ethnobiological knowledge is preserved and shared. This module addresses learning content, including plant identification, ecological roles, and medicinal applications, as well as the mechanisms and strategies of learning and teaching. It explores how social, cognitive, and ecological dynamics interact to shape the transmission of knowledge.

Ethno-pedagogy emphasizes both formal and informal educational structures, encompassing a range of approaches from ritualized practices and intergenerational communication to embodied and experiential learning. These interconnected pathways form the basis for how

ethnobiological knowledge is structured, transmitted, and retained across generations. For instance, formal structures may include apprenticeship models, where younger community members learn directly from elders, while informal structures might involve storytelling, songs, and daily communal activities. Such processes are central to maintaining biocultural resilience, enabling communities to adapt knowledge systems while preserving core cultural and ecological principles. The ethno-pedagogical module draws upon various interdisciplinary theoretical perspectives, each contributing to a deeper understanding of how ethnobiological knowledge is transmitted.

2.1. Cultural Pedagogy

As conceptualized by Alexander [46], cultural pedagogy investigates how cultural norms, values, and worldviews influence learning and teaching processes. This theoretical framework emphasizes that knowledge transmission is not merely an individual cognitive activity but an inherently contextual process shaped by the socio-cultural and ecological environments in which communities operate. Through this lens, learning is understood as deeply intertwined with cultural practices, social structures, and ecological relationships, forming a dynamic interplay of tradition, adaptation, and innovation.

In many indigenous cultures, the collective nature of learning is a key characteristic. Unlike formalized Western educational systems that often emphasize individual achievement, Indigenous pedagogies prioritize communal engagement and collective responsibility. This communal approach ensures that knowledge is transferred and embedded within the community's social fabric. For instance, group rituals, communal storytelling, and cooperative work exemplify how knowledge is shared and reinforced. These practices foster a sense of shared responsibility for maintaining ecological balance, cultural heritage, and social cohesion. Moreover, such methods contribute to the resilience of communities by enabling them to adapt to environmental and social changes while preserving core values and traditions [47], [48].

Cultural pedagogy also highlights the interplay between the tangible and intangible aspects of learning. For example, while skills like plant identification or crafting tools involve practical, hands-on experience, the accompanying stories, myths, and symbolic meanings imbue these practices with cultural significance. This holistic approach ensures that learners acquire technical skills and internalize the values and worldviews underpinning them. The transmission of knowledge about flora and fauna is deeply tied to their cosmological beliefs and cultural identity [49], [50]. In the Amazonian Yanomami culture, medicinal plant knowledge is transmitted through practice and oral traditions emphasizing the spiritual relationships between humans and the natural world [51].

The role of cultural pedagogy extends beyond the preservation of traditional knowledge. It also provides a foundation for developing culturally responsive educational strategies. Recognizing the value of indigenous pedagogies, researchers and educators have increasingly advocated for integrating these approaches into formal education systems. The concept of "funds of knowledge" acknowledges the rich cultural and experiential knowledge that students bring from their communities into the classroom [52]–[54]. By leveraging these cultural resources, educators can create more inclusive and effective learning environments. Similarly, Brayboy and Maughan [55] argue that incorporating Indigenous knowledge systems into mainstream education fosters greater cultural relevance and equity, empowering marginalized communities to assert their identities and worldviews.

Cultural pedagogy also provides valuable insights for addressing contemporary challenges such as biodiversity loss, climate change, and cultural homogenization [56], [57]. By emphasizing the interconnectedness of cultural and ecological systems, this framework advocates preserving biocultural diversity as a key component of sustainability. Studies have shown that communities with strong cultural ties to their environment are likelier to engage in sustainable practices and advocate for conservation efforts [27], [58]–[60]. Furthermore, recognizing cultural pedagogy has policy implications, particularly in education, conservation, and community development. Policies that support the integration of traditional knowledge systems and cultural practices can enhance communities' resilience and adaptive capacity in the face of global challenges [61], [62].

2.2. Ecological Learning Theory

Ecological learning theory, as conceptualized by Lane and further explored by other scholars, emphasizes the critical role of direct interaction with the natural environment in shaping human understanding and the development of practical skills. This theory posits that learning is not a passive process of information absorption but rather an active, dynamic engagement with one’s surroundings. Such interactions enable individuals to form deep, context-specific knowledge that is inherently tied to the ecological realities of their environment.

A central tenet of this theory is the multisensory nature of ecological learning. Identifying medicinal plants in traditional communities goes beyond visual recognition. It often involves tactile exploration, such as feeling the texture of leaves; olfactory analysis, like smelling the plant's aroma; and sometimes even auditory cues, such as the rustling of leaves in the wind or the sound of seeds [63]. These sensory engagements create a rich tapestry of information that reinforces memory and enhances the learner's ability to recall and apply knowledge effectively in various contexts. This multisensory approach deepens the learner's ecological awareness and establishes strong cognitive connections between specific environmental stimuli and their associated knowledge [64], [65].

Ecological learning theory also highlights the situated nature of knowledge. Learning occurs within specific ecological settings where practical skills and cultural practices are intertwined with the local environment. For example, traditional ecological knowledge (TEK) systems, such as those of the Inuit in the Arctic or the Kayapo in the Amazon, are

deeply embedded in the landscapes and ecosystems these communities inhabit. Knowledge of ice formations, animal migrations, or plant cycles is not abstract but is intimately tied to the physical and ecological contexts of these groups. Such knowledge ensures its applicability and adaptability as it evolves in response to changing environmental conditions [60], [66], [67].

Experiential learning, as a core component of ecological learning theory, reinforces the development of practical skills and ecological literacy. It involves direct participation in activities such as farming, hunting, fishing, or foraging, where individuals learn by doing rather than merely observing or theorizing. These activities often integrate traditional methods with ongoing ecological observations, fostering a cycle of learning that adapts to environmental changes while preserving cultural heritage. The Maasai of East Africa acquired their deep knowledge of cattle husbandry and land management through hands-on experience guided by elders. This process transmits technical skills and instills values of stewardship and respect for natural resources [68]–[70].

Ecological learning theory has broader implications for education and sustainability. This approach ensures that knowledge remains practical and adaptable by embedding learning within ecological contexts. It aligns with calls for place-based education, which advocates for curricula grounded in local ecosystems and community needs. Such educational strategies foster a deeper connection between learners and their environments, encouraging sustainable practices and environmental stewardship [71]–[73]. Moreover, integrating ecological learning principles into formal education can bridge traditional and scientific knowledge systems, providing holistic solutions to contemporary environmental challenges [74]–[76].

Ecological learning theory emphasizes the inextricable connection between human learning and the natural world. By emphasizing active engagement, multisensory experiences, and situated knowledge, this theory provides a robust framework for understanding how communities acquire, adapt, and sustain ecological knowledge. Its application extends beyond traditional settings, offering valuable insights for modern education, conservation, and sustainable development.

2.3. Social Learning Theory

Bandura's Social Learning Theory [77] underscores the significant role of observational learning, imitation, and modeling in acquiring new behaviors, skills, and knowledge. This theory posits that individuals do not learn in isolation but rather within a social context where observation of role models, reinforcement, and interaction shape their learning process. According to Bandura [78], cognitive processes such as attention, retention, reproduction, and motivation are integral to observational learning, emphasizing the interplay between the learner and their environment.

In ethno-pedagogy, this theory offers a robust framework for understanding the transmission of indigenous knowledge and practices within communities. Traditional ecological knowledge, encompassing fishing techniques, crafting, and preparing herbal remedies, is often passed down through social interactions involving observation, imitation, and participation. For example, elders in indigenous communities act as practitioners and educators, guiding the younger generation through demonstrations and direct involvement in traditional practices.

Rogoff [79] highlights the importance of guided participation, wherein learners observe and engage in meaningful interactions that integrate them into the community's cultural practices. Wenger's [80] The concept of communities of practice reinforces the idea that learning is a social process embedded in shared activities and mutual engagement, central to the sustainability of ethnobiological knowledge.

Moreover, Bandura's [81] reciprocal determinism—where personal factors, environmental influences, and behaviors continuously interact—sheds light on how ethnobiological practices are preserved and adapted. For instance, as younger generations learn traditional techniques, they may innovate and modify practices in response to contemporary challenges, ensuring both the relevance and survival of indigenous knowledge systems.

Feedback mechanisms also play a crucial role in this learning process. Positive reinforcement, such as recognition from elders or successful outcomes of applied skills, motivates learners to refine and sustain these practices. On the other hand, community rituals and collective activities serve as platforms for transmitting and validating knowledge, aligning with an emphasis on cultural mediation in learning.

Social Learning Theory offers a vital lens for understanding how observation, imitation, and interaction influence the transmission of ethnobiological and cultural knowledge. By embedding learning within the social fabric of communities, this theory explains the persistence of traditional knowledge and highlights its adaptability to evolving environmental and societal needs.

2.4. Cognitive Processes

As introduced by Neisser [82] in his foundational work on cognitive psychology and further expanded by Ross and Revilla-Minaya [83], cognitive theories delve into the mechanisms through which individuals perceive, process, store, and retrieve information. These mental frameworks are crucial for comprehending how knowledge is organized, contextualized, and applied, particularly in domains such as ethnobiology, where knowledge is intricately intertwined with cultural and ecological systems.

In ethnobiological contexts, cognitive processes play a central role in structuring and transmitting knowledge. Indigenous communities often develop local taxonomies—classification systems for plants, animals, and ecological phenomena—that reflect ecological realities, cultural values, and practical needs. The identification of plants is frequently based on observable traits like morphology, habitat, and seasonality, as well as their utilitarian or symbolic roles in the community [84]. This categorization is not arbitrary but emerges from a deep interaction with the environment, guided by practical utility and cultural significance.

Mnemonic devices play a crucial role in preserving and transmitting knowledge across generations. Songs, rhymes, proverbs, and narratives serve as cognitive tools that simplify complex information, ensuring it remains memorable and accessible. These tools are vital in oral cultures, where written records are minimal or absent. For instance, in many Indigenous communities, plant-based medicinal knowledge is often encoded in poetic forms or ritual chants that simultaneously engage memory and reinforce cultural identity [85]. Such methods aid retention and foster collective participation, as these mnemonics are often shared during communal events or rites of passage.

Moreover, the cognitive strategies employed in ethnobiological learning reflect a dynamic interaction between perception and application. Individuals acquire knowledge through direct engagement with their environment—what Gibson [86] termed "affordances"—and subsequently organize them into functional schemas. These flexible schemas enable individuals to adapt their knowledge to new challenges or changing ecological conditions.

The role of narratives and storytelling in ethnobiology extends beyond serving as memory aids; they also provide frameworks for problem-solving and ethical reasoning. For example, traditional tales about the origins of specific plants or animals often encode ecological insights or conservation principles, subtly guiding behavior in ways that sustain local ecosystems. Cognitive theories thus illuminate how knowledge is stored and contextualized for meaningful application.

Cognitive processes provide a crucial foundation for the retention, organization, and transmission of ethnobiological knowledge. This knowledge is preserved, adapted, and rendered actionable through tools like taxonomies, mnemonics, and narratives, ensuring its relevance across generations and in response to ecological or cultural changes. These processes highlight the intersection of cognition, culture, and ecology, underscoring the richness and resilience of indigenous knowledge systems.

2.5. Broader Implications

The ethno-pedagogical module emphasizes the interplay of cultural, ecological, social, and cognitive dimensions in the transmission of knowledge, offering a holistic framework for understanding and sustaining biocultural diversity and ecological resilience. This integrated approach provides significant insights into how communities adapt to and thrive within their environments while preserving their cultural identity.

Recognizing the pedagogical value of traditional knowledge systems can transform education by fostering culturally responsive curricula that bridge Indigenous and scientific knowledge systems. Integration respects the epistemological foundations of Indigenous knowledge while enhancing its relevance in modern educational contexts [27]. Incorporating traditional ecological knowledge (TEK) into science curricula can help students understand ecological processes in ways that are both grounded in cultural context and aligned with scientific principles.

As Sobel [87] and Semken et al. [88] emphasized that place-based education is particularly effective in fostering environmental stewardship. Engaging learners in direct interactions with their local environment fosters a deeper sense of responsibility and connection to ecological systems. For instance, learning modules that involve traditional agricultural practices or biodiversity mapping encourage students to view their surroundings as dynamic learning spaces, thereby enriching their cognitive and emotional engagement with conservation.

Ethno-pedagogy provides a framework for reinforcing community-led conservation initiatives. Conservation strategies can become more sustainable and inclusive by valuing and integrating traditional ecological knowledge. For example, participatory approaches that involve indigenous communities in biodiversity monitoring and resource management are often more effective than top-down interventions. These methods enhance ecological outcomes and empower communities by acknowledging their role as stewards of their environments.

Furthermore, the dynamic interplay between cultural traditions and ecological practices highlights the importance of preserving biocultural diversity. As elaborated by Maffi [27] this concept underscores that cultural and biological diversity are mutually reinforcing and that their preservation is critical for global sustainability. Policies recognizing the symbiosis between cultural and ecological systems can foster resilience against environmental and societal challenges.

The integration of ethno-pedagogy into policy-making has the potential to address global challenges, including biodiversity loss, climate change, and educational inequities. For instance, policies that promote the inclusion of Indigenous knowledge in climate adaptation strategies can lead to more contextually appropriate and practical solutions. Similarly, supporting the preservation of Indigenous languages, as many Traditional Ecological Knowledge (TEK) systems are encoded in local dialects, can further strengthen efforts to safeguard biocultural heritage.

3. STRUCTURAL COMPONENTS

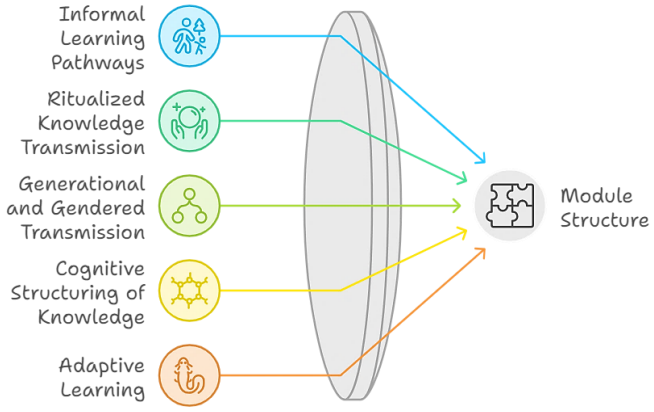

Figure 1. Module Structural Components

In ethno-pedagogy, a module refers to a carefully organized segment of educational content that aims to weave

in the unique cultural heritage, values, and traditional knowledge of a specific ethnic or cultural group. These modules are crafted to enhance cultural awareness and appreciation, foster identity development, and connect learners to meaningful practices of their heritage. We propose that each category presented in the framework of this module can be disaggregated into several key components. Each is briefly explained below through examples.

3.1. Informal Learning Pathways

As codified in the Declaration of Belem, ethnobiologist have, for decades, acknowledged the significance of Indigenous Peoples' environmental knowledge and the role of Indigenous Peoples as stewards of most of the world's biodiversity [89]–[91]. To stimulate curiosity, we use some elements from the cultural iceberg. The observable actions involved in transmitting ethnobiological knowledge, such as observation, participation, and imitation, are part of surface culture. These are the visible, behavioral aspects of how knowledge is passed down in Indigenous peoples and local communities. The underlying values and beliefs that drive the importance of this knowledge transmission process, such as the notion that knowledge is "deeply embedded in daily life," reflect a deep cultural perspective. This refers to the fundamental, often unconscious ways communities value ethnobiological knowledge and its transmission across generations, rooted in long-held beliefs about the relationship between people, nature, and survival.

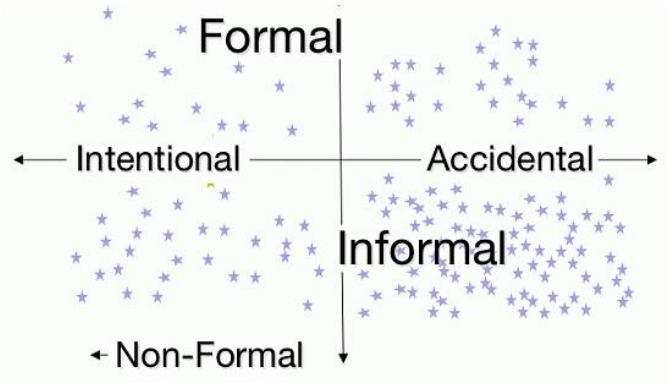

Figure 2. Informal Learning [92].

Informal learning is often experiential and context-specific, relying on non-verbal cues, embodied practices, and direct interaction with the natural world. For instance, children may learn about the medicinal properties of plants by observing their elders' preparations of remedies or participating in foraging activities.

3.2. Ritualized Knowledge Transmission

For this module, we offer a ritualizing component as a response that fully acknowledges the role of rituals and cultural ceremonies in constituting and maintaining communities that are under threat from “new knowledge.” Rituals are part of the specific spiritual or symbolic knowledge that many communities possess about their species, ecosystems, or practices. Ritualized knowledge transmission is significant in cases where knowledge boundaries are deeply ingrained. For example, seasonal ceremonies associated with the planting or harvesting of crops may be designed not only to celebrate abundance but also to convey ecological knowledge about soil fertility, pest management, or plant cycles. Although they may be characterized as fragile or malleable, these traditions are not simple hearsay or personal reminiscence; they are community memories, regularly recounted and periodically verified by knowledgeable elders.

3.3. Generational and Gendered Transmission

Cavalli-Sforza and Feldman [29] describe the transmission of knowledge from parents to their offspring as vertical transmission. This structural component of the proposed module is sensitive to the socio-cultural norms that govern who is permitted to teach and learn certain forms of ethnobiological knowledge. In many societies, knowledge is often gendered within specific domains, such as ethnobotanical knowledge, which is traditionally passed down from mothers to daughters. In contrast, others, such as hunting techniques, are passed down from father to son. Likewise, different stages of life may determine when individuals are introduced to specific types of knowledge, creating a structured learning progression.

3.4. Cognitive Structuring of Knowledge

Across the world, countless examples demonstrate how local communities contribute lessons to the reinvention of cognitive categories for conserving natural resources, memories, identities, and cultural symbols. This process involves the transmission and structuring of knowledge in ways that are deeply rooted in both cultural and ecological contexts. Ethnobiological knowledge is often systematized according to local taxonomies—classifications that reflect the community’s interaction with their environment and are shaped by cultural values, linguistic frameworks, and ecological necessities [93], [94].

Local taxonomies typically organize plants, animals, and ecological phenomena into practical and relevant categories to the community's needs. For instance, folk classifications often include nuanced distinctions between species based on their uses (medicinal, culinary, or spiritual) or ecological roles (such as pollinators or indicators of seasonal changes). These categorizations serve as a practical guide for resource use and a means of preserving cultural heritage and ecological knowledge [95], [96].

Learning and internalizing these cognitive frameworks involves a combination of observational learning, oral transmission, and participation in cultural practices [97]. Knowledge is encoded in memory through direct interaction with the environment and is reinforced through repeated exposure. For example, individuals learn to identify plants or animals by their morphological characteristics, habitats, or the seasons during which they are available. Cognitive psychologists suggest that such knowledge may be stored in hierarchical structures that range from broad categories (e.g.,

trees) to specific species (e.g., mango tree). This hierarchical structuring aids recall and decision-making in practical contexts [98], [99].

Mnemonic devices, such as songs, stories, rhymes, or proverbs, play a crucial role in facilitating the recall and transmission of complex knowledge. In some indigenous communities, stories about the origins of plants and their uses serve as entertainment and a teaching tool. Such devices ensure that ethnobiological knowledge is passed down intergenerationally, even without written records [100], [101]. Furthermore, ethnobiological knowledge is applied through heuristic thinking—simple rules or mental shortcuts that guide decision-making. For instance, farmers may use the appearance of certain animal species as indicators of the best time to plant crops. This practical knowledge is often encoded in rituals or practices that align with ecological cycles, demonstrating an integration of empirical observation and cultural tradition [102], [103].

The proposed ethno-pedagogical module investigates how these cognitive frameworks can be studied, preserved, and integrated into modern educational systems. Educators can design culturally responsive pedagogies that respect and incorporate traditional ecological knowledge by understanding how local knowledge systems function and are transmitted. This approach supports the preservation of cultural heritage and contributes to sustainable resource management and ecological resilience.

3.5. Adaptive Learning

This structural component enables the modification of the knowledge system, ensuring cultural survival and adaptation in response to external changes. As environments change due to external factors (e.g., climate change, globalization), the ethno-pedagogical module also accommodates adaptive learning. Communities may modify their traditional knowledge systems in response to new environmental or social pressures, and this adaptation is often reflected in how knowledge is transmitted. For example, new techniques for water conservation or agricultural innovation may be integrated into existing knowledge frameworks and passed on through revised teaching practices.

4. THEORETICAL IMPLICATIONS

The proposed structured approach provides a comprehensive explanation of knowledge transmission within ethnobiological systems. This approach offers several key theoretical implications that deepen our understanding of cultural resilience, epistemic diversity, and the mechanisms of cross-cultural learning.

4.1. Cultural Resilience

Resilience, a multifaceted concept, is crucial for understanding how communities adapt to environmental and social changes while maintaining cultural integrity. The proposed model emphasizes the processes of learning and transmission, showcasing how communities sustain cultural resilience through the adaptive management of ethnobiological knowledge. By preserving core ethnobiological principles and adapting their applications, communities ensure the survival of biocultural and ecological systems [104], [105].

For instance, communities facing environmental shifts such as climate change or resource depletion often innovate by integrating new knowledge with traditional practices. This blending of traditional and modern approaches creates hybrid systems that are both innovative and deeply rooted in cultural identity [106]–[108]. Agroforestry systems exemplify this adaptation, where traditional ecological knowledge (TEK) informs sustainable land-use practices that buffer against environmental shocks, such as soil erosion and biodiversity loss [109]–[111]. Similarly, Indigenous fire management practices in Australia, rooted in millennia of ecological understanding, have proven effective in mitigating wildfire risks while preserving biodiversity [112].

The resilience of ethnobiological systems is further reinforced by their ability to foster hope and continuity. By linking cultural traditions with future adaptability, these systems demonstrate that cultural heritage can evolve without being eroded. For example, the Kayapó people of the Amazon combine traditional ecological practices with modern technologies, such as GIS mapping, to protect their territories and biodiversity [113]. These cases demonstrate how communities can effectively respond to external pressures while preserving their biocultural diversity.

Moreover, the adaptive strategies within these systems contribute to ecological resilience by promoting sustainable practices attuned to local environmental conditions. Research on Polynesian traditional agriculture highlights how complex knowledge systems enable sustainable food production in fragile island ecosystems [114]. Such examples underscore the importance of preserving and supporting ethnobiological systems as dynamic reservoirs of adaptive strategies.

4.2. Epistemic Diversity

The proposed framework highlights the importance of epistemic diversity—the coexistence of multiple ways of knowing and understanding the world. Ethnobiological knowledge systems are inherently diverse, reflecting the unique cultural values, ecological settings, and social structures of specific communities. Pedagogical strategies such as storytelling, songs, rituals, apprenticeship, and hands-on learning encapsulate this diversity, illustrating distinct epistemological priorities [47], [115].

This epistemic diversity extends beyond academic curiosity, becoming a vital resource for addressing global challenges. The coexistence of diverse knowledge systems offers a broader repertoire of strategies for managing ecological and social challenges. The ritual use of plants in one community may offer pharmacological insights, while another community's ecological management practices can contribute to biodiversity conservation [116], [117]. Such pluralistic approaches can inform more inclusive and sustainable policy-making frameworks.

Integrating traditional and scientific knowledge has already proven effective in various contexts. Indigenous

ecological knowledge has complemented scientific assessments in fisheries management, resulting in more sustainable practices [118]. Recognizing the legitimacy of diverse epistemologies can facilitate collaborative problem-solving and promote the equitable inclusion of marginalized voices in decision-making processes [119].

4.3. Cross-Cultural Comparisons

The modular approach to ethnobiological pedagogy facilitates cross-cultural comparisons, enabling researchers to analyze how knowledge is transmitted, adapted, and retained across diverse contexts. These comparisons reveal both universal patterns and unique adaptations in ethnobiological knowledge systems. For instance, apprenticeship models in one culture may parallel narrative instruction in another, effectively transmitting complex ecological knowledge [36], [120].

Such cross-cultural research also sheds light on the mechanisms that underpin the retention of biocultural diversity. Studies comparing oral traditions across linguistic groups have highlighted the role of language as a repository of ecological knowledge and cultural memory [121]. Indigenous communities in the Amazon use highly specialized vocabulary to describe ecological phenomena, serving as a tool for environmental management and a means of cultural expression [122].

Furthermore, comparative studies underscore the importance of linguistic diversity in preserving biocultural systems. Initiatives documenting endangered languages, such as those supported by UNESCO's Atlas of the World's Languages in Danger, have shown that linguistic erosion often coincides with the loss of critical ecological knowledge [123]. These findings underscore the importance of collaborative efforts to safeguard linguistic and ecological heritage.

5. METHODOLOGICAL CONSIDERATIONS

The proposed module has both theoretical and practical significance, offering a robust framework for understanding the transmission of ethnobiological knowledge within local communities. To operationalize this framework, researchers must adopt interdisciplinary methodologies integrating ethnography, cognitive science, education theory, and ecology [4], [124]. Such an approach enables a nuanced examination of how knowledge is generated, shared, and retained, as well as how it adapts to shifting cultural and environmental contexts.

Ethnographic methods, particularly participant observation, are indispensable for documenting the informal and embodied learning processes within communities. By immersing themselves in daily activities, ceremonies, and rituals, researchers can gain insight into how environments are experienced as meaningful spaces. This methodology enables the documentation of thoughts, emotions, and activities often overlooked in more formalized approaches [125]. Through these immersive experiences, researchers can uncover the implicit teaching methods embedded within cultural practices, including both the symbolic and practical aspects of knowledge transmission.

Cognitive elicitation techniques from anthropology provide additional tools for exploring how individuals mentally organize ethnobiological knowledge. Methods such as free listing, pile sorting, triad tests, and cultural consensus analysis are particularly effective for revealing local taxonomies and individuals' associations between categories [126]–[128]. These techniques allow researchers to map the cognitive frameworks underlying local classifications of plants, animals, and ecological phenomena, illustrating how these frameworks are internalized and transmitted within communities [129], [130].

Studying intergenerational knowledge transmission requires surveys and interviews to examine how ethnobiological knowledge changes across different age groups. Such research investigates whether younger generations retain, adapt, or discard traditional knowledge, providing insights into cultural continuity and change [131], [132]. This approach also helps identify the factors influencing these dynamics, including access to education, environmental changes, and exposure to external cultural influences.

Finally, ecological interaction studies provide a means to observe the application of ethnobiological knowledge in real-world contexts. By examining practices such as hunting, foraging, or farming, researchers can assess how knowledge is practically employed and the decision-making processes that guide these activities [133], [134]. Such studies offer valuable insights into the functional aspects of knowledge transmission, highlighting its adaptive significance and role in sustainable resource management.

The ethno-pedagogical module thus represents a comprehensive framework for studying the transmission of ethnobiological knowledge. By combining theoretical and practical approaches, this framework offers valuable insights into the mechanisms that sustain traditional knowledge systems while also suggesting pathways for their preservation and integration into modern educational and ecological practices. Through interdisciplinary research, it becomes possible to maximize the benefits of this novel framework and contribute to the broader understanding of cultural and ecological sustainability.

6. CONCLUSION

The ethno-pedagogical module offers guidance on maximizing the benefits of this novel and comprehensive framework for studying the transmission of ethnobiological knowledge. There has been much research on knowledge transmission in ethnobiological systems. We hope it will be helpful and inspire more researchers to separate pedagogical processes as a distinct component of ethnobiological systems. We have provided examples where the context of the proposed framework enables researchers to explore social, cognitive, and ecological factors that influence the transmission of knowledge from one generation to the next. The theoretical insights gained from this approach contribute to a deeper understanding of cultural resilience, biocultural

diversity, and the sustainability of traditional ecological knowledge. As the world faces accelerating environmental and cultural change, understanding the mechanisms of knowledge transmission will be crucial for preserving the intricate relationships between people and nature.

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