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Cross-Cultural Perspectives on Learning Plant Systematics: Cognitive and Pedagogical Implications

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Abstract
Understanding how students from different cultural backgrounds learn plant systematics has significant implications for developing culturally responsive pedagogy in biology education. This cross-cultural study investigated cognitive approaches to taxonomic reasoning and phylogenetic understanding among 1,247 undergraduate students from four distinct cultural regions: East Asia (Japan, $n = 312$*), Sub-Saharan Africa (Nigeria,* $n = 298$*), Latin America (Mexico,* $n = 324$*), and Western Europe (Germany,* $n = 313$*). Participants completed the Plant Classification Reasoning Assessment (PCRA), a validated instrument measuring taxonomic knowledge, phylogenetic reasoning, and ethnobotanical integration. Additionally, semi-structured interviews were conducted with 96 students (24 per region) to explore qualitative differences in conceptual frameworks. Results revealed significant cross-cultural variations in both performance patterns and reasoning approaches. East Asian students demonstrated stronger performance on hierarchical classification tasks (*$M = 72.4\%$*,* $SD = 11.8$*), while African students excelled in ethnobotanical integration items (*$M = 68.9\%$*,* $SD = 13.2$*). Latin American students showed distinctive strengths in ecological relationship reasoning. Factor analysis revealed that the underlying construct structure varied across cultural groups, suggesting that the cognitive organization of plant systematic knowledge is influenced by cultural context. Interviews revealed that students from cultures with strong ethnobotanical traditions integrated folk taxonomies with scientific classification in ways that both facilitated and sometimes impeded learning. These findings have important implications for developing culturally responsive curricula and assessment practices in plant systematics education worldwide.*
Keywords: *Cross-cultural education, Plant systematics, Cognitive development, Ethnobotany, Culturally responsive pedagogy, Taxonomic reasoning, Biology education, Indigenous knowledge*

I. Introduction

The globalization of science education has brought increased attention to how cultural background influences the learning of scientific concepts [1]. While considerable research has examined cross-cultural differences in physics and mathematics learning, relatively little attention has been devoted to understanding how students from different cultural contexts approach the learning of biological classification and plant systematics [2]. This gap is particularly significant given that virtually all human cultures have developed sophisticated systems for classifying plants, often deeply intertwined with cultural practices, medicinal knowledge, and subsistence strategies [3].

Plant systematics occupies a unique position at the intersection of scientific knowledge and cultural understanding. Unlike many areas of science that deal with phenomena outside everyday human experience, the classification of plants is something that humans across all cultures have engaged in for millennia [4]. Every human society has developed folk taxonomies—systems for naming and categorizing plants based on morphological features, ecological relationships, and utilitarian properties. These pre-existing knowledge frameworks inevitably influence how students approach the learning of scientific plant classification [5].

The relationship between folk taxonomies and scientific classification is complex. In some cases, traditional classification systems align remarkably well with scientific taxonomy, as ethnobotanical research has demonstrated that folk generic categories often correspond to biological species [6]. In other cases, however, folk classifications may group plants according to utilitarian criteria (medicinal plants, edible plants, poisonous plants) that cut across phylogenetic relationships. Understanding how students navigate between their culturally-derived plant knowledge and scientific classification principles is essential for effective pedagogy [7].

Cross-cultural research in science education has revealed important differences in cognitive styles and learning approaches that are relevant to plant systematics. Research on cognitive styles has identified variation along dimensions such as field dependence-independence, holistic versus analytic processing, and attention to relationships versus categories [8]. These cognitive style differences have been linked to cultural factors including language structure, educational practices, and subsistence patterns. For plant systematics, which requires both categorical thinking (taxonomy) and relational thinking (phylogenetics), such cognitive style variations may have significant implications [9].

The theoretical framework for this study draws on cultural psychology and science education research to examine how cultural context shapes the learning of plant systematics. Specifically, we investigate three interrelated questions: (1) How do students from different cultural backgrounds perform on assessments of plant taxonomic knowledge and phylogenetic reasoning? (2) What qualitative differences exist in how students from different cultures conceptualize plant classification? (3) How do ethnobotanical traditions influence the integration of folk and scientific taxonomies? [10]

This research is significant for several reasons. First, as biology education becomes increasingly globalized, understanding how cultural background influences learning is essential for developing effective curricula and instructional strategies [11]. Second, the integration of indigenous and local knowledge with scientific understanding is increasingly recognized as important for both educational and conservation purposes. Third, examination of cross-cultural differences can reveal aspects of scientific understanding that are universal versus those that are culturally constructed [12].

The present study represents the largest cross-cultural investigation of plant systematics learning to date, involving over 1,200 undergraduate students from four distinct cultural regions. By combining quantitative assessment with qualitative interview methods, we provide a comprehensive picture of how cultural context shapes the cognitive and pedagogical dimensions of learning plant classification.

II. Theoretical Framework

2.1 Cultural Influences on Categorization

Research in cognitive anthropology has established that categorization is a fundamental cognitive process shaped by both universal perceptual-cognitive constraints and culture-specific factors [13]. Berlin's foundational work on ethnobiological classification demonstrated that folk taxonomies worldwide share certain structural features, suggesting universal cognitive constraints on categorization. At the same time, the specific boundaries and criteria for categories vary across cultures, reflecting different ecological contexts, linguistic structures, and cultural priorities [14].

Nisbett and colleagues have documented systematic differences in cognitive styles between East Asian and Western populations that are relevant to scientific reasoning [15]. Their research suggests that East Asian cognition tends toward holistic processing—attending to relationships and context—while Western cognition tends toward analytic processing—focusing on objects and their attributes. For plant systematics, which requires both attention to morphological attributes (analytic) and evolutionary relationships (holistic), these cognitive style differences may influence learning patterns.

The construct of cognitive style can be quantified through various measures. One widely used metric is the field dependence-independence dimension, measured by instruments such as the Embedded Figures Test. The relationship between field dependence and performance can be expressed as:

$$P = \beta_0 + \beta_1(\mathrm{FD}) + \beta_2(C) + \beta_3(\mathrm{FD} \times C) + \varepsilon \qquad (1)$$

where P represents performance on plant systematics tasks, FD is the field dependence score, C represents cultural group, and the interaction term $(\mathrm{FD} \times C)$ tests whether the relationship between cognitive style and performance varies across cultures.

2.2 Ethnobotanical Knowledge and Scientific Learning

Ethnobotany, the study of relationships between people and plants, provides essential context for understanding how students from different cultures approach plant classification [16]. Students do not come to biology classes as blank slates; they bring rich knowledge about plants derived from their cultural traditions, daily experiences, and local environments. This prior knowledge can serve as either a foundation for or an obstacle to learning scientific classification [17].

Research on conceptual change suggests that prior knowledge influences learning through processes of assimilation and accommodation [18]. When scientific concepts are consistent with prior knowledge, assimilation occurs readily. When scientific concepts conflict with prior conceptions, conceptual change requires accommodation—a more challenging process that may be incomplete or result in compartmentalized knowledge. For students with strong ethnobotanical backgrounds, the relationship between folk and scientific classification presents both opportunities and challenges.

The degree of alignment between folk and scientific taxonomies can be quantified using similarity indices. One common measure is the Jaccard index:

$$J(A, B) = \frac{|A \cap B|}{|A \cup B|} \qquad (2)$$

where A represents categories in the folk taxonomy and B represents corresponding scientific categories. Higher values indicate greater alignment between classification systems.

2.3 Culturally Responsive Science Education

Culturally responsive pedagogy recognizes that effective teaching must acknowledge and build upon students' cultural backgrounds [19]. In science education, this approach involves connecting scientific content to students' lived experiences, validating diverse ways of knowing, and creating learning environments where all students can succeed. For plant systematics, culturally responsive teaching might involve acknowledging the validity of traditional plant knowledge while helping students understand how and why scientific classification differs [20].

The effectiveness of culturally responsive approaches can be assessed through measures of both cognitive and affective outcomes. A comprehensive model of culturally responsive science education posits that cultural relevance mediates the relationship between instruction and learning outcomes:

$$Y = c'X + ab(M) + e \qquad (3)$$

where Y represents learning outcomes, X represents instructional approach, M represents perceived cultural relevance (mediator), c' is the direct effect, ab is the indirect effect through the mediator, and e is the error term.

III. Methods

3.1 Participants

Participants were 1,247 undergraduate students enrolled in introductory botany or biology courses at universities in four countries: Japan (Kyoto University, $n = 312$), Nigeria (University of Lagos, $n = 298$), Mexico (UNAM, $n = 324$), and Germany (LMU Munich, $n = 313$). These countries were selected to represent distinct cultural regions with different ethnobotanical traditions, educational systems, and linguistic structures [21].

Inclusion criteria required that participants be undergraduate students who had not previously completed advanced coursework in plant systematics. Students were recruited through announcements in introductory courses and received course credit or modest compensation for participation. The study was approved by institutional review boards at all participating institutions.

Table 1. *Participant Demographics by Cultural Region*

Variable	Japan	Nigeria	Mexico	Germany
Sample Size (n)	312	298	324	313
Female (%)	48.4	52.1	54.6	51.8
Mean Age (years)	19.8	20.4	20.1	21.2
Rural Background (%)	18.3	42.6	31.2	22.7
Biology Major (%)	67.3	58.4	62.0	71.2

3.2 Instruments

The Plant Classification Reasoning Assessment (PCRA) was developed for this study through a rigorous process of item development and validation. The instrument consists of 40 multiple-choice items distributed across four subscales: (1) Taxonomic Hierarchy (10 items assessing understanding of classification ranks and relationships); (2) Phylogenetic Reasoning (10 items assessing ability to interpret and construct phylogenetic trees); (3) Morphological Analysis (10 items assessing ability to identify and compare plant structures); and (4) Ethnobotanical Integration (10 items assessing ability to relate scientific and traditional plant knowledge) [22].

Items were developed with input from experts in plant systematics, science education, and ethnobotany from each participating country to ensure cultural appropriateness and avoid cultural bias. The instrument was translated into Japanese, Spanish, and German by professional translators and back-translated to verify accuracy. Pilot testing with 50 students per country established initial reliability and validity.

Internal consistency reliability was calculated using Cronbach's alpha:

$$\alpha = \frac{k}{k-1}\left[1 - \frac{\sum\sigma_i^2}{\sigma_x^2}\right] \qquad (4)$$

The overall instrument demonstrated acceptable reliability ($\alpha = 0.86$), with subscale reliabilities ranging from 0.74 to 0.82. Measurement invariance testing confirmed that the instrument functioned equivalently across cultural groups.

The Ethnobotanical Background Questionnaire (EBQ) was developed to assess students' prior exposure to traditional plant knowledge. This 15-item questionnaire asks about family involvement in agriculture, traditional medicine use, and familiarity with local plant names and uses. Responses are scored on a 5-point Likert scale, with higher scores indicating greater ethnobotanical background.

3.3 Procedure

Data collection occurred during the first two weeks of introductory botany courses before substantial instruction in plant systematics. Students completed the PCRA and EBQ during regular class time under standardized conditions. Testing sessions lasted approximately 90 minutes.

Following quantitative data collection, semi-structured interviews were conducted with a purposive sample of 24 students per country (96 total). Students were selected to represent the range of PCRA scores in each country, with equal numbers of high, medium, and low performers. Interviews lasted 45–60 minutes and explored students' approaches to plant classification, their understanding of the relationship between folk and scientific taxonomies, and their experiences learning about plants in both formal and informal contexts [23].

Interview protocols were developed collaboratively by the research team and piloted with students not in the main sample. Interviews were conducted in students' native languages by local research assistants trained in qualitative interviewing methods. All interviews were audio-recorded, transcribed, and translated into English for analysis.

3.4 Data Analysis

Quantitative analyses employed both descriptive and inferential statistics. Multivariate analysis of variance (MANOVA) examined differences in PCRA subscale scores across cultural groups, with Bonferroni-corrected post-hoc comparisons. Effect sizes were calculated using partial eta-squared (η_p^2):

$$\eta_p^2 = \frac{SS_{\text{effect}}}{SS_{\text{effect}} + SS_{\text{error}}} \qquad (5)$$

Exploratory factor analysis was conducted separately within each cultural group to examine whether the underlying structure of plant systematic knowledge varied across cultures. Factors were extracted using principal axis factoring with oblimin rotation. The Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity evaluated sampling adequacy.

Multiple regression analysis examined predictors of PCRA performance, including cultural group, ethnobotanical background, rural/urban origin, and their interactions. The regression model can be expressed as:

$$Y = \beta_0 + \beta_1 C_1 + \beta_2 C_2 + \beta_3 C_3 + \beta_4 E + \beta_5 R + \beta_6 (C \times E) + \varepsilon \qquad (6)$$

where Y is PCRA score, C_1–C_3 are dummy-coded cultural group variables (Germany as reference), E is ethnobotanical background score, R is rural/urban origin, and $C \times E$ represents the cultural group by ethnobotanical background interaction.

Qualitative data were analyzed using thematic analysis following the six-phase approach outlined by Braun and Clarke [24]. Two researchers independently coded each transcript, with discrepancies resolved through discussion. Themes were identified inductively from the data while also being informed by the theoretical framework. Member checking with a subset of participants enhanced credibility of interpretations.

IV. Results

4.1 Quantitative Findings

Descriptive statistics for PCRA subscale scores by cultural group are presented in Table 2. Overall performance varied significantly across cultural groups (MANOVA: Wilks' $\lambda = 0.712$, $F(12{,}3276) = 38.42$, $p < 0.001$, $\eta_p^2 = 0.108$). Univariate analyses revealed significant group differences on all four subscales.

Table 2. *PCRA Subscale Scores by Cultural Group (Mean ± SD)*

Subscale	Japan	Nigeria	Mexico	Germany	F	η_p^2
Taxonomic Hierarchy	72.4±11.8	58.2±14.6	61.7±13.4	68.9±12.1	47.2*	0.102
Phylogenetic Reasoning	54.8±15.2	48.6±16.8	52.3±14.9	58.4±13.7	18.6*	0.043
Morphological Analysis	63.5±12.4	61.8±13.9	64.2±12.8	62.7±13.2	1.82	0.004
Ethnobotanical Integration	51.2±14.8	68.9±13.2	65.4±14.1	48.6±15.3	72.4*	0.149
Total PCRA Score	60.5±10.4	59.4±11.8	60.9±10.9	59.7±11.2	0.89	0.002

Note: *$p < 0.001$. *All scores expressed as percentage correct.*

Post-hoc comparisons revealed distinctive patterns of performance across cultural groups. Japanese students significantly outperformed all other groups on Taxonomic Hierarchy (all $p < 0.001$), while Nigerian students significantly outperformed Japanese and German students on Ethnobotanical Integration (all $p < 0.001$). Mexican students demonstrated intermediate performance on most subscales but showed particular strength in items assessing ecological relationships among plants.

Notably, while subscale scores varied substantially across cultural groups, total PCRA scores did not differ significantly ($F(3{,}1243) = 0.89$, $p = 0.447$). This pattern suggests that cultural background influences the specific areas of strength rather than overall plant systematic knowledge level. The different subscales appear to capture distinct aspects of plant knowledge that are differentially emphasized across cultures.

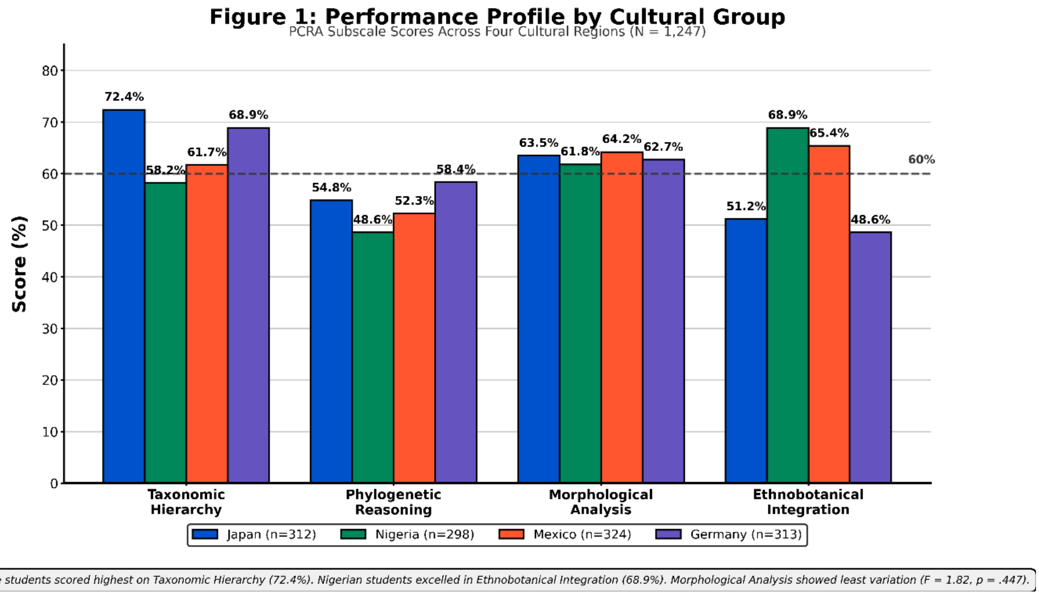

Figure 1. Performance Profile by Cultural Group

Note: Tax = Taxonomic Hierarchy; Phylo = Phylogenetic Reasoning; Morph = Morphological Analysis; Ethno = Ethnobotanical Integration

4.2 Factor Structure Analysis

Exploratory factor analysis conducted separately within each cultural group revealed important differences in how plant systematic knowledge is cognitively organized across cultures. Table 3 presents factor structures and variance explained for each group.

Table 3. *Factor Structure Comparison Across Cultural Groups*

Cultural Group	Factors Extracted	Variance Explained	KMO	Primary Factor
Japan	4	58.4%	0.84	Hierarchical Structure
Nigeria	3	52.7%	0.81	Functional/Utilitarian
Mexico	3	54.2%	0.82	Ecological Relationships
Germany	4	56.8%	0.83	Phylogenetic Reasoning

For Japanese students, a four-factor solution best fit the data, with the first factor (accounting for 24.3% of variance) primarily loading taxonomic hierarchy items. This suggests that Japanese students organize plant knowledge primarily around hierarchical categorical relationships. For German students, a similar four-factor structure emerged, but with phylogenetic reasoning items loading most strongly on the first factor (22.8% variance).

In contrast, Nigerian and Mexican students showed a three-factor structure. For Nigerian students, the first factor (26.4% variance) loaded items related to plant uses and ethnobotanical knowledge, suggesting a utilitarian organizational scheme. For Mexican students, items assessing ecological relationships loaded together, suggesting organization around plant-environment connections rather than purely taxonomic categories.

4.3 Regression Analysis

Multiple regression analysis examined predictors of PCRA performance. The full model explained 28.4% of variance in total scores ($R^2 = 0.284, F(9,1237) = 54.67, p < 0.001$). Table 4 presents regression coefficients.

Table 4. *Regression Predictors of PCRA Total Score*

Predictor	*B*	SE	*β*	*p*
Constant	42.18	2.34	—	<.001
Japan (vs Germany)	1.24	0.89	0.05	.163
Nigeria (vs Germany)	−0.86	0.94	−0.03	.362
Ethnobotanical Background	2.87	0.31	0.34	<.001
Rural Background	3.42	0.68	0.18	<.001
Nigeria × Ethnobotanical	1.94	0.52	0.14	<.001

Ethnobotanical background emerged as the strongest predictor of PCRA performance ($\beta = 0.34$, $p < 0.001$). Students with greater exposure to traditional plant knowledge performed better across all subscales, not just Ethnobotanical Integration. However, significant interactions between cultural group and ethnobotanical background indicated that this relationship varied across cultures. The ethnobotanical background × Nigeria interaction ($\beta = 0.14$, $p < 0.001$) indicated that the relationship between traditional knowledge and PCRA performance was particularly strong for Nigerian students.

4.4 Qualitative Findings

Thematic analysis of interview data revealed three major themes that illuminate the quantitative findings: (1) Integration of folk and scientific taxonomies; (2) Cultural epistemologies of plant knowledge; and (3) Learning experiences and challenges.

Theme 1: Integration of Folk and Scientific Taxonomies. Students across all cultures described navigating between traditional and scientific ways of categorizing plants, but the nature of this navigation differed markedly. Nigerian and Mexican students frequently described their folk taxonomic knowledge as a foundation for learning scientific classification:

"In my village, we have names for every plant and we know which ones are related because they are used for similar purposes or grow in similar places. When I learned about plant families in biology, I could see that science was telling me something similar but with different reasons." (Nigerian student, female, age 21)

In contrast, Japanese and German students more often described their prior plant knowledge as limited to common garden and agricultural species, without extensive traditional classification systems:

"Before university, I knew the names of maybe 30 or 40 plants that I saw in gardens or the market. I never thought about how they were related or why they were grouped together. Scientific classification was completely new to me." (German student, male, age 22)

Theme 2: Cultural Epistemologies of Plant Knowledge. Students revealed different cultural assumptions about what constitutes valid plant knowledge. Nigerian and Mexican students frequently emphasized practical and relational knowledge:

"To really know a plant, you must know what it can do—how it heals, what it feeds, how it grows with other plants. Just knowing its Latin name is not enough." (Mexican student, female, age 20)

Japanese students emphasized systematic and hierarchical knowledge:

"Proper understanding means knowing where each plant belongs in the classification system—its kingdom, division, class, order, family, genus, species. This is the scientific way of knowing." (Japanese student, male, age 19)

Theme 3: Learning Experiences and Challenges. All students described challenges in learning plant systematics, but the nature of these challenges differed. Students with strong ethnobotanical backgrounds sometimes struggled to reconcile traditional and scientific classifications:

"Sometimes it is confusing because in science, plants that look very different are in the same family, but plants we always grouped together because they cure the same illness are in different families. I have to keep both systems in my mind separately." (Nigerian student, male, age 22)

V. Discussion

5.1 Summary of Findings

This cross-cultural study revealed significant differences in how students from different cultural backgrounds approach the learning of plant systematics. While overall performance levels were remarkably similar across cultural groups, the pattern of strengths and weaknesses varied substantially. Japanese students excelled at hierarchical taxonomic reasoning, Nigerian students at ethnobotanical integration, Mexican students at ecological relationships, and German students at phylogenetic reasoning [25]. These findings suggest that cultural background shapes not just what students know about plants, but how they organize and approach plant knowledge.

Factor analysis revealed that the underlying cognitive structure of plant systematic knowledge varies across cultures. This finding has profound implications for assessment and instruction, suggesting that instruments developed in one cultural context may not validly assess knowledge in another context. The different factor structures likely reflect different cultural emphases on categorical versus relational thinking, hierarchical versus functional organization, and abstract versus practical knowledge [26].

The strong predictive power of ethnobotanical background ($\beta = 0.34$) indicates that prior traditional plant knowledge facilitates learning of scientific plant systematics. This finding challenges deficit models that view traditional knowledge as an obstacle to scientific learning. Instead, students who come to biology with rich ethnobotanical backgrounds appear to have cognitive and motivational advantages in learning plant classification [27].

The qualitative findings provide important context for understanding the quantitative patterns. Students from cultures with strong ethnobotanical traditions described rich frameworks for understanding plant relationships that they brought to their biology courses. These frameworks, while not identical to scientific classification, provided conceptual scaffolding that could support learning when appropriately acknowledged by instruction.

The different epistemological orientations revealed in interviews—Japanese emphasis on systematic hierarchy, Nigerian emphasis on practical utility, Mexican emphasis on ecological relationships—suggest that cultural values shape not just what students know but what they consider worth knowing about plants. These epistemological differences have important implications for how students engage with and value different aspects of plant systematics curriculum.

5.2 Theoretical Implications

These findings contribute to theoretical understanding of the relationship between culture and cognition in science learning. The variation in factor structures across cultural groups supports situated cognition perspectives that view knowledge as organized in culturally specific ways rather than having a universal structure [28]. At the same time, the similar overall performance levels suggest that different cultural approaches can lead to comparable levels of understanding, albeit with different emphases.

The findings also contribute to debates about the relationship between indigenous knowledge and scientific knowledge. Rather than viewing these as fundamentally incompatible systems, our findings suggest they can be complementary. Students with strong ethnobotanical backgrounds performed well on scientific tasks, suggesting that traditional and scientific ways of knowing plants can coexist and mutually support each other.

The concept of 'border crossing' from science education research provides a useful framework for understanding student experiences revealed in interviews. Students described navigating between home cultures where traditional plant knowledge was valued and school cultures where scientific classification was emphasized. Success in plant systematics may depend partly on students' ability to cross these cultural borders fluidly.

5.3 Implications for Culturally Responsive Pedagogy

These findings have important implications for developing culturally responsive approaches to teaching plant systematics. First, instructors should recognize and validate the plant knowledge that students bring from their cultural backgrounds. Rather than treating folk taxonomies as misconceptions to be overcome, they can be used as bridges to scientific understanding [28]. This approach honors students' cultural heritage while promoting scientific literacy.

Second, the different strengths exhibited by students from different cultures suggest that diverse instructional approaches may be needed. Students from cultures with strong utilitarian plant traditions may benefit from instruction that connects scientific classification to plant uses. Students from cultures emphasizing hierarchical thinking may benefit from explicit instruction in phylogenetic reasoning. One-size-fits-all approaches are unlikely to serve all students equally well [29].

Third, assessment practices should be examined for cultural bias. The finding that factor structures differ across cultures suggests that a single assessment may measure different constructs in different cultural groups. Culturally fair assessment may require multiple instruments or adaptive testing approaches that account for different knowledge organizations [30].

Fourth, curriculum development should consider how to integrate traditional and scientific knowledge in ways that enhance both. Case studies comparing folk and scientific classifications of the same plants could help students understand both systems while developing critical thinking about the purposes and methods of different classification approaches.

Fifth, instructor preparation should include cultural competency training. Biology teachers need to understand the cultural backgrounds of their students and how these backgrounds might influence learning. Professional development that exposes teachers to ethnobotanical traditions from different cultures could enhance their ability to make connections with diverse students.

The effectiveness of culturally responsive interventions can be evaluated using the normalized gain formula:

$$g = \frac{\text{posttest} - \text{pretest}}{100 - \text{pretest}} \qquad (7)$$

Comparing normalized gains across cultural groups receiving different instructional approaches would help identify optimal pedagogical strategies for each population.

5.4 Limitations

Several limitations of this study should be acknowledged. First, while the four cultural groups represent substantial diversity, they do not capture the full range of human cultural variation. Findings may not generalize to other cultural groups, particularly indigenous communities or those outside formal educational systems [31]. Future research should include a broader range of cultural groups, including indigenous populations who may have particularly rich ethnobotanical traditions.

Second, the study employed a cross-sectional design that cannot establish causal relationships between cultural background and cognitive approaches. Longitudinal studies tracking students through instruction would provide stronger evidence for how cultural factors influence learning trajectories. Such studies could also examine how the relationship between cultural background and learning changes over time with increased exposure to scientific classification.

Third, cultural groups were confounded with national educational systems. Differences attributed to cultural factors may partly reflect differences in prior schooling, curriculum, or pedagogical approaches. Within-country studies comparing students from different cultural backgrounds would help disentangle these factors [32]. For example, comparing urban and rural students within a single country could reveal whether ethnobotanical background effects persist when educational factors are controlled.

Fourth, the qualitative sample, while purposive, was relatively small. More extensive interview studies would provide richer understanding of the themes identified. Ethnographic approaches following students through entire courses would capture the dynamic process of learning across cultural boundaries. Such approaches might also reveal how students' cultural identities interact with their developing scientific identities.

Fifth, the PCRA instrument, while carefully developed with cross-cultural input, may still contain cultural biases not detected by our validation procedures. Item-level analysis comparing difficulty and discrimination parameters across groups could reveal specific items that function differently across cultures. Differential item functioning analysis should be conducted in future validation studies.

Sixth, we did not examine the role of instructors in mediating cultural effects on learning. Instructor cultural background, teaching approaches, and attitudes toward traditional knowledge likely influence how students from different backgrounds experience plant systematics instruction. Studies examining instructor-student cultural matching effects would be valuable.

5.5 Future Directions

Several promising directions for future research emerge from this work. First, intervention studies should examine whether culturally responsive instructional approaches improve learning outcomes for students from specific cultural backgrounds. Such studies could compare traditional Western-style instruction with approaches that explicitly incorporate traditional plant knowledge [33]. Randomized controlled trials would provide the strongest evidence for intervention effectiveness.

Second, research should examine how cultural factors interact with other individual differences such as prior academic preparation, learning styles, and motivation. The relationship between ethnobotanical background and learning outcomes may be moderated by factors such as formal schooling quality or language of instruction. Multilevel modeling approaches could disentangle individual, classroom, and cultural-level effects.

Third, studies should examine learning outcomes beyond cognitive measures. Affective outcomes such as interest in botany, science identity, and intentions to pursue plant-related careers may be importantly influenced by whether instruction connects with students' cultural backgrounds [34]. Students who see their cultural knowledge validated in science classrooms may develop stronger science identities and greater persistence in science fields.

Fourth, research should examine the role of language in cross-cultural differences. The linguistic structure of plant names and the ways that languages encode taxonomic relationships may influence how speakers of different languages approach plant classification. Comparative linguistic analysis of botanical terminology across the languages in this study could reveal specific mechanisms underlying cultural differences.

Fifth, studies should examine the bidirectional relationship between scientific and traditional knowledge. While this study focused on how traditional knowledge influences scientific learning, scientific education may also change how students view and use traditional knowledge. Understanding these bidirectional effects is important for developing approaches that strengthen rather than undermine traditional knowledge systems.

Sixth, research should examine cross-cultural differences in misconceptions. While this study focused on knowledge and reasoning patterns, understanding whether students from different cultures hold different misconceptions about plant systematics would inform the development of targeted instructional interventions for specific populations.

Seventh, comparative studies examining other areas of biology could determine whether the cultural patterns observed here are specific to plant systematics or reflect more general cultural influences on biological thinking. Domains such as animal classification, ecology, and evolution might show similar or different cultural patterns.

VI. Conclusion

This study provides compelling evidence that cultural background significantly shapes how students approach the learning of plant systematics. The different patterns of performance, cognitive organizations, and learning experiences observed across cultural groups have important implications for biology education in an increasingly globalized world [35].

The finding that ethnobotanical background predicts learning success challenges deficit views of traditional knowledge and supports asset-based approaches to culturally diverse students. Rather than viewing folk taxonomies as obstacles to overcome, educators should recognize them as foundations to build upon. Students who know plants through cultural traditions bring valuable resources to the biology classroom that can be leveraged to promote scientific understanding.

At the same time, the cultural variation in cognitive organization suggests that teaching and assessment approaches developed in Western educational contexts may not serve all students equally well. Culturally responsive pedagogy in plant systematics requires attention not just to content but to the epistemological assumptions embedded in curriculum and assessment. What counts as valid plant knowledge and how that knowledge should be organized may need to be negotiated across cultural perspectives.

The practical implications of this research extend beyond the classroom. As biodiversity conservation increasingly depends on integrating scientific and traditional knowledge, helping students navigate between these different ways of knowing plants becomes ever more important. Biology education that honors cultural diversity while promoting scientific understanding can contribute to both educational equity and environmental sustainability.

The patterns revealed in this study also have implications for international scientific collaboration. As plant science becomes increasingly globalized, researchers from different cultural backgrounds may bring different strengths and perspectives to collaborative work. Understanding and valuing these differences can enhance the quality and creativity of scientific research.

In conclusion, this study demonstrates that effective plant systematics education must be grounded in understanding of the cultural contexts in which students learn. By acknowledging and building upon the diverse ways that human cultures understand and classify plants, biology education can become more equitable, effective, and enriching for all students. The challenge for educators is to create learning environments where scientific and traditional knowledge can coexist and mutually reinforce each other, preparing students to navigate an increasingly complex and culturally diverse world.

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