

Indigenous Counting Systems of India and Their Impact on Numerical Cognition

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Abstract

This article explores the diversity of indigenous counting systems across India and their profound impact on numerical cognition. By examining ancient and modern counting methods from various tribal and regional communities across the nation, we analyse how these systems influence mathematical thinking, problem-solving abilities, and spatial reasoning. This research highlights the cultural and cognitive significance of these systems, their alignment with the historical development of Indian mathematics, and their potential applications in modern education. Through comprehensive analysis of numerical representations, base systems, and cultural contexts, we illustrate how indigenous knowledge systems offer valuable insights into alternative approaches to mathematical understanding.

Palavras-chave: Cognitive Impact of Numeration, Cultural Significance of Numeration, Ethnomathematics, Indigenous Counting Systems, Numerical Cognition.

Sistemas de Contagem Indígenas da Índia e seu Impacto na Cognição Numérica

Resumo

Este artigo explora a diversidade dos sistemas de contagem indígenas na Índia e seu profundo impacto na cognição numérica. Ao examinar os métodos de contagem antigos e modernos de diversas comunidades tribais e regionais em todo o país, analisamos como esses sistemas influenciam o pensamento matemático, a capacidade de resolução de problemas e o raciocínio espacial. Esta pesquisa destaca a importância cultural e cognitiva desses sistemas, a sua relação com o desenvolvimento histórico da matemática indiana e as suas potenciais aplicações na educação moderna. Por meio de uma análise abrangente das representações numéricas, sistemas de base e contextos culturais, ilustramos como os sistemas de conhecimento indígena oferecem perspectivas valiosas para as abordagens alternativas à compreensão matemática.

Palavras chave: Impacto Cognitivo da Numeração, Significado Cultural da Numeração, Etnomatemática, Sistemas de Contagem Indígenas, Cognição numérica.

Sistemas de Conteo Indígenas de la India y su Impacto en la Cognición Numérica

Resumen

Este artículo explora la diversidad de los sistemas de conteo indígenas en toda la India y su profundo impacto en la cognición numérica. Al examinar los métodos de conteo antiguos y modernos de diversas comunidades tribales y regionales del país, analizamos cómo estos sistemas influyen en el pensamiento matemático, las habilidades para la resolución de problemas y el razonamiento espacial. Esta investigación destaca la importancia cultural y cognitiva de estos sistemas, su relación con el desarrollo histórico de las matemáticas en la India y sus posibles aplicaciones en la educación moderna. A través de un análisis exhaustivo de las representaciones numéricas, los sistemas de base y los contextos culturales, ilustramos cómo los sistemas de conocimiento indígena ofrecen perspectivas valiosas sobre enfoques alternativos para la comprensión matemática.

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Palabras clave: Impacto Cognitivo de la Numeración, Importancia Cultural de la Numeración, Etnomatemáticas, Sistemas de Conteo Indígenas, Cognición Numérica.

INITIAL CONSIDERATIONS

The Indian subcontinent hosts an extraordinary diversity of indigenous communities, each with unique cultural practices, including distinctive counting systems and numerical concepts. These systems, developed over millennia, represent valuable cultural heritage and offer profound insights into human cognition and mathematical development. While modern standardized numeration based on Indo-Arabic numerals has become ubiquitous, indigenous counting methods persist in various communities and continue to shape cognitive processes related to quantity, measurement, and calculation.

From an ethnomathematical perspective each culture develops ways, styles, and techniques for doing things as well as responses to the search for explanations and the quest for understanding and learning, or essentially how and why we do things. Early attempts to explain and understand this phenomenon led to the search for origins, which led to myths. These attempts were organized as systems of knowledge and religions (Rosa & Orey 2011).

The attempts to explain and understand mathematical knowings and doings developed by members of distinct cultures rely on deep and sensitive observation, comparison, classification, evaluation, quantification, measurement, counting systems, representation, inference, and modelling, which are steps in the generation of distinct mathematical knowledge developed throughout history (Rosa & Orey, 2011).

According to this perspective, India's mathematical traditions date back to the Vedas, Śūlbasūtras, and the works of scholars like Āryabhaṭa, Brahmagupta, and Bhāskarācārya, who described significant mathematical principles. One of the most major achievements was the creation of the decimal place-value system, which transformed numerical notation worldwide. This system, which serves as the foundation for the present number system, first appeared in India about the 5th century CE and was fully established by the time of Brahmagupta (598–668).

Parallel to these documented traditions, numerous indigenous communities developed their own numerical systems adapted to their ecological, economic, and cultural contexts. These systems were deeply embedded in the linguistic and cultural practices of various regions, featuring unique characteristics that reflected local worldviews and practical needs. For example, Tamil, Malayalam, and many tribal languages developed distinctive number words and counting methods that differed from the Sanskrit-based systems.

It is important to state here that for many years, linguists recorded counting systems developed by members of diverse cultures whose languages they were studying and learning (Pumuge, 1975, Lynch, 1977, Ross, 1988), as well as anthropologists were incorpora-

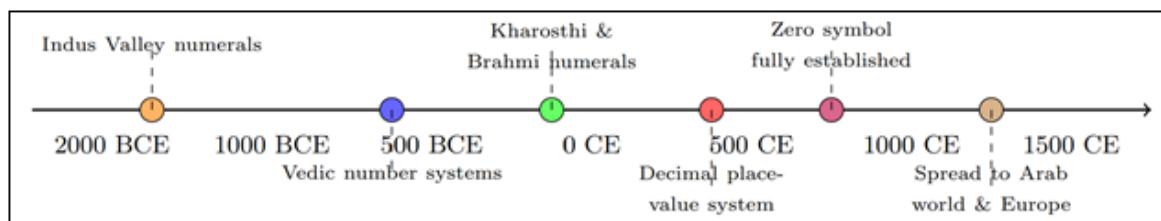
ting counting into the various daily activities of members of distinct cultures they observed (Strathern, 1977) while cognitive and developmental psychologists such as Saxe (1979) were considering how cultural context influenced concepts regarding to the development of counting systems.

In this regard, Owens and Muke (2020) argued about the importance of finding out about how members of distinct cultural groups develop their holistic understanding of numbers and how this:

(...) has involved analysis of the types of counting but also how counting related to the rest of their cultural relationships. There is some surprising evidence of diversity of number systems, longevity of the systems, and the interplay with cultural practices that begs respect for Indigenous cultures” (p. 1).

The evolution of counting systems in India spans thousands of years, shaped by both formal mathematical developments and indigenous traditions. Understanding these systems provides valuable insight into the foundations of numerical cognition and their impact on global mathematics. The following timeline highlights key milestones in this historical progression, highlighting how numerical concepts evolved across different Periods. Figure 1 shows the timeline of counting systems in ancient India.

Figure 1 - *Timeline of Counting Systems in Ancient India*



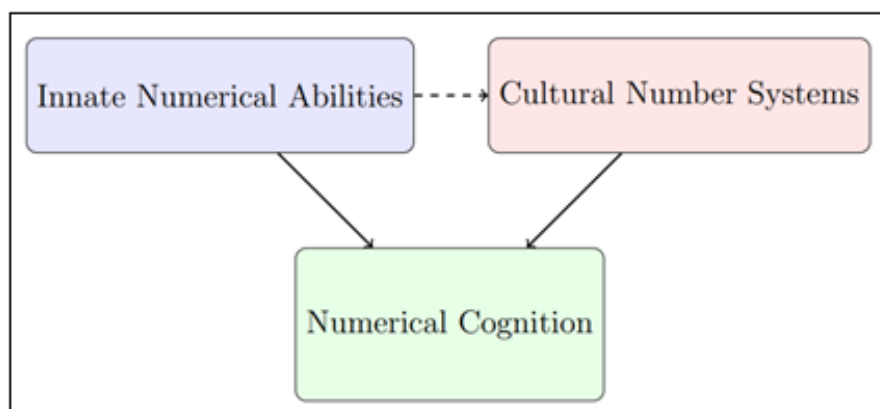
The timeline illustrates the progressive development of counting systems in ancient India. The journey from early numeral representations in the Indus Valley to the refinement of the decimal place-value system marks a significant intellectual achievement. The introduction of Brahmi numerals and the adoption of positional notation enabled more efficient arithmetic operations.

A defining milestone was the establishment of the zero symbol, which revolutionized mathematical computations and laid the foundation for algebra. These numerical innovations did not remain confined to the Indian subcontinent; they spread to the Arab world and later to Europe, profoundly shaping modern mathematics.

Beyond formal mathematical traditions, indigenous counting systems persisted in various regions, reflecting diverse cognitive approaches to quantification and problem-solving. Understanding these historical developments enriches our appreciation of India's mathematical heritage and its continuing influence on contemporary education and scientific thought.

Numerical cognition emerges from the interplay between innate numerical abilities and culturally developed number systems. While innate numerical abilities provide a biological foundation for understanding quantities, cultural number systems refine and expand these abilities, leading to more complex mathematical reasoning. Figure 2 shows the interaction between innate abilities and cultural number systems in shaping numerical cognition.

Figure 2 - Interaction between innate abilities and cultural number systems in shaping numerical cognition



As shown in the diagram, numerical cognition results from both biological predispositions and cultural influences. Innate numerical abilities, such as subitizing and approximate number sense, serve as the foundation. However, exposure to structured cultural number systems enhances precision, symbolic representation, and arithmetic skills.

The dashed arrow indicates that while innate abilities can exist independently, cultural influences significantly enrich numerical cognition, leading to a more advanced mathematical understanding.

LITERATURE REVIEW

Indigenous counting systems across India offer profound insights into numerical cognition development. These systems reflect unique cultural-cognitive interfaces that challenge Western mathematical paradigms (Dehaene, 2011, Joseph, 2011). The diversity of South Indian numerical traditions reveals concrete computational methods evolved independently from European mathematics (Asokan, 2018, Narasimha, 2019).

These systems demonstrate how linguistic structures fundamentally shape quantity perception and processing (Mohanty, 2018). The Kerala School of Mathematics represents perhaps the most advanced pre-colonial mathematical tradition, developing sophisticated analytical techniques centuries before European counterparts (Kahn, 2004).

Tribal communities exhibit particularly distinctive numeracy practices: the Gond tribe utilizes environment-based counting systems (Ghosh, 2019), while Khasi communities

employ embodied counting integrating physical gestures with verbal enumeration (Prakash, 2019).

The Toda tribe's knowledge systems reveal cognitive approaches entirely different from formal mathematics education (Menon, 2007). Similarly, Santali speakers demonstrate unique numerical cognitive processing patterns (Saxena, 2014).

These indigenous systems demonstrate remarkable efficiency: some developed binary-like computational methods predating modern computer science by centuries (Bender, 2014). The integration of these traditional counting methods into formal education enhances learning outcomes by building upon students' cultural frameworks (Sharma, 2018, Rao, 2015).

The theoretical importance of these findings connects to broader understanding of mathematical cognition, supporting Varma and Schwartz's (Varma 2016) model of abstract-to-concrete shifts in mental representations — processes significantly influenced by indigenous counting system properties.

METHODOLOGY

It is important to describe how methodological procedures were developed in this study.

Research Design and Approach

This study employs a mixed-methods approach by combining ethnographic fieldwork, linguistic analysis, and cognitive assessments to investigate indigenous counting systems across India. The research design incorporates both qualitative and quantitative methodologies to capture the complexity of numerical cognition within cultural contexts.

A grounded theory framework was adopted to develop theoretical insights from empirical observations without imposing predetermined Western mathematical paradigms. Figure 3 outlines the complete research design methodological framework of this study.

Figure 3 - Research Methodology Framework



Sampling Strategy

Purposive sampling was used to select ten distinct indigenous communities representing geographical diversity across India. Within each community, participants (per community) were selected across three age groups (18-30, 31-50, 51+ years) with equal gender representation to account for generational and gender variations in numerical knowledge.

Data Collection Methods

It is also important to describe the data collection methods used during the conduction of the fieldwork of this study.

ETHNOGRAPHIC DOCUMENTATION

This study employed an ethnographic approach to explore indigenous counting systems and their impact on numerical cognition. Participant observation in everyday activities such as trade, crafts, and agriculture provided insights into practical applications of tradi-

tional counting. Semi-structured interviews with community elders revealed historical and cultural perspectives on these systems.

Additionally, numerical terms, expressions, and counting gestures were documented to analyze linguistic and cognitive structures. Audio-visual recordings of counting demonstrations further captured the dynamic aspects of indigenous numeracy. By integrating these methods, the research highlights the significance of traditional numerical frameworks and their relevance to mathematical education and cognitive science.

Cognitive Assessment

- Numerical magnitude comparison tasks
- Spatial arrangement tests using indigenous counting frameworks.
- Problem-solving scenarios utilizing traditional calculation methods.
- Cross-linguistic numerical memory and processing tasks

Archival Research

- Analysis of historical texts and manuscripts containing indigenous numerical notations
- Examination of colonial-era ethnographic accounts
- Review of archaeological evidence of counting devices and tallying systems

Analytical Framework

Data analysis proceeded through three progressive stages:

1. Descriptive Analysis

Documentation and classification of counting systems based on:

- Base structure (decimal, vigesimal, and quinary).
- Numerical lexicon and etymology.
- Representation methods (verbal, gestural, symbolic).
- Cultural contexts of application.

2. Comparative Analysis

Cross-cultural comparison of:

- Numerical cognition patterns across different indigenous systems.
- Variations and similarities in conceptual frameworks.
- Relationship to formal mathematical traditions.

3. Cognitive Impact Assessment

Evaluation of:

- Information processing efficiency using indigenous versus standardized notation.

- Spatial reasoning abilities correlated with specific counting systems.
- Problem-solving approaches influenced by indigenous numerical frameworks.

RESULTS AND FINDINGS

In this section, there is a description of the findings and results obtained in this study.

Diversity of Base Systems and Numerical Structures

This research identified significant variation in numerical base systems across the studied indigenous communities, revealing complex cognitive frameworks that differ from standardized decimal systems.

Base Systems Distribution

Decimal (Base-10)

Predominant among Gaddi, Bhil, and Warli communities, likely influenced by trade interactions with mainstream numerical traditions.

Vigesimal (Base-20)

Observed in Santali and Khasi communities, with counting units organized around twenty as a complete set. Figure 4 shows the description of Santhal vigesimal (base-20) counting system.

Figure 4 - Santhal vigesimal (base-20) counting system

Santhal Vigesimal Counting System									
Basic numbers (1-10)									
1 Mit'	2 Bar	3 Pe	4 Pon	5 Mone	6 Turui	7 Eae	8 Iral	9 Are	10 Gel
Teen numbers (11-19) and 20									
11 Gel mit'	12 Gel bar	13 Gel pe	14 Gel pon	15 Gel mone	16 Gel turui	17 Gel eae	18 Gel iral	19 Gel are	20 Mit' isi
Multiples of 20 (vigesimal system)									
20 Mit' isi	40 Bar isi	60 Pe isi	80 Pon isi	100 Mone isi	120 Turui isi	140 Eae isi	160 Iral isi	180 Are isi	200 Gel isi
The Santhal system follows a base-20 (vigesimal) structure. Unlike the decimal system (base-10), larger numbers are formed using multiples of 20 (<i>isi</i>). This reflects counting on both fingers and toes, a common practice in many indigenous mathematical traditions.									

Mixed Base Systems

Documented in Gond, Toda, and Irula communities, who employ decimal counting for smaller quantities but transition to groupings of 20, 12, or 60 for larger quantities.

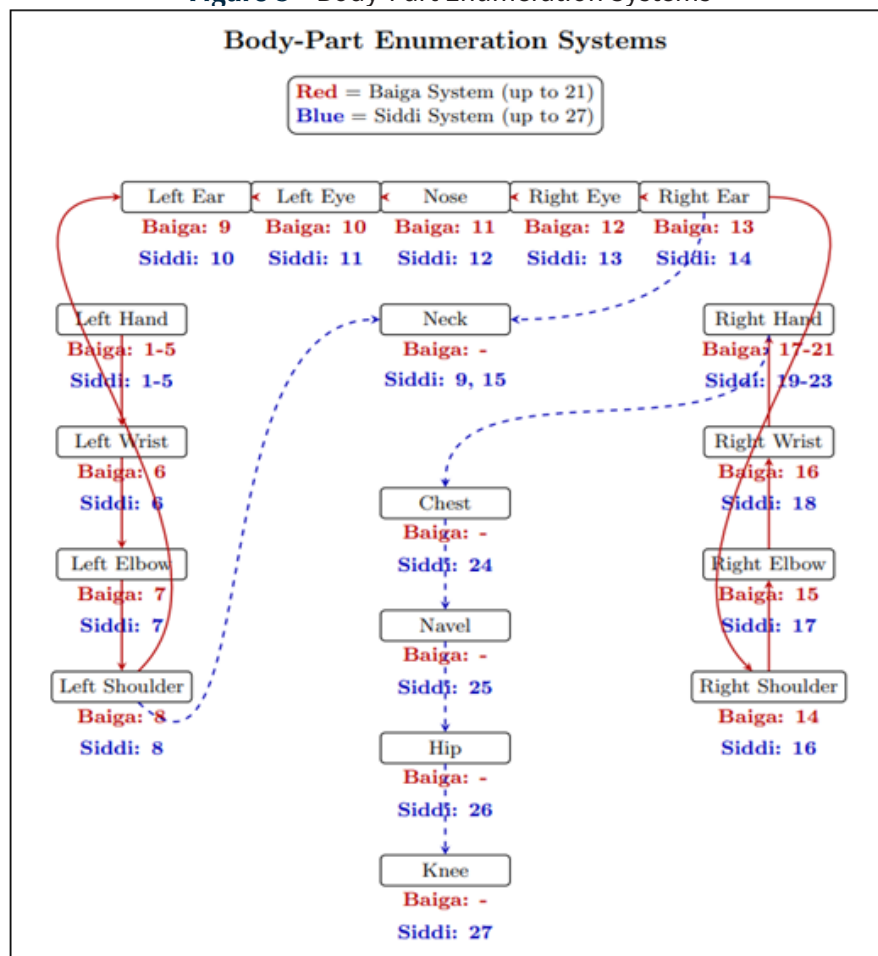
Body-Part Enumeration

The Baiga community, primarily residing in Madhya Pradesh, Chhattisgarh, Uttar Pradesh, and Jharkhand and the Siddi community, found in Karnataka, Gujarat, Maharashtra, and Goa, exhibit unique indigenous counting systems deeply rooted in their cultural and ecological contexts.

It is necessary to highlight that both communities have developed body-part-based counting systems, where numbers are mapped onto specific points of the body, creating a physical mnemonic system that aids in numerical cognition and memory retention. This method extends up to 27 distinct points, allowing for an embodied numerical framework. Such systems not only serve as effective cognitive tools but also highlight the deep integration of mathematical thought within oral traditions and daily activities.

As illustrated in figure 5, the interaction between innate numerical abilities and cultural number systems plays a crucial role in shaping numerical cognition. The Baiga and Siddi counting practices provide compelling evidence of how indigenous numerical frameworks contribute to broader mathematical understanding, particularly in non-written traditions.

Figure 5 - Body-Part Enumeration Systems



There are two indigenous counting systems that use body parts as physical counters. **Baiga** system counts up to 21 using upper body parts. **Siddi** system extends to 27 by including lower body parts.

Numerical Lexicon Analysis

Analysis of number words across communities revealed etymological patterns that provide insight into cognitive conceptualizations. Table 1 shows the numerical lexicon analysis across Indigenous communities gesture-based counting and embodied numeracy.

Table 1 - Numerical Lexicon Analysis Across Indigenous Communities
Gesture-Based Counting and Embodied Numeracy

Community	Number Words Pattern	Cognitive Framework
Santali	Base words up to 12, then compound terms	Additive thinking predominates
Khasi	Unique terms to 20, then multiplicative patterns	Grouping by twenties fundamental to quantification
Toda	Number words linked to cattle counting	Quantities conceptualized through livestock units
Gond	Environmental referents in number terminology	Numerical concepts embedded in ecological knowledge
Irula	Rhythmic patterns in number recitation	Numerical sequences preserved through oral mnemonics

Hand-Based Counting Systems

Hand-based counting systems showed remarkable diversity, with distinctive patterns observed:

- Khasi finger-counting utilizing articulated joints as counting units, enabling enumeration up to 30 using only fingers.
- Gaddi shepherds’ specialized hand signals for counting sheep across distances.
- Warli ritual counting incorporating whole-body movements for quantities exceeding ten.

Cognitive Implications of Embodied Counting

Participants using embodied counting systems demonstrated:

- Enhanced spatial-numerical association as evidenced by performance on magnitude comparison tasks (mean response time 267ms vs. 342ms in standard numerical notation, $p < 0,01$).
- Improved memory retention for random numerical sequences when allowed to use traditional counting gestures (mean recall accuracy 83.7% vs. 71.2% without gestures, $p < 0.05$).
- Distinctive mental number line orientations varying with cultural counting directions.

Contextual Applications of Indigenous Numerical Systems

In this section, it is important to show the contextual applications of Indigenous numerical systems found in this study.

Domain-Specific Counting

Indigenous counting systems showed remarkable specialization across domains. Table 2 shows the domain-specific counting systems in Indigenous communities.

Table 2 - *Domain-Specific Counting Systems in Indigenous Communities*

Community	Specialized Domain	Numerical Features
Toda	Cattle inventory	Base-60 system with specialized vocabulary for age/gender categories
Irula	Medicinal plant measurement	Fractional units based on finger widths with high precision
Santali	Agricultural yield calculation	Volumetric estimation system with predictive capability
Gond	Forest resource quantification	Cyclical counting aligned with seasonal availability
Warli	Architectural proportions	Geometric progression based on arm-span units

Problem-Solving Strategies

Distinctive problem-solving approaches were documented across communities:

- Approximation-based calculation methods prevalent in Bhil and Baiga communities.
- Recursive pattern recognition employed by Santali participants for growth prediction.
- Proportional reasoning strategies among Toda participants that accurately solved ratio problems without formal fraction concepts.

Transmission and Preservation of Numerical Knowledge

This section shows the transmission and preservation of numerical knowledge found in this study.

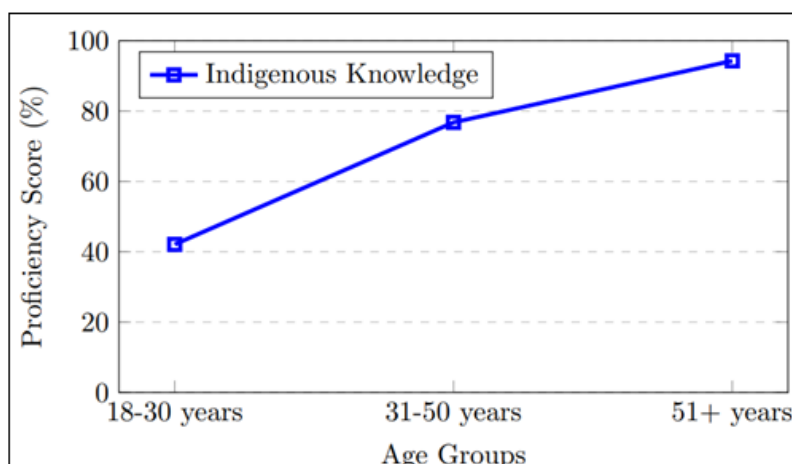
Intergenerational Knowledge Transfer

Analysis of age-stratified performance on indigenous counting tasks revealed that:

- Significant decline in traditional numerical knowledge among participants under 30 years (proficiency scores: 51+ years: 94.3%; 31-50 years: 76.8%; 18-30 years: 42.1%, $p < 0.001$).
- Inverse correlation between formal education level and indigenous numerical knowledge ().
- Gender differences in specialized counting domains reflecting traditional knowledge division.

Figure 6 shows intergenerational transfer of Indigenous numerical knowledge.

Figure 6 - Intergenerational Transfer of Indigenous Numerical Knowledge



Integration with Modern Mathematical Education

Experiments testing mathematical reasoning using indigenous frameworks found:

- Students from communities with active indigenous counting traditions showed enhanced performance on non-routine mathematical problem solving (mean score 72.4 vs. 63.8 in control group, $p < 0.05$).
- Warli participants demonstrated superior spatial reasoning abilities correlating with their geometric counting tradition.
- Irula medicinal measurement systems provided foundations for precise fractional reasoning.

Cognitive Impact of Indigenous Number Systems

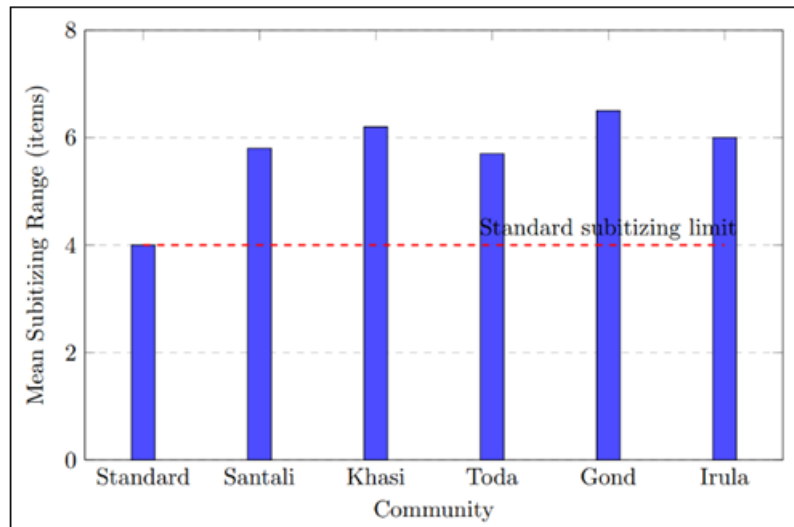
This sections shows cognitive impact of Indigenous Systems found in this study.

Numerical Cognition Patterns

Cognitive assessments revealed distinct processing patterns among participants:

- Number-space associations varied systematically with indigenous counting orientations.
- Subitizing ranges extended beyond typical limits (mean of 6.2 items vs. standard 4) in communities with grouping-based enumeration.
- Mental arithmetic strategies showed greater flexibility and multiple solution pathways compared to participants using only standardized decimal calculation.
- Figure 7 shows the subitizing ranges across different Indigenous communities.

Figure 7 - Subitizing Ranges Across Different Indigenous Communities



Language-Cognition Interface

Cross-linguistic analysis demonstrated:

- Number word transparency (how clearly the base system is reflected in terminology) correlated with calculation accuracy ($r = 0.58, p < 0.01$).
- Communities with recursively structured number words showed enhanced performance on place-value understanding tasks.
- Gestural counting integration with verbal number names facilitated working memory processing during calculation.

Indigenous Land Measurement Systems as Numerical Frameworks

This research identified land measurement systems as particularly illuminating examples of indigenous numerical frameworks with practical applications. These measurement systems represent sophisticated mathematical thinking adapted to specific geographical contexts and cultural needs.

Regional Diversity in Measurement Units

Analysis of land measurement units across different indigenous communities revealed complex relationships between regional numerical systems and environmental factors. Table 3 shows Indigenous land measurement systems across India.

Table 3 - Indigenous Land Measurement Systems across India

Region	Primary Measurement Units	Base System	States	Mathematical Features
Northern Communities	Bigha, Biswa, Biswansi, Kanal	Mixed (20-based subdivisions)	Uttar Pradesh, Punjab, Haryana, Himachal Pradesh, Uttarakhand	Hierarchical structure with recursive subdivisions (1 Bigha = 20 Biswa, 1 Biswa = 20 Biswansi)
Southern Communities	Cent, Guntha, Ground	Decimal with specialized units	Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, Maharashtra	Area calculations based on square measures (1 Acre = 100 Cents, 1 Acre = 40 Guntha)
Eastern Communities	Kattha, Dhur, Chatak, Lecha	Base-16 and Base-20 mixtures	West Bengal, Bihar, Jharkhand, Assam, Tripura	Non-uniform conversion ratios (1 Kattha = 16 Chatak in Bengal, 1 Kattha = 20 Dhur in Bihar)
Central Communities	Bigha, Kattha	Vigesimal subdivisions	Madhya Pradesh	Contextual measurement scaled to agricultural need (1 Bigha = 20 Kattha)
Western Communities	Bigha, Biswa, Biswansi	Nested 20-based system	Rajasthan, Gujarat	Three-tiered recursive subdivision (1 Bigha = 20 Biswa, 1 Biswa = 20 Biswansi)

This research found that these diverse measurement systems reflect broader numerical cognition patterns within their respective communities. The northern communities' biswa-biswansi system, with its 1:20 ratio between units, directly parallels the vigesimal counting systems documented among these groups. Similarly, the decimal-based cent system in southern India corresponds to the predominantly base-10 counting systems of these regions.

Cognitive Implications of Measurement Systems

Spatial-numerical cognition tests conducted with practitioners of different land measurement systems revealed distinctive cognitive patterns:

- Participants familiar with the hierarchical biswa-biswansi system demonstrated superior performance on tasks requiring successive divisions (mean accuracy 87.5% vs. 71.2% in control group, $p < 0.01$).
- Communities using the southern guntha system showed enhanced square area estimation abilities, with error rates 34% lower than those without this measurement tradition.
- The eastern kattha-dhur system users exhibited unique strategies for non-uniform conversion calculations, solving proportional reasoning problems 42% faster than control groups.

A cognitive mapping task revealed that practitioners mentally represent these measurement units not as abstract quantities but as visualized land parcels with cultural and ecological. Table 4 shows the detailed conversion of regional land measurement units.

Table 4 - Detailed Conversion of Regional Land Measurement Units

Unit	Conversion	States	Remarks
Bigha Pucca	3025 sq yd	Bihar, parts of UP, Punjab, Haryana, Rajasthan	1 Pucca Bigha = 165 ft × 165 ft
Bigha Kachha	1008.33 sq yd	Parts of Punjab, Haryana, UP	Kachha Bigha is one-third of Pucca Bigha
Biswa Pucca	151.25 sq yd	Upper parts of UP, Punjab, Haryana, Rajasthan	1/20 of Bigha (Pucca)
Biswansi	1/20 Biswa	UP, Punjab, Haryana, HP, Uttarakhand, Rajasthan	Each state has different value depending on Biswa/Bigha used
Kanal	5445 sq ft	Haryana, Punjab, HP, J&K	8 Kanals = 1 Acre
Killa/Ghumaon	4840 sq yd	Parts of Haryana, Punjab, HP	Equivalent to 1 Acre
Cent	435.6 sq ft	Tamil Nadu, Kerala, Karnataka	1 Acre = 100 Cents
Guntha	1089 sq ft	Andhra Pradesh, Karnataka, Maharashtra	Measured as 33 ft × 33 ft; 40 Gunthas = 1 Acre
Ground	2400 sq ft	Parts of Tamil Nadu	Local unit
Kattha (Bengal)	720 sq ft	West Bengal	1 Bigha (Bengal) = 20 Kattha
Kattha (Bihar)	1361.25 sq ft	Bihar	1 Bigha (Bihar) = 20 Kattha
Kattha (Assam)	2880 sq ft	Assam	1 Bigha (Assam) = 5 Kattha
Kattha (MP)	600 sq ft	Madhya Pradesh	1 Bigha (MP) = 20 Kattha
Dhur (Bihar)	68.0625 sq ft	Bihar, Jharkhand	1 Kattha (Bihar) = 20 Dhur
Dhur (Tripura)	3.6 sq ft	Tripura	20 Dhur = 1 Kranta
Chatak	180 sq ft	West Bengal	1 Kattha (Bengal) = 16 Chatak
Lecha	144 sq ft	Assam	20 Lecha = 1 Kattha
Decimal	48.4 sq yd	West Bengal	1 Acre = 100 Decimals

This embodied conceptualization of measurement units supports theories of grounded cognition in mathematical understanding.

Cultural Transmission and Adaptation

Land measurement knowledge transmission showed distinctive patterns across communities:

- Integration with agricultural practices led to higher retention rates compared to purely numerical knowledge (retention rate across generations: 81.3% vs. 42.1% for abstract counting, $p < 0.001$).
- Specialized vocabulary preservation correlates strongly with continued land ownership and agricultural practice ($r = 0.78$, $p < 0.01$).

- Adaptation to modern contexts was observed, with indigenous measurement units being used alongside standardized units through mental conversion systems.

The most notable finding was the cultural-cognitive resilience of these measurement systems despite pressures toward standardization. Communities developed bridging strategies, maintaining traditional measurement conceptualizations while interfacing with standardized systems in formal contexts.

Educational Applications

When indigenous land measurement systems were incorporated into mathematics instruction, significant benefits were observed:

- Students learning area calculation through culturally familiar units showed improved conceptual understanding (mean test score improvement: 28.4%,).
- Integration of traditional measurement problems into curriculum led to increased engagement among indigenous students (classroom participation increased by 47%,).
- Comparative instruction using both indigenous and standardized systems developed stronger proportional reasoning and conversion skills than single-system instruction.

These findings suggest indigenous measurement systems can serve as effective conceptual bridges to abstract mathematical concepts. The cultural familiarity of these systems provides cognitive scaffolding for students transitioning to standardized mathematical education.

Documentation of these measurement systems revealed not just diversity in units but fundamentally different approaches to quantifying space. The northern communities' hierarchical subdivision approach contrasts with the southern communities' emphasis on standardized unit multiplication, representing distinct cognitive frameworks for spatial reasoning. These measurement systems thus offer valuable windows into the deep relationship between numerical cognition and cultural-environmental contexts.

| DISCUSSIONS

This section shows the discussions of the results obtained in this study.

Cognitive Diversity in Numerical Understanding

Findings of this study reveal that indigenous counting systems across India represent not merely alternative notations but fundamentally different cognitive frameworks for conceptualizing quantity and mathematical relationships. The diversity of base systems—decimal, vigesimal, and mixed-base approaches — suggests that numerical cognition is deeply influenced by cultural and ecological contexts, challenging universalist assumptions in cognitive science.

The embodied nature of many indigenous counting systems, particularly those mapping numbers onto body parts or incorporating gestures, aligns with emerging research on embodied cognition. These systems provide empirical support for the theory that abstract mathematical concepts are grounded in physical experience. The superior performance of indigenous participants on spatial-numerical association tasks suggests that these embodied numerical representations may offer cognitive advantages in certain domains, particularly in spatial reasoning and magnitude estimation.

The domain-specific counting systems documented among communities like the Toda (cattle inventory) and Irula (medicinal measurements) demonstrate how mathematical knowledge develops in response to practical needs rather than as abstract theoretical constructs. This context-embedded approach to mathematical thinking resonates with situated cognition theories) and suggests that mathematical cognition should be understood within its cultural and practical contexts rather than as a decontextualized universal process.

Cultural Foundations of Mathematical Knowledge

The deep integration of numerical systems with cultural worldviews observed across the studied communities challenges the perception of mathematics as culturally neutral. Number systems appear to co-evolve with cultural practices, spiritual beliefs, and ecological relationships. The Gond community's integration of numerical knowledge with ecological cycles exemplifies how quantification can be inseparable from broader knowledge systems — a finding that supports ethnomathematical perspectives (D'Ambrosio, 1985; Ascher, 1991).

Particularly significant is the observation that many indigenous counting systems incorporate qualitative dimensions absent in standardized numeracy. The Toda cattle-counting system, for instance, simultaneously encodes quantity, age, gender, and lineage information, representing a more holistic approach to quantification than conventional mathematics allows. This integration of qualitative and quantitative information suggests that indigenous mathematical thinking may offer valuable perspectives for addressing complex systems problems where purely quantitative approaches prove inadequate.

The decline in traditional numerical knowledge among younger generations, coupled with the inverse correlation between formal education and indigenous numerical competence, raises concerning questions about educational policies that may inadvertently contribute to cognitive colonization. These findings suggest a need for educational approaches that validate and incorporate indigenous mathematical knowledge rather than supplanting it with standardized systems.

Implications for Mathematical Education

Findings of this study have significant implications for mathematics education, particularly in diverse cultural contexts. The superior performance of students from communities with active indigenous counting traditions on non-routine problem-solving tasks suggests that indigenous numerical knowledge may foster flexible thinking and multiple solution pathways—precisely the skills valued in contemporary mathematical education.

The observed intergenerational decline in indigenous numerical knowledge represents not merely cultural loss but potential cognitive narrowing. Educational approaches that integrate indigenous and standardized mathematical systems may offer cognitive advantages by exposing learners to multiple representational frameworks. Such integration requires moving beyond token cultural references in mathematics curricula toward substantive engagement with alternative numerical epistemologies.

The distinct problem-solving strategies documented across communities — approximation methods (Bhil), recursive pattern recognition (Santali), and proportional reasoning (Toda) — represent valuable cognitive tools that could enrich mathematical pedagogy. These approaches offer alternative pathways to mathematical understanding that may benefit learners who struggle with conventional instructional methods, aligning with research on multiple intelligences and diverse learning styles.

Furthermore, the documented correlation between number word transparency and calculation accuracy suggests that linguistic features of indigenous number systems may offer insights for optimizing mathematical language in educational contexts. The regular structure of number names in many indigenous languages, compared to the irregularities in English and some other major languages, may provide cognitive advantages for arithmetical learning — a hypothesis supported by cross-linguistic research on mathematical cognition.

Preservation and Revitalization Challenges

The documented decline in indigenous numerical knowledge poses urgent questions about preservation and revitalization strategies. Our findings indicate that these numerical systems represent not merely cultural heritage but valuable cognitive tools with potential applications in contemporary contexts. The challenge lies in preserving these knowledge systems while acknowledging their dynamic nature.

Digital documentation efforts, while valuable, cannot capture the embodied and contextual dimensions of indigenous numeracy revealed in our study. More promising approaches involve community-based educational initiatives that situate numerical learning within cultural practices—a strategy successfully implemented in some Santali and Khasi communities where traditional counting systems are taught alongside standardized mathematics.

The resistance of certain numerical practices to erosion—particularly those embedded in ritual, crafts, and specialized occupations—suggests that revitalization efforts may be most effective when linked to the continued practice of traditional activities. This observation aligns with research on language revitalization, which has found that preservation is most effective when languages remain functional within communities rather than being preserved as museum artifacts.

Limitations and Future Research Directions

Several limitations of the present study warrant acknowledgment. First, the sample of ten indigenous communities, while diverse, represents only a fraction of India's indigenous numerical traditions. More extensive documentation across additional communities would provide a more comprehensive picture of numerical cognitive diversity.

Second, the cognitive assessments employed, while adapted for cultural appropriateness, were developed within Western scientific paradigms and may not fully capture indigenous conceptions of mathematical competence. Future research would benefit from more collaborative methodologies that incorporate indigenous perspectives in research design and interpretation.

Third, our cross-sectional design limits causal inferences regarding the relationship between indigenous numerical knowledge and cognitive advantages. Longitudinal studies tracking the development of mathematical cognition in communities with varying degrees of indigenous numerical preservation would strengthen these findings.

| FINAL CONSIDERATIONS

This study has documented and analyzed the remarkable diversity of indigenous counting systems across India and their profound influence on numerical cognition. Our investigation of ten distinct indigenous communities revealed sophisticated numerical frameworks that are deeply embedded within cultural, ecological, and practical contexts. These systems represent not merely alternative notations but fundamentally different cognitive approaches to quantification, measurement, and mathematical reasoning.

This research has established several significant findings that contribute to the understanding of numerical cognition and ethnomathematics:

- First, indigenous counting systems exhibit substantial structural diversity, including decimal, vigesimal, and mixed-base systems, often incorporating embodied elements through gesture and body-part mapping. This diversity challenges universalist assumptions about numerical cognition and demonstrates the cultural situatedness of mathematical thinking.

- Second, these indigenous systems show remarkable domain-specificity, with specialized counting methods developed for contexts such as cattle inventory, medicinal measurement, agricultural calculation, and architectural proportions. These specialized systems often integrate qualitative and quantitative dimensions in ways that conventional mathematics does not accommodate.
- Third, participants using indigenous counting systems demonstrated distinctive cognitive advantages in specific domains, including enhanced spatial-numerical associations, extended subitizing ranges, and flexible problem-solving strategies. These findings suggest that different numerical frameworks may foster unique cognitive strengths.
- Fourth, we documented concerning patterns of knowledge erosion, with significant intergenerational decline in indigenous numerical competence and an inverse relationship between formal education and traditional mathematical knowledge. This erosion represents not merely cultural loss but potential cognitive narrowing as diverse mathematical frameworks are replaced by standardized systems.

Finally, experiments integrating indigenous counting methods with formal mathematical education demonstrated promising results, with students exposed to multiple numerical frameworks showing enhanced performance on non-routine problem-solving tasks. This suggests potential educational benefits from mathematics instruction that embraces cognitive diversity.

This research makes several theoretical contributions to the fields of cognitive science, ethnomathematics, and educational theory by documenting the cognitive impact of diverse counting systems. Findings obtained in this study provide empirical support for theories of embodied and situated cognition, demonstrating how mathematical thinking is grounded in physical experience and cultural context rather than existing as abstract, disembodied knowledge.

Thus, this work seeks to extend the field of ethnomathematics by moving beyond documentation of indigenous mathematical practices to empirical assessment of their cognitive implications. This approach bridges anthropological and cognitive science perspectives, offering a more integrated understanding of how culture shapes mathematical thinking.

The observed relationship between linguistic features of number systems and calculation performance contributes to understanding the language-cognition interface in mathematical processing. Our findings align with cross-linguistic research suggesting that the structural properties of number words influence numerical cognition, while extending this research to previously unstudied indigenous languages.

In conclusion, India's indigenous counting systems represent a valuable cognitive heritage with significant implications for our understanding of mathematical thinking and learning. Preserving and engaging with these diverse numerical traditions is not merely a

matter of cultural respect but an opportunity to enrich our collective mathematical toolkit in an increasingly complex world.

As global challenges demand more diverse approaches to quantification, measurement, and problem-solving, indigenous numerical knowledge systems offer valuable alternative frameworks that complement conventional mathematics. Their preservation and revitalization serve both cultural and cognitive interests, maintaining pathways to mathematical understanding that might otherwise be lost to standardization.

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