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Orang Asli Communities as Catalysts of Ai-Driven Knowledge Innovation in Malaysia: A Human-Centred Framework for Inclusive Research Incubation

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ABSTRACT

The rapid expansion of artificial intelligence (AI) in research and innovation ecosystems has largely been driven by technocentric paradigms that marginalise indigenous knowledge systems, particularly within developing contexts such as Malaysia. This conceptual paper addresses this gap by proposing a human-centred framework that positions Orang Asli communities as active catalysts of AI-driven knowledge innovation and inclusive research incubation. Drawing on interdisciplinary literature across human-centred AI, indigenous epistemology, innovation ecosystem theory and decolonial perspectives, the study synthesises a novel framework—the Human-Centred Indigenous AI Knowledge Incubation (HCI-AIKI) Model. The framework conceptualises the dynamic interaction between indigenous knowledge systems, human-centred AI, enabling policy ecosystems, and knowledge co-creation processes in generating inclusive and sustainable innovation outcomes. It advances the argument that AI should function as an assistive and culturally responsive tool that enhances, rather than replaces, community-based knowledge practices. The proposed model contributes theoretically by integrating relational epistemologies with AI-driven innovation, thereby extending existing human-centred AI discourse into Orang Asli contexts. Practically, it offers strategic insights for policymakers, researchers and institutions in Malaysia to develop inclusive AI ecosystems that empower Orang Asli communities, reduce epistemic inequality and foster sustainable knowledge incubation aligned with national digital transformation goals.

1. Introduction

The rapid advancement of artificial intelligence (AI) has fundamentally reshaped the landscape of knowledge production, research innovation, and socio-economic development worldwide. As a general-purpose technology, AI is increasingly embedded within innovation ecosystems, influencing how knowledge is generated, disseminated, and applied across sectors. Governments and

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institutions worldwide have consequently prioritised AI as a strategic driver of digital transformation, economic competitiveness, and sustainable development [31]. In Malaysia, national initiatives such as the Malaysia Digital Economy Blueprint and AI Roadmap reflect a strong commitment to leveraging AI for inclusive growth and innovation [26]. However, despite its transformative potential, prevailing discourse on AI-driven innovation remains largely technocentric, often privileging data-intensive, algorithmic, and Western epistemological paradigms [9,46]. Such dominance raises critical concerns regarding inclusivity, epistemic diversity, and the marginalisation of alternative knowledge systems, particularly those rooted in indigenous communities [20,37].

Indigenous knowledge systems represent rich, contextually embedded, and culturally grounded forms of knowledge that have evolved through generations of lived experience, ecological interaction, and community-based practices [7,48]. These systems are inherently relational, emphasising the interconnectedness of humans, nature, and society, and are frequently transmitted through oral traditions, collective memory, and cultural practices [16,25]. In the Malaysian context, indigenous communities, including the Orang Asli in Peninsular Malaysia and diverse ethnic groups in Sabah and Sarawak, possess extensive knowledge related to biodiversity conservation, sustainable resource management, and local adaptation strategies [11,27,56]. Despite their significance, such knowledge systems are frequently underrepresented or excluded from formal research and innovation frameworks, contributing to what scholars describe as epistemic injustice and knowledge asymmetry [19,33].

The growing integration of AI into research ecosystems presents both opportunities and risks for indigenous knowledge. On the one hand, AI technologies offer powerful tools for knowledge preservation, pattern recognition, and decision support, potentially enhancing the visibility and application of indigenous knowledge in addressing complex societal challenges [2,37]. On the other hand, the uncritical deployment of AI may reinforce existing inequalities through the extraction, commodification, or misrepresentation of indigenous knowledge without adequate consent, contextual understanding, or ethical safeguards [39,41]. This tension underscores the need for a more inclusive and ethically grounded approach to AI development that recognises indigenous communities not merely as sources of data, but as active agents in knowledge creation and innovation processes.

Human-Centred Artificial Intelligence (HCAI) has emerged as a critical paradigm for aligning AI systems with human values, social contexts, and ethical principles [47]. Unlike purely technology-driven approaches, HCAI emphasises participation, transparency, fairness, and the augmentation of human capabilities rather than their replacement [12]. Within the context of indigenous communities, a human-centred approach is particularly relevant because it prioritises cultural sensitivity, community engagement, and respect for local epistemologies. Such an approach facilitates the co-design of AI systems that respond to community needs while safeguarding indigenous knowledge against exploitation or misinterpretation [32,53].

At the same time, the concept of knowledge incubation within innovation ecosystems provides a useful lens for understanding how ideas evolve into impactful innovations through collaboration, capacity building, and institutional support [1]. Traditional innovation models, such as the Triple Helix framework, emphasise interactions among academia, industry, and government; however, these models may overlook the role of communities, particularly indigenous communities, as important contributors to knowledge production [17]. Expanding such frameworks to incorporate indigenous actors is therefore consistent with calls for more inclusive and participatory innovation ecosystems that recognise diverse knowledge sources and societal needs.

Despite increasing scholarly attention to AI, human-centred design, and indigenous knowledge, a significant gap remains in the literature concerning their integration within a coherent conceptual

framework, particularly in the Malaysian context. Existing studies tend to examine AI adoption, Orang Asli knowledge preservation, or innovation ecosystems in isolation, with limited efforts to theorise their intersection [37,52]. Furthermore, existing models rarely position Orang Asli communities as catalysts of AI-driven innovation rather than as passive beneficiaries [45]. Addressing this gap is critical to advancing both theoretical understanding and the practical implementation of inclusive AI ecosystems.

In response to this gap, this conceptual paper develops a **Human-Centred Indigenous AI Knowledge Incubation (HCI-AIKI) framework** that integrates Orang Asli epistemologies with AI-driven innovation processes within Malaysia's socio-cultural and policy landscape. The proposed framework conceptualises the dynamic relationships among Orang Asli knowledge systems, human-centred AI, enabling ecosystems, and knowledge co-creation processes in generating inclusive and sustainable innovation outcomes. By positioning indigenous communities at the centre of AI-enabled knowledge ecosystems, this study contributes to the growing discourse on inclusive innovation, the decolonisation of knowledge production, and ethical AI development. Ultimately, the proposed framework offers a novel perspective for reimagining research incubation in Malaysia, in which technological advancement is balanced with cultural integrity, social equity, and Orang Asli community empowerment.

2. Literature Review

2.1 AI in Knowledge Innovation Ecosystems

Artificial intelligence (AI) has emerged as a transformative force in contemporary knowledge ecosystems, reshaping how knowledge is generated, processed, and utilised across domains. As a general-purpose technology, AI enhances research productivity through data-driven insights, predictive modelling, and the automation of complex analytical tasks [22]. Within innovation ecosystems, AI accelerates knowledge discovery, facilitates interdisciplinary collaboration, and enables more efficient decision-making processes [6]. These capabilities position AI as an important driver of innovation in the knowledge economy, particularly within national digital transformation agendas.

However, the integration of AI into knowledge systems is not without challenges. AI-driven innovation may reflect dominant epistemological assumptions embedded within datasets, algorithms, and technological infrastructures [58]. This tendency may contribute to epistemic homogenisation, whereby diverse knowledge systems, particularly non-Western and community-based forms of knowledge, are marginalised or excluded from formal innovation processes [5]. Furthermore, reliance on large-scale data extraction raises ethical concerns regarding ownership, consent, and the commodification of knowledge, particularly when indigenous communities are involved [21].

In response, there is growing recognition of the need to reconfigure AI-enabled innovation ecosystems to become more inclusive, participatory, and context-sensitive. Such a shift requires moving beyond purely technological paradigms towards approaches that integrate the social, cultural, and ethical dimensions of knowledge production [54]. This reorientation is particularly relevant in multicultural contexts such as Malaysia, where diverse knowledge traditions coexist and have the potential to contribute to national innovation.

2.2 Human-Centred Artificial Intelligence (HCAI)

Human-Centred Artificial Intelligence (HCAI) has gained prominence as a paradigm that seeks to align technological development with human values, needs, and societal contexts. Unlike conventional AI approaches that predominantly emphasise efficiency and performance, HCAI prioritises usability, transparency, fairness, ethical responsibility, and human agency [47]. It positions AI as a means of augmenting human capabilities rather than replacing them, thereby promoting collaborative human–AI interactions [12].

The theoretical foundations of HCAI draw upon interdisciplinary perspectives, including human–computer interaction, technology ethics, and socio-technical systems theory [38]. Central to this paradigm is participatory design, which involves relevant stakeholders in the development and deployment of AI systems to enhance contextual relevance, inclusivity, and social acceptability. Such participation is particularly important when engaging marginalised communities because it enables local knowledge, cultural values, and lived experiences to be incorporated into technological solutions [47].

In the context of Orang Asli communities, HCAI provides an important framework for addressing issues related to power, representation, and knowledge ownership. By prioritising community participation and ethical governance, HCAI may mitigate risks associated with data exploitation, cultural misappropriation, and algorithmic bias [18]. Furthermore, it supports the development of culturally responsive AI systems that respect indigenous epistemologies while contributing to community empowerment [12]. Nevertheless, empirical applications of HCAI within indigenous contexts remain limited, highlighting the need for conceptual and practical frameworks capable of bridging technological innovation with indigenous knowledge systems.

2.3 Indigenous Knowledge Systems and Epistemologies

Indigenous Knowledge Systems (IKS) are increasingly recognised as valuable sources of knowledge for addressing complex global challenges, including environmental sustainability, health, biodiversity conservation, and community resilience. These systems are characterised by their holistic, relational, and context-specific nature, emphasising the interconnectedness between human and non-human entities [REF]. In contrast to Western scientific paradigms that frequently emphasise objectivity and reductionism, indigenous epistemologies are deeply grounded in lived experience, cultural practices, intergenerational knowledge, and collective memory [REF].

Previous studies demonstrate that IKS provide alternative and complementary ways of understanding and interacting with the world [23]. In Malaysia, indigenous communities, including the Orang Asli of Peninsular Malaysia and diverse ethnic groups in Sabah and Sarawak, possess extensive ecological knowledge, particularly in areas such as biodiversity conservation, traditional medicine, sustainable resource management, and adaptation to local environments [27,56]. Such knowledge has considerable potential to contribute to innovation processes, particularly those aimed at addressing localised social and environmental challenges.

Despite this potential, the integration of Orang Asli knowledge into formal research and innovation systems remains limited. Structural barriers, including institutional biases, insufficient recognition, and unequal power relations, may marginalise Orang Asli voices within formal knowledge-production processes [56]. Concerns have also been raised regarding the appropriation and commodification of indigenous knowledge without adequate consent, recognition, or benefit-sharing [24]. These challenges highlight the need for frameworks that not only recognise the value

of Orang Asli knowledge but also facilitate its ethical, equitable, and culturally appropriate integration into innovation ecosystems.

2.4 Knowledge Incubation and Innovation Ecosystems

Knowledge incubation refers to the processes through which ideas and knowledge are nurtured, refined, developed, and transformed into innovative outcomes through collaboration, resource mobilisation, capacity building, and institutional support. Within innovation ecosystems, these processes are facilitated by interactions among multiple stakeholders, including academia, industry, government, and society [30]. Models such as the Triple Helix and Quadruple Helix frameworks have been widely employed to conceptualise such interactions, emphasising collaboration among different actors as a fundamental driver of innovation [55].

Although these models have significantly advanced the understanding of innovation processes, conventional applications may inadequately represent community actors, particularly indigenous communities [4]. Such omission reflects a broader tendency to prioritise formal institutions over informal and community-based knowledge systems, potentially leaving valuable sources of knowledge and innovation underutilised.

Recent scholarship therefore advocates more inclusive innovation ecosystems that incorporate diverse stakeholders and knowledge systems [36]. Within this perspective, communities are recognised as active participants in knowledge co-creation rather than merely passive recipients of innovation [35]. Knowledge incubation consequently becomes a participatory process that integrates local knowledge, develops community capacities, facilitates collaborative learning, and supports empowerment. Such an approach is particularly relevant in Malaysia, where inclusive development and the recognition of socio-cultural diversity are important dimensions of sustainable innovation.

2.5 Integrating AI, Orang Asli Knowledge and Inclusive Innovation in Malaysia

The intersection of AI, Orang Asli knowledge, and innovation ecosystems represents a promising yet underexplored area of research. In Malaysia, the increasing emphasis on digital transformation and AI adoption creates opportunities to integrate Orang Asli knowledge into innovation processes while simultaneously promoting inclusivity and sustainability. However, meaningful integration requires careful consideration of ethical, cultural, technological, and institutional factors.

Existing studies on AI in Malaysia have predominantly focused on technological adoption, economic impacts, and policy development, with comparatively limited attention given to socio-cultural dimensions [14]. Similarly, research concerning Orang Asli knowledge has often concentrated on its preservation and documentation rather than its active integration into contemporary innovation processes [56]. This fragmentation highlights the need for a holistic framework capable of bridging AI, indigenous epistemologies, and innovation ecosystems.

HCAI provides a valuable lens for facilitating this integration because it emphasises ethical design, stakeholder participation, human agency, and contextual sensitivity. Integrating HCAI principles with Orang Asli epistemologies may facilitate the development of AI systems that are not only technologically capable but also culturally relevant and socially inclusive [3,56]. Furthermore, embedding such systems within inclusive innovation ecosystems may strengthen knowledge-incubation processes and facilitate the transformation of Orang Asli knowledge into innovative solutions capable of benefiting indigenous communities and wider society.

Overall, the literature demonstrates the transformative potential of AI within knowledge and innovation ecosystems, the importance of human-centred approaches in promoting ethical and

inclusive technological development, and the value of indigenous knowledge systems in addressing complex societal and environmental challenges. Nevertheless, a significant gap remains in integrating these domains within a unified conceptual framework, particularly within the Malaysian context. Addressing this gap is essential for advancing inclusive innovation and recognising Orang Asli communities as active contributors to, rather than passive beneficiaries of, AI-driven knowledge ecosystems.

3. Theoretical Foundation

The development of an inclusive framework that positions Orang Asli communities as catalysts of AI-driven knowledge innovation requires a multidimensional theoretical foundation. Accordingly, this study integrates four complementary theoretical perspectives: **Human-Centred Artificial Intelligence (HCAI)**, **Indigenous Knowledge Theory**, **Innovation Ecosystem Theory**, and **Decolonial Theory**. Collectively, these perspectives provide a theoretical basis for explaining the complex interactions among technological systems, knowledge structures, institutional actors, and socio-cultural contexts. Their integration facilitates a holistic understanding of how AI can be ethically and effectively embedded within Orang Asli knowledge ecosystems in Malaysia while promoting inclusivity, equity, cultural integrity, and sustainability.

3.1 Human-Centred Artificial Intelligence (HCAI)

Human-Centred Artificial Intelligence provides a critical theoretical lens for reconceptualising the role of AI in knowledge innovation. Unlike conventional AI paradigms that primarily prioritise automation, optimisation, and efficiency, HCAI emphasises the alignment of AI systems with human values, societal contexts, and ethical considerations [47]. It advocates transparency, explainability, fairness, accountability, and responsible AI design to ensure that technological systems serve human needs and societal objectives [42].

A fundamental principle of HCAI is **augmentation rather than replacement**, whereby AI enhances human capabilities, supports decision-making, and facilitates knowledge creation without undermining human agency [REF]. This principle is particularly important in knowledge-intensive environments where human judgement, cultural understanding, contextual interpretation, and lived experience remain indispensable. Within innovation ecosystems, HCAI therefore promotes collaborative human–AI interactions capable of supporting more inclusive and adaptive knowledge processes [REF].

In the context of Orang Asli communities, HCAI plays a mediating role by ensuring that AI systems are culturally responsive, socially appropriate, and ethically grounded. Participatory design, as a core component of HCAI, involves stakeholders, including Orang Asli communities, directly in the development and deployment of AI technologies [10]. Such participation helps ensure that AI systems reflect local values, knowledge practices, cultural contexts, and community priorities rather than imposing externally determined technological assumptions.

Furthermore, HCAI provides mechanisms for addressing concerns related to algorithmic bias, indigenous data sovereignty, knowledge ownership, and ethical governance, all of which are particularly important when AI systems interact with indigenous knowledge [40]. HCAI therefore serves as a critical theoretical mechanism for bridging technological innovation with cultural integrity, human agency, and social inclusivity.

3.2 Indigenous Knowledge Theory

Indigenous Knowledge Theory provides the epistemological foundation for recognising and integrating forms of knowledge that have historically been marginalised within dominant knowledge-production systems. It challenges the privileging of Western epistemological paradigms by emphasising the legitimacy and value of local, culturally embedded, and context-specific knowledge systems [7]. Indigenous knowledge is inherently relational, holistic, dynamic, and adaptive, evolving through continuous interactions among communities, cultural practices, and their social and natural environments [2].

Unlike positivist approaches that tend to prioritise objectivity, universality, and generalisability, indigenous epistemologies place greater emphasis on lived experience, collective memory, relationality, and contextual understanding [16]. In Malaysia, indigenous communities, including the Orang Asli of Peninsular Malaysia and ethnic communities in Sabah and Sarawak, possess rich knowledge systems associated with biodiversity, ecological sustainability, resource management, and traditional practices [8,27]. These knowledge systems have evolved through generations of adaptation and resilience and therefore offer potentially valuable insights for addressing contemporary challenges such as climate change, sustainable resource management, biodiversity conservation, and community development.

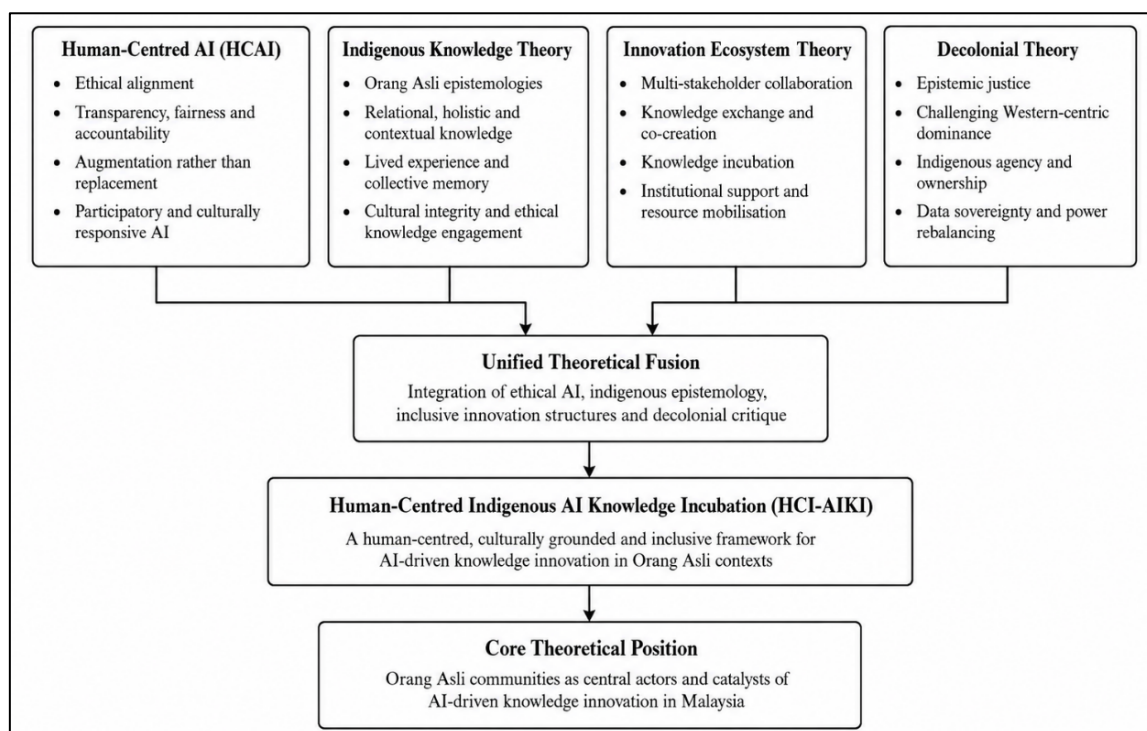


Fig. 1. Integrated Theoretical Framework Underpinning the HCI-AIKI Model

Despite their significance, Orang Asli knowledge systems remain underrepresented within formal research and innovation frameworks, contributing to epistemic exclusion and the underutilisation of indigenous knowledge [56]. Indigenous Knowledge Theory also foregrounds the ethical dimensions of knowledge engagement, particularly issues concerning ownership, consent, recognition, cultural integrity, and benefit-sharing [44]. The appropriation or commodification of indigenous knowledge without adequate recognition, participation, or compensation raises important concerns regarding epistemic justice and equity [19].

Consequently, integrating indigenous knowledge into AI-driven innovation requires more than technological adaptation. It necessitates ethical sensitivity, cultural respect, equitable participation, and mechanisms that protect indigenous communities' rights over their knowledge. Within the proposed HCI-AIKI framework, Indigenous Knowledge Theory therefore positions Orang Asli communities as active knowledge holders and contributors to innovation rather than passive recipients of externally developed technologies.

This perspective further emphasises **knowledge co-creation**, whereby new knowledge emerges through meaningful and equitable interaction between indigenous and non-indigenous actors. Such an approach aligns with the broader objective of establishing inclusive innovation ecosystems that recognise epistemological plurality and enable diverse knowledge systems to contribute meaningfully to AI-driven innovation.

3.3 Innovation Ecosystem Theory

Innovation Ecosystem Theory provides a structural perspective for understanding how knowledge is generated, exchanged, and transformed into innovation through interactions among multiple stakeholders [49]. Traditional models, particularly the Triple Helix framework, emphasise the roles of academia, industry, and government in driving innovation [55]. More recent extensions, including the Quadruple and Quintuple Helix models, incorporate civil society and environmental dimensions, thereby providing a more comprehensive understanding of contemporary innovation ecosystems [51].

Within these ecosystems, knowledge incubation refers to the processes through which ideas and knowledge are nurtured, refined, and translated into practical applications [30]. These processes encompass knowledge exchange, capacity building, resource mobilisation, and institutional support [57]. However, conventional innovation ecosystem models often inadequately recognise the role of Orang Asli communities as important contributors to knowledge production. Such exclusion limits the diversity of knowledge inputs and may reduce the potential for inclusive and contextually relevant innovation [29].

Integrating Orang Asli communities into innovation ecosystems therefore requires a transition towards more participatory and inclusive models of innovation. This involves recognising indigenous communities as co-creators of knowledge and incorporating their perspectives, priorities, and expertise into decision-making processes. In Malaysia, such an approach is particularly important given the country's cultural diversity and commitment to inclusive development. Embedding Orang Asli knowledge within innovation ecosystems can enhance the contextual relevance, sustainability, and social impact of innovation outcomes. Innovation Ecosystem Theory therefore provides the structural foundation for the proposed framework by explaining how interactions among Orang Asli communities, AI technologies, and institutional actors can facilitate knowledge incubation and innovation. It further highlights the importance of collaboration, coordination, resource mobilisation, and institutional support in enabling inclusive innovation processes.

3.4 Decolonial Theory

Decolonial Theory provides a critical perspective for examining the power relations and epistemic hierarchies that shape knowledge production and innovation systems. It challenges the dominance of Western-centric epistemologies and advocates the recognition and validation of alternative knowledge systems, including those of indigenous communities [34]. From a decolonial perspective, contemporary research and innovation systems may perpetuate historical inequalities by privileging

certain forms of knowledge while marginalising others, thereby contributing to epistemic injustice and inequality.

Within the context of AI, Decolonial Theory also highlights the risks associated with digital colonialism, whereby data extraction, algorithmic development, and technological deployment may reinforce existing power imbalances [15]. Orang Asli communities may be particularly vulnerable to such dynamics when their knowledge is appropriated, decontextualised, or represented within AI systems without adequate control, consent, recognition, or benefit-sharing. These concerns underscore the importance of ethical governance mechanisms that prioritise indigenous data sovereignty, community ownership, and equitable participation.

Decolonial Theory further emphasises **epistemic plurality**, whereby multiple ways of knowing are recognised as legitimate and valuable within knowledge systems [13]. This perspective aligns closely with inclusive innovation, which seeks to incorporate diverse knowledge sources while addressing structural and societal inequalities. By integrating Decolonial Theory into the proposed framework, this study advocates the reconfiguration of AI-driven innovation ecosystems to strengthen indigenous agency, recognise epistemological diversity, and promote epistemic justice.

3.5 Unified Theoretical Fusion

The integration of HCAI, Indigenous Knowledge Theory, Innovation Ecosystem Theory, and Decolonial Theory provides a comprehensive and cohesive theoretical foundation for understanding AI-driven knowledge innovation within Orang Asli contexts. Each theoretical perspective contributes a distinct but complementary dimension to the proposed framework.

HCAI serves as the **ethical and operational mechanism**, ensuring that AI systems are aligned with human values, cultural contexts, and community needs. Indigenous Knowledge Theory provides the **epistemological foundation**, validating community-based knowledge systems and emphasising relational, contextual, and culturally grounded ways of knowing. Innovation Ecosystem Theory contributes the **structural perspective**, explaining how knowledge can be co-created, exchanged, incubated, and transformed through interactions among multiple stakeholders. Decolonial Theory provides the **critical perspective**, addressing power asymmetries, challenging epistemic hierarchies, and promoting epistemic justice.

Collectively, these theoretical perspectives underpin the proposed **Human-Centred Indigenous AI Knowledge Incubation (HCI-AIKI) framework**, which positions Orang Asli communities as central actors within AI-driven innovation ecosystems. This theoretical fusion advances the existing literature by bridging previously fragmented domains and providing an integrated perspective on inclusive, ethical, and culturally grounded innovation. Within the Malaysian context, it offers a foundation for reimagining research and knowledge incubation processes that combine technological advancement with cultural integrity, social inclusion, indigenous agency, and sustainable development.

4. Conceptual Framework Development

The proposed **Human-Centred Indigenous AI Knowledge Incubation (HCI-AIKI) framework** conceptualises how Orang Asli communities can function as catalysts of AI-driven knowledge innovation within inclusive research ecosystems in Malaysia. The framework is grounded in the integration of Human-Centred Artificial Intelligence (HCAI), Indigenous Knowledge Theory, Innovation Ecosystem Theory, and Decolonial Theory. It addresses the limitations of predominantly technocentric innovation models by embedding cultural, ethical, epistemological, and community-driven dimensions into AI-enabled knowledge processes. The framework therefore shifts the

conceptualisation of indigenous communities from passive recipients of technological innovation towards active knowledge holders, co-creators, and innovation partners.

4.1 Conceptual Overview of the Framework

The HCI-AIKI framework captures the dynamic and multi-layered relationships among Orang Asli knowledge systems, AI technologies, institutional ecosystems, knowledge processes, and innovation outcomes. Central to the framework is the proposition that meaningful AI-driven innovation emerges from the intersection of **contextual knowledge represented by indigenous epistemologies, ethical technological systems represented by HCAI, and supportive institutional environments**.

The framework comprises five interconnected components: **(1) Indigenous Knowledge Systems (IKS), (2) Knowledge Co-Creation Processes, (3) Human-Centred AI as a mediating mechanism, (4) Knowledge Incubation Processes, and (5) Inclusive and Sustainable Innovation Outcomes**. In addition, **Policy and Ecosystem Support** is conceptualised as a moderating factor that influences the strength and effectiveness of the relationships among these components. Together, these elements provide a systematic explanation of how indigenous knowledge can interact with AI and institutional structures to generate culturally relevant, ethically grounded, and socially beneficial innovation.

4.2 Indigenous Knowledge Systems as Foundational Input

Indigenous Knowledge Systems (IKS) constitute the foundational input of the HCI-AIKI framework and represent a primary source of contextualised and culturally embedded knowledge. These systems encompass ecological wisdom, traditional practices, community values, collective experiences, and knowledge derived from long-term interactions with specific socio-cultural and environmental contexts [2,57,REF].

In Malaysia, indigenous communities, particularly the Orang Asli of Peninsular Malaysia as well as ethnic communities in Sabah and Sarawak, possess extensive knowledge relevant to sustainable development, biodiversity conservation, ecological management, and community resilience [27,56]. Within the HCI-AIKI framework, IKS are not conceptualised as static repositories of traditional information but as dynamic and evolving knowledge systems capable of interacting with contemporary technological and institutional processes.

The integration of IKS addresses epistemic limitations within conventional innovation models by introducing plurality into the sources of knowledge that inform AI-driven innovation. Nevertheless, such integration must be undertaken ethically, with particular attention to informed consent, knowledge ownership, community control, benefit-sharing, and cultural integrity [7]. This ensures that technological engagement strengthens rather than diminishes indigenous agency.

4.3 Knowledge Co-Creation as a Transformative Process

Knowledge co-creation represents the collaborative process through which Orang Asli knowledge interacts with the expertise and resources of external stakeholders, including researchers, technologists, policymakers, and institutional actors, to generate new forms of knowledge. This process is inherently iterative, participatory, and relational, aligning closely with the principles of human-centred design and inclusive innovation [47].

Within the HCI-AIKI framework, knowledge co-creation serves as a critical bridge between **Orang Asli knowledge systems and AI-enabled innovation processes**. It facilitates reciprocal learning in which Orang Asli communities contribute contextual knowledge, cultural understanding, and lived

experience, while researchers and technologists contribute analytical methods and technological capabilities. Such interaction may generate hybrid forms of knowledge that are simultaneously culturally grounded and technologically enhanced.

Importantly, co-creation challenges conventional top-down approaches to knowledge production by promoting more horizontal and participatory relationships among stakeholders. It ensures that Orang Asli communities are meaningfully involved in decision-making throughout the innovation process, thereby strengthening the contextual relevance, legitimacy, ownership, and sustainability of innovation outcomes [16]. Such an approach is particularly relevant in Malaysia, where socio-cultural diversity necessitates innovation processes that are responsive to different knowledge traditions and community contexts.

4.4 Human-Centred AI as a Mediating Mechanism

Human-Centred AI functions as a **mediating construct** within the HCI-AIKI framework, shaping how co-created indigenous knowledge is translated into AI-enabled knowledge incubation and innovation. As a mediating mechanism, HCAI ensures that AI systems are designed, developed, and implemented in ways that align with human values, cultural contexts, community priorities, and ethical principles [10].

The mediating role of HCAI operates through three interrelated dimensions:

Ethical Alignment involves ensuring fairness, transparency, accountability, privacy, and responsible governance within AI systems.

Participatory Design involves the meaningful participation of Orang Asli communities throughout AI design, development, implementation, and evaluation.

Contextual Adaptation involves tailoring AI systems to the linguistic, cultural, social, and environmental contexts in which Orang Asli knowledge is embedded.

Through these dimensions, HCAI facilitates the transformation of knowledge inputs into meaningful and context-sensitive outputs while mitigating risks associated with algorithmic bias, data exploitation, and epistemic misrepresentation [28]. Furthermore, HCAI positions AI as an assistive and augmentative technology rather than a substitute for human knowledge and judgement. This distinction is particularly important for Orang Asli knowledge systems, which depend substantially on human interpretation, cultural context, relational understanding, and lived experience.

4.5 Knowledge Incubation Processes

Knowledge incubation refers to the processes through which co-created knowledge is refined, developed, tested, and transformed into practical and innovative applications. Within the HCI-AIKI framework, knowledge incubation encompasses activities such as capacity building, knowledge translation, experimentation, validation, resource mobilisation, and institutional support [30,40].

This stage represents the operational core of the framework, where co-created knowledge progresses towards actionable innovation. AI technologies may contribute to this process through data analysis, pattern recognition, predictive modelling, knowledge organisation, and decision support, thereby enhancing the capacity to transform knowledge into practical applications. However, effective knowledge incubation depends on maintaining alignment with indigenous perspectives, ethical principles, and community-defined needs.

Within Malaysia, these processes may be facilitated through collaborative arrangements involving universities, research institutions, government agencies, technology partners, and Orang Asli communities. Such collaborations provide opportunities to translate indigenous knowledge into

broader innovation applications while ensuring appropriate community participation, recognition, ownership, and equitable distribution of benefits.

4.6 Innovation Outcomes: Inclusive and Sustainable Impact

The ultimate outcome of the HCI-AIKI framework is the generation of **inclusive and sustainable innovation**. Such outcomes are characterised by their capacity to address locally relevant challenges, strengthen community agency, and contribute to broader societal objectives, including environmental sustainability, social equity, cultural preservation, and sustainable development.

Innovation outcomes within the framework extend beyond conventional measures of technological advancement or economic value to encompass **social, cultural, ecological, and community impacts**. For example, AI-enabled applications informed by Orang Asli ecological knowledge could contribute to sustainable resource management and biodiversity conservation, while culturally responsive educational technologies could support learning and knowledge preservation within Orang Asli communities.

By positioning Orang Asli communities at the centre of knowledge and innovation processes, the HCI-AIKI framework seeks to ensure that innovation outcomes are not only technologically viable but also socially meaningful, culturally appropriate, and responsive to community priorities. This orientation aligns with broader international calls for responsible and inclusive innovation that places human well-being and sustainability at the centre of technological development [50].

4.7 Policy and Ecosystem Support as a Moderating Factor

Policy and Ecosystem Support is conceptualised as a **moderating factor** that influences the strength and effectiveness of relationships within the HCI-AIKI framework. It encompasses government policies, regulatory and institutional frameworks, digital infrastructure, funding mechanisms, capacity-building initiatives, research support, and multi-stakeholder collaboration.

Within Malaysia, national initiatives related to digital transformation and AI development provide an enabling environment for implementing the proposed framework. Nevertheless, the effectiveness of these initiatives depends on their ability to incorporate inclusive, participatory, and culturally sensitive approaches. Relevant policies should therefore address issues such as indigenous data sovereignty, ethical AI governance, equitable access to digital technologies, community participation, and mechanisms for protecting indigenous knowledge.

The moderating role of Policy and Ecosystem Support emphasises the importance of system-level conditions in enabling inclusive innovation. Strong institutional and policy support can strengthen knowledge co-creation, facilitate effective knowledge incubation, improve access to technological resources, and enhance the translation of indigenous knowledge into inclusive and sustainable innovation outcomes.

4.8 Conceptual Propositions

Based on the theoretical foundations and relationships established within the HCI-AIKI framework, the following propositions are advanced:

P1: Indigenous Knowledge Systems positively influence AI-driven knowledge innovation through knowledge co-creation processes.

P2: Human-Centred AI mediates the relationship between knowledge co-creation and knowledge incubation.

P3: Knowledge incubation processes positively influence inclusive and sustainable innovation outcomes.

P4: Policy and ecosystem support moderate the relationships among knowledge co-creation, AI integration, and innovation outcomes.

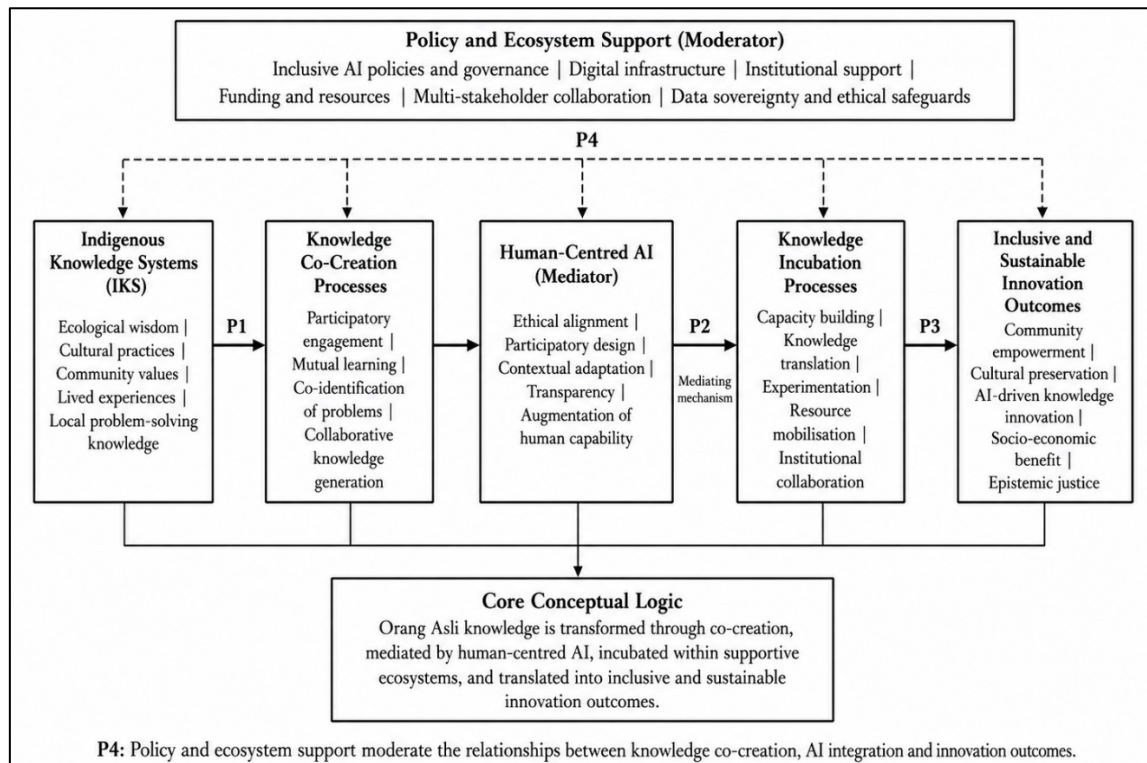


Fig. 2. Human-Centred Indigenous AI Knowledge Incubation (HCI-AIKI) Conceptual Framework

Ultimately, the HCI-AIKI framework advances existing literature by offering a holistic, integrative model that bridges AI, Orang Asli knowledge and innovation ecosystems within a human-centred paradigm. It moves beyond traditional technocentric approaches by emphasising cultural inclusivity, ethical responsibility, and community empowerment. In the Malaysian context, indeed, the framework provides a conceptual foundation for reimagining research incubation processes that are aligned with national digital transformation goals while preserving Orang Asli knowledge and promoting social equity. By positioning Orang Asli communities as catalysts of innovation, the framework contributes to the development of more inclusive, sustainable and contextually relevant AI-driven knowledge ecosystems.

5. Discussion

The proposed Human-Centred Indigenous AI Knowledge Incubation (HCI-AIKI) framework offers an integrative perspective on how artificial intelligence (AI) can interact with Orang Asli knowledge systems to foster inclusive and sustainable innovation in Malaysia. The framework synthesises Human-Centred Artificial Intelligence (HCAI), indigenous epistemologies, Innovation Ecosystem Theory, and Decolonial Theory to explain how AI-driven knowledge innovation can be reconfigured to become more equitable, culturally grounded, and socially meaningful. Rather than treating technological advancement as the primary determinant of innovation, the framework positions

Orang Asli knowledge, human agency, ethical AI, and supportive institutional ecosystems as interconnected components of the innovation process.

5.1 Reframing AI-Driven Innovation through Orang Asli Epistemologies

A central theoretical contribution of this study is the reconceptualisation of AI-driven innovation as not merely a technological process but also an epistemological process. Existing literature has largely conceptualised AI as a mechanism for enhancing efficiency, productivity, knowledge processing, and data-driven decision-making [3,15]. Although these perspectives demonstrate the technological value of AI, they may inadequately account for the diversity of knowledge systems that can inform innovation processes.

By foregrounding Indigenous Knowledge Systems (IKS), the HCI-AIKI framework challenges the dominance of Western-centric epistemologies and introduces a more pluralistic approach to knowledge innovation [16,20]. Indigenous epistemologies emphasise relationality, contextuality, lived experience, and holistic understanding, providing alternative and complementary approaches to conceptualising and addressing complex societal and environmental problems [23,40]. Integrating such perspectives into AI-driven innovation can broaden the knowledge base from which technological solutions are developed and enhance their contextual relevance, particularly in addressing local challenges related to environmental sustainability, biodiversity, resource management, and community development.

This approach is consistent with growing calls for epistemic diversity within innovation ecosystems, whereby multiple knowledge systems are recognised as legitimate contributors to knowledge production and innovation [19,20]. The HCI-AIKI framework therefore extends the conceptual boundaries of AI-driven innovation by positioning Orang Asli knowledge not as supplementary information but as a foundational knowledge resource capable of shaping innovation trajectories.

5.2 The Mediating Role of Human-Centred AI

The framework further highlights the critical mediating role of Human-Centred Artificial Intelligence (HCAI) in translating co-created indigenous knowledge into AI-enabled knowledge incubation and innovation. HCAI shifts the emphasis from technology-centred development towards value-sensitive and context-aware AI systems that prioritise human well-being, agency, ethical responsibility, and social context [12,47,10].

Within the HCI-AIKI framework, HCAI serves as a bridge between indigenous knowledge and technological innovation by ensuring that knowledge integration respects cultural integrity, community values, and equitable participation. This mediating role is particularly important in addressing ethical concerns associated with AI deployment, including algorithmic bias, data ownership, knowledge appropriation, and potential exploitation [41,REF].

Participatory design represents an important mechanism through which HCAI can operationalise these principles. Meaningful involvement of Orang Asli communities in the design, development, governance, and evaluation of AI systems may improve the contextual relevance and legitimacy of technological applications while simultaneously strengthening community agency. Rather than positioning communities as data providers or end-users, participatory HCAI recognises them as co-creators and decision-makers within innovation processes.

Furthermore, conceptualising AI as an assistive and augmentative technology rather than an autonomous substitute for human knowledge is consistent with the relational and interpretive

characteristics of Orang Asli knowledge systems [12,56]. Within this perspective, AI functions as a mechanism for augmenting human capabilities while preserving the central role of cultural interpretation, lived experience, and human judgement in knowledge processes.

5.3 Knowledge Co-Creation and Incubation as Inclusive Processes

Knowledge co-creation and knowledge incubation constitute important mechanisms through which indigenous knowledge can contribute to innovative outcomes. Co-creation represents a departure from hierarchical and top-down approaches to knowledge production towards more collaborative, reciprocal, and participatory relationships among stakeholders [47,17]. This orientation is consistent with contemporary innovation perspectives that emphasise stakeholder participation and multi-actor collaboration as important drivers of knowledge development and innovation [4,51].

Within the Malaysian context, knowledge co-creation can facilitate meaningful engagement among Orang Asli communities, researchers, policymakers, technologists, and industry actors. Such interactions provide opportunities for reciprocal learning and the integration of diverse perspectives, potentially producing hybrid forms of knowledge that combine indigenous contextual understanding with contemporary scientific and technological capabilities. This process can enhance the relevance, legitimacy, and social value of innovation while ensuring that community knowledge remains central to the development process.

Knowledge incubation extends co-creation by providing the mechanisms and support structures required to transform co-created knowledge into practical applications. These mechanisms include capacity building, experimentation, resource mobilisation, institutional collaboration, knowledge translation, and technological support [55]. The integration of Orang Asli knowledge into these processes expands the diversity of knowledge inputs within innovation ecosystems and can strengthen their contextual responsiveness and resilience. Consequently, co-creation and incubation function as complementary processes through which epistemological diversity can be translated into inclusive and sustainable innovation outcomes.

5.4 The Moderating Role of Policy and Ecosystem Support

The inclusion of Policy and Ecosystem Support as a moderating factor emphasises the importance of institutional and structural conditions in enabling inclusive AI-driven innovation. While indigenous knowledge, knowledge co-creation, and HCAI provide the epistemological and operational foundations of the framework, the effectiveness of these relationships is influenced by the wider policy, institutional, infrastructural, and governance environment.

Malaysia's national strategies relating to digital transformation and AI development provide an important enabling context for the implementation of inclusive innovation frameworks. Nevertheless, technological advancement alone may not guarantee equitable participation. Policies should explicitly recognise the rights, knowledge systems, and priorities of Orang Asli communities, particularly in relation to indigenous data sovereignty, intellectual property, informed consent, benefit-sharing, and equitable access to technological resources [31].

Institutional collaboration among government agencies, universities, research institutions, industry actors, and Orang Asli organisations is similarly important for facilitating knowledge co-creation and incubation. Strong ecosystem support can provide resources, infrastructure, institutional legitimacy, and capacity-building opportunities that strengthen the translation of indigenous knowledge into sustainable innovation. Conversely, fragmented governance, inadequate

resources, or limited community representation may weaken these relationships. Policy and ecosystem conditions therefore shape the extent to which the proposed framework can generate meaningful and sustainable outcomes.

5.5 Advancing Inclusive and Sustainable Innovation in Malaysia

The HCI-AIKI framework contributes to broader discussions of inclusive and sustainable innovation by illustrating how AI can be integrated with Orang Asli knowledge to address social and environmental challenges while promoting cultural diversity and social equity. In Malaysia, where socio-cultural diversity is a defining characteristic, integrating Orang Asli knowledge into innovation processes is particularly relevant to ensuring that technological development remains contextually responsive and socially inclusive.

By positioning Orang Asli communities as catalysts and co-creators of innovation, the framework challenges conventional narratives that position indigenous communities at the margins of development processes. Instead, it recognises their agency, expertise, and capacity to contribute meaningfully to national knowledge and innovation ecosystems. This perspective is consistent with broader international efforts to promote inclusive innovation and address structural inequalities [50].

The framework also highlights the potential for AI to contribute to sustainable development through applications such as environmental monitoring, biodiversity conservation, sustainable resource management, and community-based decision support. When these technological capabilities are integrated with the contextual and ecological knowledge of Orang Asli communities, innovation may become simultaneously technologically enabled, environmentally responsive, and culturally grounded.

5.6 Theoretical and Conceptual Contributions

From a theoretical perspective, this study contributes to the literature by integrating previously fragmented theoretical domains into a coherent conceptual framework addressing the intersection of AI, Orang Asli knowledge, and innovation ecosystems. While previous studies have commonly examined these areas separately, the HCI-AIKI framework conceptualises their interrelationships within a unified model.

First, the framework extends HCAI by incorporating Orang Asli epistemologies and positioning cultural context, indigenous agency, and epistemological diversity as important considerations in human-centred AI development. Second, it extends Innovation Ecosystem Theory by explicitly incorporating Orang Asli communities as active knowledge actors rather than peripheral stakeholders or beneficiaries. Third, the integration of Indigenous Knowledge Theory establishes indigenous epistemologies as foundational inputs into AI-driven knowledge innovation. Fourth, the incorporation of Decolonial Theory enables the framework to address power relations, representation, knowledge ownership, and epistemic justice, dimensions that may receive insufficient attention within mainstream technological innovation models.

Collectively, these contributions provide a theoretical basis for conceptualising AI-driven innovation as a socio-technical and epistemological process rather than a purely technological one. The HCI-AIKI framework therefore offers a comprehensive approach for reimagining knowledge innovation in Malaysia by connecting technological advancement with indigenous epistemologies, ethical responsibility, cultural integrity, community agency, and sustainable development.

6. Policy and Practice Implications

6.1 Policy Implications

The HCI-AIKI framework has several implications for AI and innovation policy in Malaysia. At the policy level, there is a need for inclusive AI governance frameworks that explicitly recognise and protect indigenous knowledge systems. AI policies frequently prioritise technological development, productivity, and economic competitiveness; however, inclusive AI governance should also account for cultural and epistemological diversity.

Policymakers should therefore consider mechanisms that address indigenous data sovereignty, intellectual property rights, informed consent, knowledge ownership, benefit-sharing, and the ethical use of Orang Asli knowledge. Such mechanisms are important for ensuring that Orang Asli communities retain meaningful control over how their knowledge and data are collected, represented, utilised, and potentially commercialised.

National AI strategies should also incorporate human-centred principles, including transparency, fairness, accountability, and participatory design. In particular, meaningful community engagement should be embedded throughout the development of AI applications involving Orang Asli knowledge, data, or socio-cultural contexts. Such participation can strengthen ethical governance while improving the contextual relevance and social legitimacy of AI applications.

In addition, stronger alignment is required among digital transformation, social inclusion, indigenous development, and sustainability policies. Collaboration among government agencies, research institutions, technology providers, and Orang Asli organisations can establish enabling environments for knowledge co-creation and incubation. Targeted funding, digital infrastructure, research support, and capacity-building programmes may further strengthen Orang Asli participation in AI-driven research and innovation.

6.2 Practice Implications

From a practical perspective, the HCI-AIKI framework emphasises co-design and participatory approaches in developing AI-enabled solutions. Researchers, AI developers, practitioners, and institutional actors should meaningfully engage Orang Asli communities throughout the innovation lifecycle, including problem identification, knowledge collection, system design, implementation, evaluation, and governance. Such engagement can improve the cultural responsiveness, contextual relevance, legitimacy, and sustainability of AI systems.

Educational institutions and training providers also have an important role in operationalising the framework. Capacity-building programmes can strengthen digital literacy and AI competencies among Orang Asli communities while simultaneously encouraging researchers and technology developers to develop greater understanding of indigenous epistemologies and culturally appropriate research practices. This reciprocal approach to capacity building can reduce technological asymmetries and strengthen meaningful community participation within AI-enabled knowledge ecosystems.

Practitioners should further implement ethical mechanisms for informed consent, transparency, accountability, community control, equitable benefit-sharing, and continuous feedback. These mechanisms are particularly important for mitigating risks associated with data exploitation, knowledge appropriation, and epistemic misrepresentation.

Universities, research institutions, industry actors, and government agencies may also establish collaborative platforms or knowledge-incubation hubs involving Orang Asli communities. Such platforms could facilitate experimentation, reciprocal knowledge exchange, capacity building, co-

creation, and the development of culturally grounded technological applications. Overall, operationalising the HCI-AIKI framework requires a systemic transition towards AI ecosystems in which technological innovation, ethical responsibility, indigenous agency, and cultural diversity are treated as mutually reinforcing rather than competing priorities.

7. Limitations

This study is subject to several limitations inherent in conceptual research. First, the proposed HCI-AIKI framework is theoretical and has not yet been empirically validated. Consequently, the relationships and propositions developed in this study require further examination through quantitative, qualitative, or mixed-method research to establish their empirical robustness and practical applicability.

Second, the framework is specifically contextualised within Malaysia and particularly around Orang Asli knowledge and innovation ecosystems. Its direct applicability to indigenous communities in other socio-cultural and institutional settings may therefore be limited and would require contextual adaptation. Third, although the framework integrates multiple theoretical perspectives, it cannot fully capture the considerable heterogeneity of Orang Asli knowledge systems. Orang Asli communities comprise diverse groups with distinct languages, cultural practices, epistemologies, socio-economic conditions, and relationships with technology and external institutions. The framework should therefore not be interpreted as assuming a homogeneous indigenous knowledge system.

Finally, practical implementation challenges, including disparities in digital infrastructure, resource limitations, institutional capacity, digital and AI literacy, community readiness, trust, and access to technological resources, have not been empirically examined. Future research should therefore validate the proposed relationships and propositions across different Orang Asli communities and investigate the feasibility of implementing the HCI-AIKI framework in real-world research and innovation environments.

8. Conclusion

This study advances the discourse on artificial intelligence, indigenous knowledge, and inclusive innovation by proposing the Human-Centred Indigenous AI Knowledge Incubation (HCI-AIKI) framework, which positions Orang Asli communities as central actors within AI-driven knowledge ecosystems. Moving beyond predominantly technocentric approaches, the framework integrates Human-Centred Artificial Intelligence, Indigenous Knowledge Theory, Innovation Ecosystem Theory, and Decolonial Theory to conceptualise AI-enabled knowledge innovation as an ethical, participatory, culturally grounded, and epistemologically plural process.

The framework conceptualises Orang Asli knowledge as a foundational input into knowledge co-creation, with HCAI mediating its translation into knowledge-incubation processes and ultimately into inclusive and sustainable innovation outcomes. Policy and ecosystem support further shape these relationships by providing the institutional, governance, infrastructural, and resource conditions required for meaningful participation and innovation. Through these relationships, the framework shifts the position of Orang Asli communities from passive beneficiaries or sources of data towards active knowledge holders, co-creators, and catalysts of innovation.

Within the Malaysian context, this perspective provides a conceptual foundation for aligning AI-driven digital transformation with cultural integrity, social inclusion, indigenous agency, and sustainable development. It further highlights the importance of safeguarding indigenous knowledge

through ethical governance, community participation, data sovereignty, equitable benefit-sharing, and culturally responsive technological design. Although the proposed framework remains conceptual and requires empirical validation, it provides a foundation for future research examining how AI and indigenous knowledge can interact within inclusive innovation ecosystems.

Ultimately, the HCI-AIKI framework suggests that the future of AI-driven innovation should not be determined solely by technological capability, but also by the capacity of innovation systems to recognise and meaningfully integrate diverse ways of knowing. By placing Orang Asli communities and their knowledge systems within, rather than at the margins of, AI-enabled innovation, the framework contributes towards a more equitable, culturally grounded, and sustainable approach to knowledge production and innovation in Malaysia.

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