Responsible Artificial Intelligence Literacy and Higher Learning Institutions: Extending the TOE Framework for Education in Malaysia

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ABSTRACT

Many sectors adopt Artificial Intelligence (AI) in their operations, and this includes higher education. The AI adoption opens room for pedagogical possibilities. However, institutional adoption often suffers from strategic fragmentation and a disconnect from common norms. While developing nations like Malaysia possess advanced digital infrastructure and forward-looking national policy mandates (such as MyDIGITAL, the National AI Roadmap, and the recent National Guidelines on AI Governance and Ethics), higher learning institutions (HLIs) and Technical and Vocational Education and Training (TVET) providers struggle to operationalize responsible adoption at the instructional level. The Technology–Organization–Environment (TOE) framework, effectively captures structural and managerial determinants. However, the framework misses the mediating cognitive, ethical, and critical digital competencies needed for principled technology stewardship. To resolve this limitation, this paper conceptualizes an extended TOE–RAIL–Adoption framework that integrates Responsible Artificial Intelligence Literacy (RAIL) structured along the FAccTS dimensions of Fairness, Accountability, Transparency, and Sustainability as a pivotal mediating construct theoretically underpinned by technological pedagogical content knowledge (TPACK) model. The study bridges macro-level national AI strategies with micro-level classroom adoption. The proposed study distinguishes individual literacy competencies from institutional readiness and analyzes HLIs as systemic enablers across curriculum modernization, professional development, and governance. This paper presents five research propositions, an implementation roadmap with measurable institutional indicators, and an empirical validation agenda via PLS-SEM. These ideas provide academic leaders and policymakers with an actionable blueprint.

Keywords: Artificial Intelligence Literacy, TOE Framework, Responsible AI, Higher Education, TVET, Educational Governance

INTRODUCTION

Artificial Intelligence (AI) integration into education is seeing more progress in instructional design, institutional administration, and learning outcomes in global education systems. Opportunities to personalized learning pathways, optimized administrative efficiency and facilitate data – informed academic governance are offered by generative AI models, intelligent tutoring systems (ITS), automated assessment architectures, and predictive learning analytics. (Holmes et al., 2019; UNESCO, 2023). In Malaysia, this technological trajectory is propelled by high-level national policy agendas, including the Malaysia Digital Economy Blueprint (MyDIGITAL), the National Artificial Intelligence Roadmap 2021–2025, and the recent National Guidelines on AI Governance and Ethics (AIGE, 2024) spearheaded by the Ministry of Science, Technology and Innovation (MOSTI, 2021, 2024; MDEC, 2021). Malaysia possesses fertile technological ground to pioneer AI-enabled educational transformation. This infrastructure is supported by near-universal mobile broadband penetration exceeding 130% and nationwide fiber infrastructure deployment (MCMC, 2019),

On the other hand, AI adoption across Malaysian Higher Learning Institutions (HLIs) and Technical and Vocational Education and Training (TVET) providers remains predominantly emerging, fragmented, and opportunistic (Ahmed et al., 2022; Ngoveni, 2025). There are pioneer institutions such as Universiti Putra Malaysia (UPM), Universiti Pendidikan Sultan Idris (UPSI), Universiti Teknikal Malaysia Melaka (UTeM), and UCSI University that have deployed exploratory pilot initiatives and AI-infused courses (The Higher Education Review, 2022; UTeM Study, 2024). However, a systematic, institution-wide integration remains

exceedingly rare. Students and faculty frequently embrace generative AI tools based purely on perceived usefulness and convenience, but they remain largely unequipped to critically appraise algorithmic bias, intellectual property risks, and hallucinations (Rodzi et al., 2024; Yusoff et al., 2025). Concurrently, academic educators report profound pedagogical disorientation, intensified by institutional policy voids, ambiguous assessment integrity guidelines, and an absence of formal professional development (Ahmed et al., 2022; Symeou et al., 2025).

Educational researchers have widely relied on the Technology–Organization–Environment (TOE) framework to systematically diagnose technology adoption (Tornatzky & Fleischer, 1990). TOE is utilized to identify structural prerequisites such as ICT bandwidth (Technological), administrative commitment (Organizational), and external accreditation pressures (Environmental). But it has a theoretical blind spot that is; it models adoption primarily as an administrative, technical, or managerial endpoint (Wong & Yap, 2024; Tan & Lee, 2025). In comparison to traditional enterprise systems (such as ERP or basic learning management platforms), AI technologies are autonomous, probabilistic, and ethically opaque (UNESCO, 2023). Human critical agency is needed to guarantee educational efficacy.

This study resolves this conceptual gap by formulating the extended TOE–RAIL–Adoption framework. This paper introduces RAIL as a central mediating construct that converts structural readiness into sustainable, value-aligned pedagogical adoption. The study addresses five interconnected research objectives by basing them on the confluence of TOE (macro-institutional structure) and TPACK (micro-pedagogical operationalization):

- **Objective 1:** To identify the contemporary landscape opportunities and tensions of educational AI adoption within Malaysian HLIs and TVET institutions.
- **Objective 2:** To identify the theoretical boundary conditions of the classical TOE framework.
- **Objective 3:** To systematically conceptualize RAIL along four operational dimensions (Fairness, Accountability, Transparency, and Sustainability - FAccTS) with measurable educational indicators.
- **Objective 4:** To formulate five testable propositions and an actionable institutional implementation roadmap to guide empirical validation and practice.

LITERATURE REVIEW

Review of AI in Higher Education: Global Trends and the Malaysian Context

The spread of generative foundation models has changed academic discourse from hypothetical potential to urgent governance (Holmes et al., 2019; Tadimalla & Maher, 2025). Globally, scholars caution that unregulated educational AI adoption introduces severe systemic hazards, including epistemic dependence, algorithmic surveillance, automated reproduction of racial and gender biases, and the commodification of student cognitive data (Selwyn, 2019; Livingstone & Sefton-Green, 2016). UNESCO's (2023) global guidance cautions that without explicit human-centric governance, AI integration risks eroding pedagogical transparency and intensifying educational gaps between well-resourced and marginalized student demographics.

In Malaysia, government initiatives have historically prioritized capital infrastructure and commercial competitiveness (MDEC, 2021). The National AI Roadmap 2021–2025 established a dedicated focus on AI talent pipelines. However, its translation into higher education has been heavily skewed toward technical computer science faculties, leaving mainstream social science, arts, teacher education, and TVET curricula

unaddressed (Fachrurrazy et al., 2025; Yin Sim et al., 2024). Recent empirical inquiries within Malaysian public and private universities reveal an operational flaw. Students demonstrate high behavioral adoption rates and utilitarian satisfaction with generative tools (Mansoor et al., 2024), On the other hand, their ethical literacy, algorithmic skepticism, and knowledge of data governance remain low (Rodzi et al., 2024; Yusoff et al., 2025). At the same time, university educators acknowledge high cognitive anxiety regarding academic misconduct, generative plagiarism, and the lack of clarity of automated evaluation platforms, working without formal institutional direction (Le & Ahmad, 2024; Tan & Lee, 2025).

Theoretical Deficiencies of the Classical TOE Framework in AI Adoption

The TOE framework (Tornatzky & Fleischer, 1990) provides a widely validated taxonomy for evaluating organizational innovation diffusion across higher education (Wong & Yap, 2024; Iskandarova et al., 2024). However, conventional applications of TOE to educational technology treat the adoption decision as binary (e.g., system deployment frequency, software license usage, or LMS login metrics). Table 1 presents Critical Analysis of TOE Dimensions and Observed Limitations in Educational AI.

Table 1: Critical Analysis of TOE Dimensions and Observed Limitations in Educational AI

TOE Dimension	**Conventional Factors in Education Literature**	**Typical Empirical Focus**	**Observed Gaps & Theoretical Deficiencies**
Technological	Infrastructure, hardware availability, perceived compatibility, relative advantage.	Holmes et al. (2019); MCMC (2019)	Treats technology as a static, predictable tool; overlooks algorithmic opacity, hallucinations, model bias, and continuous generative change.
Organizational	Leadership variation, financial resource allocation, administrative IT support.	Malaysia Education Blueprint (2015–2025)	Assumes top-down managerial control; ignores academic freedom, pedagogical agency, faculty anxiety, and The lack of ethical review boards.
Environmental	Government mandates, accreditation standards, competitive industry demand.	MOSTI (2021); MDEC (2021)	Focuses on macro-policy pressure; fails to account for the lack of micro-level operational translation into instructional rubrics and codes of conduct.

Classical TOE fails to account for the normative and cognitive mediation required when deploying tools that possess agency and generative capabilities. There is a need for an intermediate literacy and ethical mechanism because high structural readiness alone accelerates uncritical, superficial, or ethically compromised technology adoption.

Conceptualizing RAIL

This study conceptualizes RAIL where the concept is expanded upon multidimensional literacy constructs (Chee, Ahn, & Lee, 2025; Nahar et al., 2025). The concept integrates ethical philosophy, critical digital sociology, and pedagogical stewardship. This will help to address the limitations of conventional digital literacy models, which focus predominantly on technical operations and functional software mastery. RAIL framework is drawn upon UNESCO's ethical recommendations (UNESCO, 2023) and Malaysia's national ethics frameworks (Mohamed Yusof et al., 2023; MOSTI, 2024). Below are the four core dimensions (FAccTS) of RAIL:

- **Fairness & Bias Mitigation:** Develop the cognitive capacity to identify algorithmic stereotypes and socio-demographic biases by questioning training data distributions and actively preventing biased results in AI-assisted grading, content generation, and administrative selection.

- **Accountability & Human Agency:** The recognition of human responsibility in AI-assisted decisions to safeguard pedagogical primacy, prevent automation bias, and maintain rigorous intellectual integrity in academic scholarship (Noller & Thimesch, 2025).
- **Transparency & Explainability:** The practical ability to audit AI decision-making workflows, demand explainable outputs from automated systems, practice honest disclosure/attribution of AI-generated content, and understand the provenance of intellectual assets (Chan et al., 2025).
- **Sustainability & Socio-Pedagogical Integrity:** The commitment to evaluating the ecological costs (computational energy consumption), socio-cultural repercussions, and long-term cognitive impacts of cognitive offloading on deep critical thinking and lifelong learning (Selwyn, 2019; Shorouk, Benlahcene, & Govindarajoo, 2025).

Table 2: Dimensions of RAIL, Operational Definitions, and Measurable Educational Indicators

RAIL Dimension	Core Operational Definition	Key Measurable Indicators in Educational Contexts
Fairness	Ability to detect, critically analyze, and counteract bias and discrimination in AI systems.	• To measure the capability of the faculty to audit automated assessment rubrics for demographic skew.
		•To measure the capability to identify students' gender/cultural stereotypes in generative model outputs.
Accountability	Preservation of human moral agency and adherence to academic/professional integrity.	• Implementation of human validation for all AI-assisted academic decisions.
		• Adherence to clear institutional AI attribution procedures in coursework and research.
Transparency	Comprehension of algorithmic mechanics, explainability, and disclosure of tool utility.	• Capability to articulate underlying generative limitations and hallucination risks.
		• Application of structured AI communication logs in academic course work.
Sustainability	Safeguarding epistemic autonomy, cognitive development, and socio-environmental health.	• Sustained growth of foundational cognitive problem-solving without premature AI offloading.
		• Curricular addition of environmental and energy effects of large-scale AI computational models.

Differentiating Individual Competencies from Institutional AI Readiness

This study identifies an explicit theoretical distinction between these two levels of analysis:

- **Institutional AI Readiness (Macro/Meso Level): It r**efers to the organizational and environmental capacity of an HLI to aid digital transformation. It includes technological capital such as high-performance compute clusters, secure API access, and campus-wide licensing. Next, there is organizational capital that encompasses of strategic leadership commitment, dedicated fiscal resources, and formal institutional ethics review committees. Finally, regulatory compliance structures that include alignment with MOHE, MQA, and MOSTI directives (Ngoveni, 2025).
- **Individual AI Literacy / RAIL (Micro Level):** This **r**efers to the internalized knowledge, ethical values, self-efficacy, and critical discernment that all educators, researchers, and students have (Chee et al., 2025; Nahar et al., 2025).

The difference between institutional readiness and individual RAIL is that the former provides the enabling infrastructure and boundaries; on the other hand the latter provides the cognitive and normative capability to

execute educational tasks responsibly. As a result, possessing only high institutional readiness produces compliance failures, student academic dishonesty, and superficial tool utilization. Conversely, high individual literacy within an institution lacking technological readiness produces structural friction and faculty frustration.

HLIs as Systemic Enablers

HLIs include research universities, comprehensive universities, and TVET colleges. These institutions are not passive consumers of technology, but they serve as systemic enablers and institutional intermediaries (Burneo-Arteaga et al., 2025; Mutia et al., 2024). By referring to Table 3, HLIs occupy a unique meso-level position that enables them to interpret abstract macro-level policy declarations (e.g., MyDIGITAL, MOSTI guidelines) into concrete pedagogical standards, disciplinary syllabi, and professional norms.

Table 3: HLIs as Systemic Enablers Across Four Core Operational Functions

HLI Functional Domain	**Strategic Interventions for RAIL Cultivation**	**Policy & Regulatory Alignment**
Curriculum Modernization	• Implement obligatory RAIL courses across undergraduate and postgraduate degrees.	• Malaysia Education Blueprint (Higher Education)
	• Implement TVET micro-credentials concentrating on practical ethical AI utilization.	• Malaysian Qualifications Agency (MQA) Guidelines
Faculty Professional Development	• Perform continuous professional development (CPD) programs on ethical prompt pedagogy.	• MOHE Higher Education Digital Transformation Plan
	• Begin certification systems for AI-assisted pedagogical assessment.	• HRD Corp Upskilling Framework
Applied Pedagogical Research	• Establish controlled 'AI Sandbox Laboratories' to pilot emerging models.	• National AI Roadmap 2021–2025
	• Perform experimental audits on educational software to assess algorithmic bias and hallucination rates.	• National Guidelines on AI Governance & Ethics (AIGE)
Policy Translation & Governance	• Devise institutional AI governance toolkits, data privacy charters, and acceptable-use policies.	• Personal Data Protection Act (PDPA 2010)
	• Establish Institutional AI Ethics Committees (IAIEC).	• National Digital Economy Blueprint (MyDIGITAL)

METHODOLOGY

Design and Search Strategy

The study aims to develop a conceptual framework at the intersection of emerging technologies, organizational behavior, and educational ethics (Grant & Booth, 2009; Green, Johnson, & Adams, 2006). The literature identification and screening process was structured following PRISMA guidelines across peer-reviewed databases from January 2019 to February 2026.

Formal literature searches were conducted across Scopus database. The Boolean search string applied was:

Search String: *("Responsible AI" OR "AI literacy" OR "artificial intelligence literacy") AND ("higher education" OR "higher learning institutions" OR "TVET") AND ("TOE framework" OR "technology adoption" OR "educational governance")*

Screening, Inclusion, and Exclusion Criteria

The identification and selection workflow yielded 284 initial records. After deduplication (removing 58 duplicate records), 226 records underwent title and abstract screening against predefined criteria:

- **Inclusion Criteria:** Studies and reports that: (i) addressed AI adoption in higher education or TVET contexts; (ii) examined teacher or student readiness and behavioral intention; (iii) analyzed digital or AI literacy frameworks; or (iv) presented relevant national or international educational policy frameworks.
- **Exclusion Criteria:** Works focused solely on commercial or industrial engineering applications of AI without pedagogical relevance; non-peer-reviewed blog posts and marketing whitepapers; and sources lacking verifiable empirical or methodological rigor.

A total of 76 full-text articles were comprehensively evaluated for quality and conceptual contribution. Ultimately, 42 focal study documents were synthesized to construct the theoretical model.

Theoretical Anchoring: Integrating TOE and TPACK

This conceptualization integrates the Technology–Organization–Environment (TOE) framework (Tornatzky & Fleischer, 1990) with the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006). The aim is to bridge macro-institutional adoption with micro-classroom instructional reality. Even though TOE provides the structural, organizational, and regulatory scaffolding needed to acquire and govern educational technology, it lacks the tool integration into teaching and learning pedagogy. TPACK addresses this pedagogical core by demonstrating that effective technological combination requires the intersection of Technological Knowledge (TK), Pedagogical Knowledge (PK), and Content Knowledge (CK).

Limitations of the Narrative Conceptual Approach

This study does not present primary quantitative survey data or longitudinal experimental interventions as it is a conceptual and theoretical synthesis. The proposed causal links are theoretical deductions formulated from peer-reviewed literature. Consequently, the generalizability of the model requires empirical verification across different HLI archetypes (research-intensive universities versus TVET colleges). Furthermore, because AI capabilities and national regulations change rapidly, continuous empirical re-evaluation of the indicators will be necessary.

THEORETICAL FRAMEWORK

The development of the theoretical framework for this study is grounded in the Technology–Organization–Environment (TOE) framework, originally proposed by Tornatzky and Fleischer (1990), which has been widely applied to analyze the adoption of technological innovations in organizational contexts, including higher education (Wong & Yap, 2024). The TOE model identifies three key dimensions that influence innovation adoption: technological readiness (e.g., infrastructure, compatibility), organizational capacity (e.g., leadership, resources, training), and environmental pressures (e.g., policy, market demand, accreditation). In the Malaysian context, this framework has been used to study the implementation of e-learning systems, digital libraries, and ICT tools in higher learning institutions (HLIs). However, the traditional TOE framework reveals a critical limitation: it focuses mainly on structural and managerial conditions while lacking the pedagogical, ethical, and literacy dimensions of technology integration. The identified gap necessitates an extension of the TOE model to account for accountable and human-centered AI adoption in education.

This study expands the TOE framework by introducing Responsible Artificial Intelligence Literacy (RAIL)

as a mediating construct that ties technological adoption with ethical and educational outcomes. RAIL integrates the FAccTS principles of Fairness, Accountability, Transparency, and Sustainability as defined by UNESCO (2023). This transforms AI adoption from a purely infrastructural or administrative decision into a literacy-driven, ethically grounded process. The benefits of RAIL extend to educators where RAIL enables the identification of bias in AI-generated content and the protection of student data. Next, students benefit from RAIL as it fosters critical engagement with AI tools, including the ability to assess the credibility of AI-generated text; and finally, for institutional leaders, it supports the development of governance mechanisms that ensure compliance and accountability. In this extended model, Higher Learning Institutions (HLIs) act as systemic enablers that operationalize responsible AI adoption through curriculum design, faculty development, applied research, and policy translation. HLIs serve as critical intermediaries between national strategies such as MyDIGITAL and the National AI Roadmap (MOSTI, 2021) and classroom-level application, ensuring alignment with both national priorities and global ethical standards.

Table 4: Extended TOE–RAIL–Education Structural Integration Matrix

TOE Dimension	**Identified Structural & Pedagogical Barriers**	**Required Mediating RAIL Competency**	**Concrete HLI Strategic Intervention**	**Malaysian National Policy Anchor**
Technology	• Proliferation of 'black-box' commercial tools.	Transparency & Fairness:	• Deploy secure on-premise/sandboxed generative AI models.	• MyDIGITAL Thrust 2 & 4
	• High risk of student data leakage and IP theft.	Critical model audit capabilities, privacy-preserving prompt techniques, and bias assessment.	• Implement AI Tool Procurement Evaluation Checklists.	• Personal Data Protection Act (PDPA 2010)
	• Unequal computing hardware across campuses.		• Establish TVET digital fabrication and AI literacy labs.	• MOSTI AI Ethics Guidelines (2024)
Organization	• Policy void and administrative inertia.	Accountability:	• Formulate Institutional AI Acceptable Use Policies (AUP).	• Malaysia Education Blueprint (Higher Education)
	• Faculty burnout and assessment disorientation.	Pedagogical integrity, human-in-the-loop validation, and ethical leadership literacy.	• Mandate Continuous Professional Development (CPD) in AI assessment.	• HRD Corp AI Upskilling Mandates
	• Lack of ethical oversight committees for AI in research.		• Establish Institutional AI Ethics Committees (IAIEC).	• MOHE AI Governance Circulars
Environment	• Shifting accreditation and MQA compliance standards.	Sustainability:	• Co-develop industry micro-credentials embedded with ethics.	• National AI Roadmap 2021–2025
	• Industry demands for AI-ready yet ethical graduates.	Socio-cultural awareness, cognitive resilience, and regulatory compliance literacy.	• Facilitate inter-university benchmarking on AI assessment integrity.	• MOSTI AI Governance & Ethics (AIGE 2024)

	• Socio-cultural diversity and regional digital divide.		• Formulate compliance toolkits aligned with MQA requirements.	• UNESCO AI Competency Framework
Cross-Cutting (Educational Core)	• Student cognitive offloading and plagiarism.	Integrated RAIL (FAccTS):	• Embed mandatory GenAI Ethics & Literacy modules into university general education (MPU).	• MOHE Digital Education Direction 2026+
	• Superficial reliance on hallucinated outputs.	Complete moral and cognitive agency over generative cognitive agents.	• Transition from memory-based assessment to authentic, process-oriented oral defense and inquiry.	• National Philosophy of Education (Falsafah Pendidikan Kebangsaan)
	• Erosion of foundational writing and analytical skills.			

Proposition Development

The TOE framework provides a strong basis for understanding the adoption of innovations within institutional contexts. The extension of TOE to the domain of artificial intelligence (AI) in higher education requires RAIL as both an outcome and a facilitating mechanism. The TOE framework makes it easier to understand the technological, organizational and environmental factors that influences and shapes institutional readiness and response (Mohamed Yusof et al., 2023). However, technological capacity, organizational support, and environmental pressures alone are insufficient to ensure ethical and sustainable AI adoption. This is because it requires investment in human capital development. The definition of RAIL is the ability to understand, perform critical evaluation, and ethically engage with AI technologies. RAIL emerges as a central construct that amplifies its impact on educational outcomes (Ngoveni, 2025; Nahar et al., 2025). By embedding RAIL into curricula, faculty development, and governance structures, Malaysian higher learning institutions can transform external mandates and internal resources into meaningful, values-driven AI practices that align with national principles of fairness, accountability, and societal well-being. This integrated approach positions RAIL as a critical mediator within the extended TOE model, ensuring that AI adoption is not merely technical but also pedagogically sound and ethically grounded.

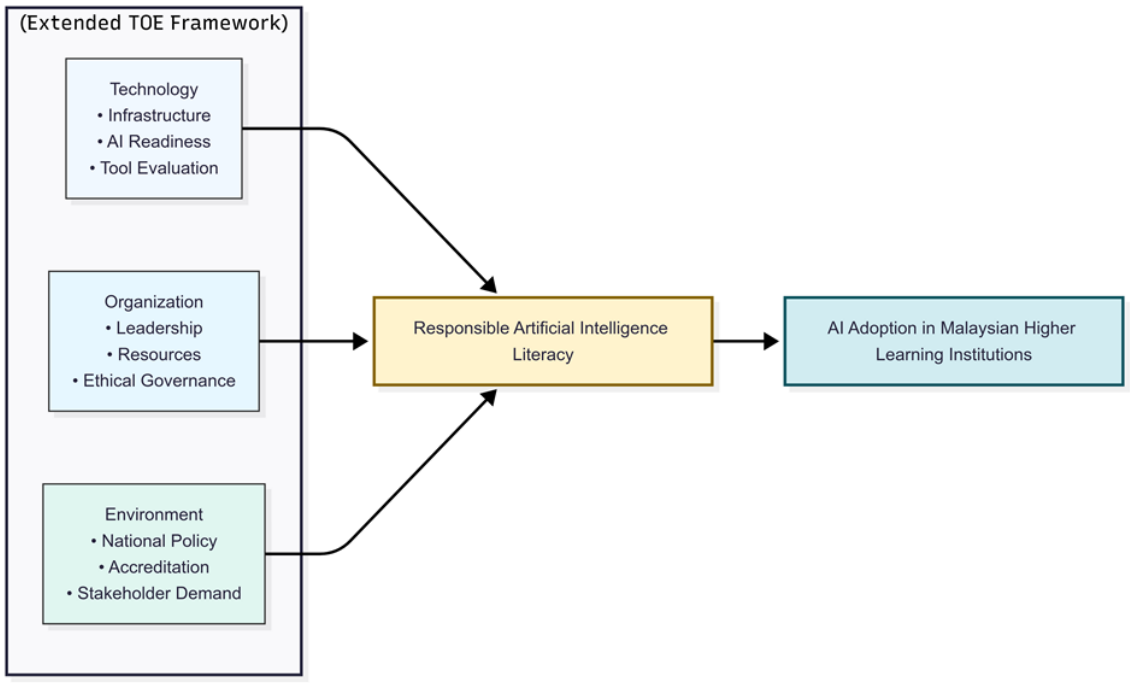


Figure 1: Conceptual Model for Responsible Artificial Intelligence Literacy and Higher Learning

Institutions: Extending the TOE Framework for Education in Malaysia

Technological Dimension and RAIL

The development of RAIL literacy in Malaysian higher learning institutions is significantly influenced by the availability of robust technology infrastructure, institutional AI readiness, and the systematic evaluation of AI tools. Reliable technological infrastructure is a prerequisite for an effective AI integration in teaching and learning environments (Ahmed et al., 2022). Institutional AI readiness, encompassing leadership support, faculty training, digital competencies, and organizational policies, determines the extent to which higher education institutions (HEIs) can adopt AI in pedagogically sound and ethically responsible ways (Ngoveni, 2025). Furthermore, the evaluation of AI tools must prioritize not only functionality and usability but also ethical dimensions such as algorithmic transparency, data privacy, bias mitigation, and accountability, aligning with Malaysia's 'Seven Responsible AI Principles' that embed national values like fairness and societal well-being (Mohamed Yusof et al., 2023). Without structured and ongoing assessment of AI tools, there is a risk of promoting uncritical adoption, which undermines the goals of responsible AI literacy and compromises student autonomy and academic integrity (Le & Ahmad, 2024). These elements—infrastructure, readiness, and tool evaluation—are interdependent and collectively shape an institutional environment where students can progress through the prepare-understand-apply-responsible use framework, ultimately becoming ethically informed AI users and innovators (Nahar et al., 2025). Therefore, it is proposed that:

Proposition 1: *Technology infrastructure availability, institutional AI readiness, and ethical evaluation of AI tools positively affect the development of responsible artificial intelligence literacy in Malaysian higher education institutions.*

Organizational Dimension and RAIL

Within the organizational dimension of the TOE framework, leadership commitment, resource allocation, and ethical governance structures contribute significantly to the development of responsible artificial intelligence literacy in Malaysian higher learning institutions. Strong leadership commitment ensures that AI integration is strategically prioritized, fostering a culture of innovation and accountability that cascades across academic and administrative units (Ngoveni, 2025). Adequate resource allocation which includes funding, personnel, and time—is essential to support AI-related training, curriculum development, and infrastructure upgrades, directly influencing educators' capacity to teach AI responsibly (Ahmed et al., 2022). Moreover, ethical governance structure are critical for ensuring that AI use in education adheres to national and institutional values, including Malaysia's 'Seven Responsible AI Principles,' which emphasize fairness, human oversight, and societal well-being (Mohamed Yusof et al., 2023). These organizational factors collectively create an enabling environment where responsible AI literacy can be systematically embedded into teaching and learning practices, guiding students through the prepare-understand-apply-responsible use framework (Nahar et al., 2025). Therefore, it is proposed that:

Proposition 2: *Leadership commitment, resource allocation, and ethical governance structures within higher education institutions positively influence the development of responsible artificial intelligence literacy in Malaysia.*

5.3 Environmental Dimension and RAIL

The environmental dimension within the TOE framework exerts significant pressure on Malaysian higher learning institutions to integrate responsible artificial intelligence literacy into their academic and operational frameworks. These external forces mandate institutional alignment with national digital transformation goals, which emphasize AI adoption across sectors while promoting ethical, inclusive, and human-centric technological development (Mohamed Yusof et al., 2023). Accreditation bodies increasingly expect higher education institutions to demonstrate digital competency and ethical AI integration in curricula, thereby influencing pedagogical reforms (Ngoveni, 2025). Moreover, stakeholders anticipate that graduates will possess not only technical AI skills but also the ethical discernment to use AI responsibly (Le

& Ahmad, 2024). However, these external pressures remain ineffective unless translated into actionable practices through structured AI literacy programs and robust institutional governance that operationalize national guidelines into teaching, learning, and research contexts (Nahar et al., 2025). Therefore, it is proposed that:

Proposition 3: *National policy directives, accreditation requirements, and stakeholder expectations positively influence the development of responsible artificial intelligence literacy in Malaysian higher education institutions when effectively mediated through institutional literacy initiatives and governance mechanisms.*

RAIL and Adoption

RAIL plays a key part in determining the successful adoption of AI technologies within Malaysian higher learning institutions by equipping students, educators, and administrators with the competencies needed to use AI ethically, critically, and effectively. RAIL acts as a foundational enabler that bridges the gap between technological availability and responsible utilization (Ngoveni, 2025). Institutions with higher levels of RAIL are better positioned to implement AI-driven pedagogies, research tools, and administrative systems in ways that align with national values, institutional integrity, and global ethical standards, such as Malaysia's 'Seven Responsible AI Principles,' which emphasize transparency, fairness, and human oversight (Mohamed Yusof et al., 2023). Furthermore, RAIL mitigates risks associated with misuse, overreliance, or unethical deployment of AI tools like ChatGPT, ensuring that adoption is not only technically sound but also educationally and socially responsible (Le & Ahmad, 2024). When embedded into curricula, policies, and professional development programs, RAIL fosters a culture of informed and principled AI integration, thereby increasing institutional readiness and stakeholder trust (Nahar et al., 2025). Therefore, it is proposed that:

Proposition 4: *Higher levels of RAIL positively influence the extent, quality, and sustainability of AI adoption in Malaysian higher learning institutions.*

Cross-Dimensional Mediation of RAIL

RAIL serves as a critical mediating variable in the relationship between the TOE framework and AI adoption in Malaysian higher learning institutions. While technological infrastructure, organizational readiness, and environmental pressures collectively create favorable conditions for AI integration, their impact on actual AI adoption is significantly amplified when mediated through a workforce and student body equipped with robust RAIL competencies—including ethical reasoning, critical evaluation of AI outputs, and awareness of bias, transparency, and data privacy (Ngoveni, 2025; Mohamed Yusof et al., 2023). RAIL enables institutions to translate external policy mandates such as MyDIGITAL and the National AI Roadmap, along with internal resources and leadership support, into responsible pedagogical practices and research applications (Le & Ahmad, 2024). Furthermore, institutions with structured AI literacy programs grounded in the prepare-understand-apply-responsible use framework are better positioned to align technological investments and governance structures with ethical and educational outcomes (Nahar et al., 2025). Without this mediating literacy layer, even well-resourced and policy-driven initiatives risk devolving into superficial or ethically unaccountable AI use. Therefore, it is proposed that:

Proposition 5: *RAIL mediates the relationship between the TOE factors and responsible AI adoption in Malaysian higher learning institutions.*

DISCUSSION AND PRACTICAL ROADMAP

The TOE–RAIL–Education framework proposed in this paper contributes theoretically and practically to the Malaysian AI adoption in education literature. It redefines adoption as an integration of structural readiness, literacy, and ethics and positions HLIs as systemic enablers. The model implications are elaborated in this section at the theoretical, educational, practical, and policy levels.

Theoretical Implications

Conceptually, the TOE–RAIL–Education model develops the TOE framework by adding RAIL as a mediating variable. TOE has previously been applied to educational research primarily with infrastructure and leadership drivers, at the expense of ethics and literacy (Wong & Yap, 2024). Adding fairness, accountability, transparency, and sustainability (FAccTS) to the TOE framework, this study advances theory by reconceptualizing adoption as simultaneously structural and ethical. It also lifts HLIs from being mere technology adopters to active institutional drivers applying responsible adoption.

Educational Implications

For administrators, students, and teachers, the model focuses on embedding RAIL in pedagogy. AI literacy and ethics should be included in teacher training, IT, engineering, and business curricula. Continuous Professional Development (CPD) and TVET micro-credentials are essential to prepare teachers to implement AI in a critical and reflective manner. Students should be empowered to critically examine AI outputs, rather than passively consuming them. Moreover, reforms in assessment must ensure AI-assisted evaluations are transparent and fair, preserving academic integrity and confidence in learning outcomes.

Practical Implementation Roadmap for HLIs

HLIs must shift from policy recipients to policy translators and innovators. They must establish AI Literacy Labs where teachers and learners can engage with tools in a managed sandbox environment. They must develop governance toolkits to help faculties comply with MOHE and MOSTI specifications. Applied research pilots are needed to test AI systems for bias, privacy, and pedagogical relevance before campus-wide procurement. Table 5 delineates an actionable implementation matrix detailing phased institutional interventions, operational owners, and measurable KPIs.

Table 5: Institutional Action Roadmap for Responsible AI Adoption in Malaysian HLIs

Phase & Horizon	**Strategic Action Milestone**	**Operational Owners**	**Measurable Key Performance Indicators (KPIs)**
Phase 1: Institutional Governance (Months 1–6)	• Establish Institutional AI Ethics Committee (IAIEC).	DVC (Academic), Registrar, Legal Office, IT Services	• 100% faculties covered under formal AI policy guidelines.
	• Promulgate campus-wide AI Acceptable Use Policy (AUP).		• Formalized risk assessment rubric deployed for academic AI software.
Phase 2: Professional Development (Months 6–12)	• Deploy mandatory Faculty RAIL-TPACK training.	Teaching & Learning Centers (TLC), Faculty Deans	• Minimum 80% full-time faculty certified in ethical AI pedagogy.
	• Establish university 'AI Pedagogy Sandbox Labs.'		• Documented bank of 50+ discipline-specific authentic assessment rubrics.
Phase 3: Curricular Integration (Months 12–18)	• Embed RAIL FAccTS modules into MPU General Studies.	Academic Affairs, TVET Curriculum Committees	• 100% first-year undergraduate and TVET student enrollment in RAIL modules.
	• Roll out TVET ethical AI micro-credentials.		• Pre/post assessment demonstrating measurable gains in bias detection.
Phase 4: Continuous Audit & Review (Months 18+)	• Annual review of algorithmic assessment tools.	Quality Assurance (QA) Unit, Research Ethics Board	• Annual Institutional AI Equity & Fairness Audit Report published.
	• Benchmarking against national guidelines (AIGE 2024).		• Zero recorded breaches of student data privacy via unauthorized platforms.

Policy Implications and National Agendas Beyond 2025

The TOE–RAIL–Education model is fully congruent with Malaysia's digital transformation agenda. Beyond the National AI Roadmap 2021–2025, the release of the National Guidelines on AI Governance and Ethics (AIGE, 2024) by MOSTI and the formation of the National Artificial Intelligence Office (NAIO) underscore a national commitment to ethical governance, human agency, and societal well-being. For policymakers in MOHE and the Malaysian Qualifications Agency (MQA), our framework provides practical criteria for incorporating responsible AI literacy into programmatic accreditation. Furthermore, dedicated funding must be allocated for AI literacy research and TVET upskilling, positioning Malaysia as an educational benchmark for responsible AI integration.

Theoretical Alignment Matrix for Empirical Testing

To facilitate direct empirical operationalization by future researchers, Table 6 maps each developed proposition to its underlying theoretical foundation and recommended measurement constructs.

Table 6: Proposition Alignment and Empirical Measurement Matrix

Proposition	Focal Structural Path	Primary Theoretical Grounding	Recommended Measurement Constructs & Key Literature
Proposition 1	Technology Readiness → RAIL	Extended TOE Framework (Tornatzky & Fleischer, 1990)	Hardware availability, tool evaluation checklists, API security (Ahmed et al., 2022).
Proposition 2	Organization Readiness → RAIL	Organizational Innovation Theory	Leadership commitment, budget allocation, presence of ethics review board (Ngoveni, 2025).
Proposition 3	Environment Pressures → RAIL	Institutional Isomorphism (DiMaggio & Powell)	MQA accreditation compliance, employer demand, national roadmap mandates (MOSTI, 2021, 2024).
Proposition 4	RAIL → Adoption	TPACK (Mishra & Koehler, 2006); FAccTS Model	Algorithmic bias detection, attribution adherence, epistemic agency (Nahar et al., 2025).
Proposition 5	TOE → RAIL (Mediation) → Adoption	Structural Mediation Paradigm (Baron & Kenny)	Structural Equation Modeling via PLS-SEM indirect effect bootstrapping (Hair et al., 2022).

Empirical Validation Agenda

Future research should proceed with empirical testing of the proposed model using a two-phase sequential mixed-methods design. A cross-sectional quantitative survey should be administered across public universities, private HLIs, and TVET colleges in Malaysia (targeting $N \geq 600$ faculty and academic leaders). The resulting empirical data should be analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) to estimate path coefficients, effect sizes (f^2), and the mediating effect (Variance Accounted For, VAF) of RAIL.

CONCLUSION

This paper has conceptualized and formulated the TOE–RAIL–Adoption model as an integrative theoretical framework to explain and guide adoption across Malaysian higher education and TVET institutions. By extending Tornatzky and Fleischer's classical TOE framework with RAIL as a central mediating construct, and theoretically uniting macro-institutional conditions with micro-pedagogical TPACK execution, the study reconceptualizes adoption as a multidimensional literacy.

The existing literature demonstrates that while Malaysia has established commendable digital connectivity and visionary national blueprints, institutional adoption in classrooms remains vulnerable. Students and educators frequently embrace tools based on immediate convenience while lacking the competencies to critically audit algorithmic bias, preserve intellectual property, or prevent cognitive dependency. The proposed TOE–RAIL–Adoption framework bridges this implementation gap by structuring RAIL across the four FAccTS dimensions—Fairness, Accountability, Transparency, and Sustainability and establishing HLIs as systemic enablers through curriculum modernization, continuous professional development, applied research, and proactive governance.

In summary, achieving meaningful and sustainable AI integration in higher learning requires far more than technological infrastructure and policy decrees. It demands an unwavering commitment to human agency, and institutional leadership. By embedding RAIL into the structural core of institutional adoption and establishing clear governance mechanisms, Malaysian universities and TVET institutions can ensure that AI fosters educational innovation. This hybrid framework offers a replicable roadmap for higher education ecosystems.

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