An Applied Inquiry Method for Interventionist Sciences

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Abstract. *The 21st century's most consequential applied disciplines, like software engineering, innovation management, marketing science, and strategic planning, face a profound epistemological crisis. These "interventionist sciences" actively construct the realities they study rather than merely describing pre-existing phenomena, yet they lack methodological frameworks adequate for their constructive mission. Operating within complex "phygital" spaces where physical, digital, and social dimensions are inseparably fused, these fields confront a validation crisis that threatens their scientific legitimacy and social responsibility. Classical scientific methods, designed for observational inquiry into stable natural phenomena, prove structurally inadequate for domains where intervention constitutes the primary mode of knowledge generation. Contemporary alternatives — Action Research, Design Science Research, and Lean methodologies — while offering valuable insights, fall short of providing the comprehensive, philosophically coherent, and ethically integrated framework required for navigating phygital complexity.*

This paper introduces the Adaptive Interventionist Method (AIM), a novel scientific methodology specifically designed for rigorous inquiry within interventionist domains. AIM operationalizes five core principles: phygital contextualization treating physical, digital, and social dimensions as inseparable reality; explicit ethical integration as an epistemically necessary component; model-centric epistemology focused on building adaptive representations rather than discovering universal laws; embedded observation and reflexivity acknowledging researcher participation in studied systems; and multi-dimensional validation concurrently assessing pragmatic utility, systemic viability, and ethical desirability. These principles structure a seven-phase inquiry cycle designed for adaptive learning in complex, uncertain environments.

Recognizing the meta-methodological challenge of validating a new scientific method, we propose a novel "bootstrapping" validation protocol wherein AIM systematically applies its own principles to test and refine its effectiveness through iterative real-world application. This approach offers a pathway for establishing methodological credibility while generating justifiable and responsible knowledge in the very fields that are actively constructing our socio-technical future. AIM represents not merely a methodological innovation but a foundational step toward legitimate scientific practice for the disciplines shaping the 21st century.

1. Introduction: The Epistemological Challenge

The 21st century is defined by disciplines whose primary mandate is not mapping pre-existing worlds but creating new ones. This shift presents a fundamental challenge to inherited philosophical frameworks for validating knowledge, frameworks forged for natural sciences. This transformation marks more than an incremental evolution in scientific practice; it represents a profound ontological reorientation that strikes at the heart of how we conceive knowledge itself.

The implications of this shift extend far beyond methodological preferences or disciplinary boundaries. They challenge fundamental epistemological assumptions about the relationship between knower and known, between theory and practice, between description and prescription. When the act of inquiry becomes indistinguishable from the act of creation, traditional criteria for validating knowledge claims – correspondence, falsifiability, replicability – begin to lose their foundational authority. The result is not merely a crisis of method but a crisis of legitimacy that threatens the scientific standing of some of the most consequential fields shaping our contemporary world.

1.1. The Rise of Interventionist Sciences

This section argues that disciplines such as software engineering, strategic management, marketing science, and innovation studies represent a departure from the epistemic stance of the classical natural sciences. They operate, in Searle's (1995) terms, primarily in the domain of institutional fact production — fields that are both interventionist and performative [Searle 1995], engaging in what we may call *ontological creativity*: the systematic constitution of new social realities through collective intentionality.

Searle distinguishes between brute facts — which exist independently of human beliefs (e.g., "water boils at 100°C at sea level") — and institutional facts, which exist only within systems of shared recognition and agreement (e.g., "this paper is money"). Institutional facts arise through constitutive rules of the form "X counts as Y in C," where an entity or event (X) is collectively accepted as having a particular status (Y) within a given context (C) ([Searle 1995], 28-33). In software engineering, for example, technological affordances (X) can be constituted as social capabilities (Y) within digital contexts (C), thereby generating realities such as "online identity" or "digital community." In marketing, symbolic universes are constructed in which material goods (X) count as sources of value or meaning (Y) in market contexts (C), creating "premium brands" or "lifestyle categories" as durable institutional facts. In both cases, the practice is not merely descriptive but constitutive: it brings new forms of social reality into existence and sustains them through ongoing recognition and shared practice.

This operational logic contrasts sharply with the natural sciences. In physics or biology, the object of study exists independently of the observer, and the methodological aim is to minimize the contamination of observation by intervention. The goal is to *discover* brute facts — objective features of the world that require no collective agreement to exist. In interventionist sciences, this separation collapses: the act of intervention is inseparable from the phenomenon under study. A platform's "user engagement," a firm's "market share," or a brand's "equity" are not *found* as one might find a mineral or a molecule; they are constituted through collective acceptance, sustained interaction, and institutional practice.

The ontological distinction between brute and institutional facts fundamentally alters the role of the researcher. In natural sciences, the investigator seeks to explain preexisting phenomena; in interventionist sciences, the investigator participates in the very processes through which the facts of the domain are created and stabilized. As Simon notes, such fields are concerned less with "how things are" than with "how they ought to be" or "how they can be made to be" [Simon 1996]. Here, *construction* replaces discovery as the primary mode of inquiry, and with it comes a different set of epistemic demands.

Validation, therefore, cannot rely solely on correspondence with an independent reality. It must also address pragmatic and constitutive questions: Does the intervention perform reliably within its intended institutional context? Does it generate sustainable advantage by creating and maintaining institutional facts? Can the constructed reality achieve and preserve collective acceptance over time, retaining its causal efficacy? In these domains, truth remains relevant but is not the sole arbiter of validity. *Performative efficacy* — the capacity to shape and sustain agreed-upon structures of reality — becomes decisive. This emphasis on performative efficacy, while consistent with Searle's ontology, extends beyond his framework into the methodological focus of this paper (see Section 3).

1.2. The "Phygital" Context

Interventionist disciplines operate within a context that is not merely an extension of the past but represents a distinct ontological condition: the "phygital" space [Meira 2025a]. This term does not refer to a simple layering of technology upon the world, but to the emergence of a new, hybrid reality born from the seamless integration and mutual constitution of the physical, digital, and social dimensions. In this space, these realms are no longer separable analytical categories; they are fundamentally co-dependent, each shaping and being shaped by the others in real time. Any intervention acts on this entire fabric simultaneously.

This reality exhibits complexity and emergence [Holland 2014], with dynamic interdependencies creating unpredictable ripple effects and "perpetual novelty." Challenges manifest as wicked problems [Rittel and Webber 1973], lacking definitive formulations, having no stopping rules, where every solution changes the problem itself. Artifacts embody politics [Winner 1980], systematically favoring particular social arrangements. Technology becomes an intimate co-creator of experience [Ihde 2009], actively mediating perception and social order.

1.3. The Methodological Misfit

Classical 20th-century philosophy of science struggles with these phygital, intervention-driven domains. Popper's falsification principle (2005) proves problematic when software designs with bugs are iterated rather than "refuted," and business strategies cannot be truly falsified amid countless intervening variables [Popper 2005]. The temporal structure of falsification assumes sufficient time for hypothesis testing, yet interventionist fields often require rapid adaptation cycles that outpace traditional validation timelines. Kuhn's paradigm conception (2012) offers limited traction in fields lacking stable paradigms, characterized instead by competing frameworks and rapid technological evolution where "normal science" puzzle-solving gives way to continuous paradigm disruption [Kuhn 2012]. Feyerabend's methodological anarchism (2010) — "anything goes" —

resonates with creative adaptation but provides insufficient structure for rigorous validation [Feyerabend 2010].

The replicability criterion central to classical science becomes deeply problematic in interventionist domains. A software system deployed in 2021 operates within a fundamentally different technological and social context than an ostensibly "identical" system deployed in 2025, making true replication impossible. Similarly, marketing campaigns cannot be genuinely replicated across different temporal, cultural, or competitive contexts without losing their essential character. This is not a methodological failure but an ontological reality: interventionist sciences operate within historically situated, continuously evolving systems where exact replication is not merely impractical but conceptually incoherent.

Perhaps most fundamentally, classical methods presuppose the discovery of pre-existing truths about an external reality, while interventionist sciences are predicated on the construction of new realities. This ontological mismatch renders classical validation criteria not merely inadequate but potentially counterproductive, as they may discourage the very creative, adaptive, and constructive activities that define excellence in these fields. The ethical dimension compounds this misfit: classical methods treat values as external to inquiry, precisely when interventionist sciences most need frameworks that integrate normative reflection as an epistemic necessity.

The core issue: classical methods presuppose system stability, variable control, and observer detachment unattainable in fields predicated on active intervention within complex, dynamic socio-technical systems. The result is not merely methodological inconvenience but a fundamental crisis of legitimacy that threatens the scientific standing of disciplines whose work increasingly shapes our collective future.

2. Contemporary Methodologies and Their Limitations

The limitations of classical scientific methods for interventionist domains have not gone unnoticed by methodological innovators. Over the past several decades, a range of alternative approaches have emerged, each attempting to address specific shortcomings of traditional inquiry when applied to contexts of active construction and intervention. These methodologies represent genuine advances in our understanding of how to conduct rigorous research within complex, dynamic systems where the researcher's role extends beyond observation to active participation and modification.

However, while each of these approaches offers valuable insights and practical tools, our analysis reveals that they fall short of providing the comprehensive, philosophically coherent, and ethically integrated framework required for the unique challenges of the phygital context. Their respective limitations, when viewed collectively, do not simply represent isolated weaknesses but systematically define the contours of a methodological vacuum that demands a fundamentally new synthesis. This section examines three prominent alternative approaches — Action Research, Design Science Research, and Lean methodologies — not to diminish their contributions, but to demonstrate how their specific strengths and limitations collectively map the requirements for a more adequate methodology.

2.1. Action Research: Humane but Localized

Action Research emerged from Kurt Lewin's (1946) profound recognition that traditional social science, despite its methodological sophistication, was failing in its most fundamental obligation: contributing meaningfully to the resolution of pressing human problems [Lewin 1946]. Lewin observed that the detached, observatory stance of conventional research often rendered it irrelevant to practitioners grappling with complex social challenges, creating a troubling disconnect between the generation of knowledge and its practical application.

The Action Research approach fundamentally reconceptualized the relationship between research and practice through its iterative cycle of diagnosis, planning, action, evaluation, and learning specification. This cycle embeds the researcher directly within the problem context, making them a collaborative partner with practitioners rather than an external analyst. The methodology's emphasis on participatory inquiry and its commitment to generating actionable insights while simultaneously producing theoretical understanding represented a significant advance in bridging the theory-practice divide that had long plagued applied social sciences.

Contemporary practitioners like Jean McNiff & Jack Whitehead (2011) and Ernest Stringer (2014) have further refined Action Research, emphasizing practitioner empowerment and the development of "living theory" that emerges directly from reflective engagement with practice [McNiff and Whitehead 2011, Stringer 2014]. This evolution has strengthened AR's capacity to generate contextually meaningful insights and foster genuine organizational and social change.

Despite these considerable strengths in bridging theory and practice and generating rich, contextually grounded understanding, Action Research faces significant limitations when viewed through the lens of 21st-century interventionist inquiry. The methodology's deep contextual embedding, while a source of practical relevance, makes the distillation of robust, transferable knowledge problematic. Validation criteria in AR are often pragmatic and situated, focusing on whether interventions "worked" for participants within specific contexts, an approach that, while ethically motivated, can lack the broader epistemological rigor required for building cumulative scientific knowledge. Most critically for our purposes, while Action Research excels at social contextualization and demonstrates deep humanistic values, it lacks the conceptual tools necessary for systematically analyzing the integrated *phygital* context that defines contemporary interventionist domains. Its traditional focus on specific organizational or community settings struggles to address the scale, complexity, and often invisible systemic effects characteristic of large-scale technological interventions that operate simultaneously across digital networks, physical infrastructures, and social systems.

2.2. Design Science Research: Rigorous but Instrumental

Design Science Research (DSR) emerged as a systematic response to a fundamental tension within the Information Systems field: how to reconcile the discipline's inherently constructive nature with the academy's demands for rigorous, scientifically credible research. This methodology represents perhaps the most sophisticated attempt to establish legitimate epistemological foundations for inquiry centered on the creation of novel artifacts rather than the discovery of natural phenomena.

The intellectual foundations of DSR trace back to Herbert Simon's (1996) seminal work on the "sciences of the artificial," [Simon 1996] but its systematic articulation began with March and Smith's (1995) foundational distinction between design science and natural science research [March and Smith 1995]. Their framework established that while natural science seeks to understand reality through observation and theory development, design science seeks to extend human capabilities through the creation of useful artifacts. This distinction provided crucial conceptual clarity for fields struggling to establish their scientific legitimacy while remaining true to their fundamentally constructive mission.

Alan Hevner and colleagues' (2004) landmark framework transformed this theoretical foundation into operational guidelines, establishing seven principles for rigorous Design Science Research that legitimized artifact creation as a valid form of scientific inquiry [Hevner et al. 2004]. Their work bridged the persistent gap between engineering practice and scientific standards, providing the Information Systems community with methodological tools that could satisfy both practical relevance and academic rigor. Subsequent developments by Peffers et al. (2007) offered more detailed process models [Peffers et al. 2007], while sophisticated evaluation frameworks like Venable et al.'s (2016) FEDS provided nuanced guidance for assessing the contributions of design science artifacts [Venable et al. 2016].

These advances established DSR as a methodologically mature approach capable of generating knowledge through systematic construction and evaluation. The framework's emphasis on iterative design, rigorous evaluation, and theoretical contribution has enabled researchers to produce artifacts that are both practically useful and scientifically credible, representing a genuine methodological innovation for constructive domains.

However, when viewed through the lens of AIM and the challenges of the complex phygital context, DSR's sophisticated framework reveals significant limitations that constrain its applicability to contemporary interventionist inquiry. The first and most fundamental limitation is its artifact-centricity. DSR takes the *artifact* — whether construct, model, method, or instantiation — as its primary unit of analysis. AIM, by contrast, positions the *intervention within a complex system* as its focal point of inquiry. This distinction is crucial: an AIM intervention might involve deploying a DSR-created artifact, but it necessarily encompasses the broader strategy for deployment, stakeholder negotiation, co-adaptation of user practices, emergent changes in the surrounding phygital ecosystem, and long-term systemic evolution. DSR's focus on discrete artifacts, while methodologically elegant, can lead to a narrower conceptualization of the problem space that potentially overlooks the broader systemic dynamics determining an intervention's ultimate consequences and social implications.

The second, and perhaps more profound, limitation concerns DSR's reliance on instrumental evaluation. The validation of DSR artifacts remains primarily instrumental, focused on utility and efficacy in solving defined problems, essentially asking "Does the artifact work? Does it represent an improvement over existing solutions?" While evaluation frameworks like FEDS demonstrate considerable sophistication, they remain anchored in this instrumental logic, emphasizing whether artifacts achieve their intended functional goals rather than examining whether those goals themselves are ethically appropriate, socially beneficial, or systemically sustainable. AIM mandates that pragmatic validation be concurrently and equally balanced with systemic evaluation (analyzing unintended consequences and long-term impacts) and ethical evaluation (assessing desirability, fairness, and distributive justice). In DSR, these broader considerations are often treated as external constraints or separate topics for post-hoc analysis rather than as integrated, non-negotiable components of the inquiry cycle itself.

2.3. Lean Methodologies: Pragmatic but A-Theoretical and A-Ethical

Lean methodologies represent perhaps the most practically successful approach to managing uncertainty and complexity in contemporary business environments. Originating from Toyota's revolutionary production system and subsequently adapted for entrepreneurial contexts by Eric Ries (2011) and Steve Blank (2020), these methodologies have fundamentally transformed how organizations approach innovation under conditions of radical uncertainty [Ries 2011, Blank 2020]. The core "Build-Measure-Learn" feedback loop, implemented through Minimum Viable Products (MVPs) and systematic customer feedback collection, provides a brilliant heuristic for rapid hypothesis testing in volatile market conditions.

The practical effectiveness of Lean approaches cannot be overstated. They have enabled countless startups to navigate market uncertainty with unprecedented efficiency, helping entrepreneurs avoid the classic trap of building products nobody wants while fostering a culture of empirical learning and adaptive responsiveness. The methodology's emphasis on validated learning over elaborate planning, its systematic approach to customer development, and its disciplined focus on actionable metrics have made it an indispensable tool for organizations operating in fast-moving, uncertain environments. The Lean Startup movement has democratized entrepreneurship by providing accessible, proven methods for testing business hypotheses with minimal resource expenditure.

Moreover, Lean methodologies have demonstrated remarkable versatility, extending far beyond their entrepreneurial origins to influence product development, organizational design, and strategic planning across diverse industries. Their emphasis on rapid iteration, customer-centricity, and evidence-based decision-making has introduced a valuable empirical discipline to domains previously dominated by intuition and conventional wisdom.

However, Lean's practical brilliance as a management philosophy should not obscure its fundamental limitations as a scientific methodology capable of generating robust, transferable knowledge for complex interventionist domains. These limitations are not incidental weaknesses but structural features that reflect Lean's origins and intended purposes.

The first limitation concerns the tactical nature of learning within Lean frameworks. The "Learn" component in "Build-Measure-Learn" is explicitly designed to provide just enough information to inform the next "Pivot or Persevere" decision. This learning is inherently instrumental and time-bounded, focused on immediate strategic choices rather than deep understanding of underlying mechanisms or principles. Lean does not include formal processes for abstracting these tactical learnings into durable, transferable knowledge that could inform future interventions in different contexts. AIM's "Adapt & Theorize" phase is specifically designed to address this gap, mandating the refinement of models and abstraction of patterns as core outputs of the inquiry process, thereby contributing to cumulative knowledge development rather than merely local decision-making.

The second and more fundamental limitation is Lean's a-ethical design. The methodology lacks any formal mechanisms for proactive ethical consideration or reflection on the broader social implications of interventions. This absence is not an oversight but reflects Lean's origins in competitive business contexts where ethical considerations are often viewed as external constraints rather than intrinsic design requirements. The emphasis on speed — epitomized in the "fail fast" mantra — can actively discourage the slow, careful, and inclusive deliberation required for grappling with complex ethical implications of interventions that may have far-reaching social consequences.

This creates what might be termed a "tyranny of the pivot," where short-term, easily measurable customer feedback is systematically prioritized over long-term vision, breakthrough innovation, or complex ethical considerations that require sustained reflection and stakeholder engagement. This stands in stark contrast to AIM, where ethical adaptability, grounded in normative commitments, is woven into every phase of the inquiry cycle, treating ethical reflection not as an external constraint but as an epistemically necessary component of generating responsible and truly useful knowledge.

2.4. The Methodological Requirement

These methodologies' limitations collectively define requirements for adequate new methodology:

1. **Native Phygital Integration**: Holistic ontology treating physical, digital, and social dimensions as inseparable, co-evolving reality rather than analytical categories to be studied in isolation. This requires methodological frameworks capable of tracing interactions across traditional boundaries, understanding how algorithmic changes reshape social power dynamics, how physical infrastructure constraints influence digital platform evolution, and how social practices co-constitute technological possibilities.
2. **Core Ethical Integration**: Elevating ethics from external motivation or post-hoc constraint to central, adaptive inquiry component that operates throughout the methodological cycle. This means treating ethical reflection not as compliance activity but as epistemically constitutive, essential for generating valid knowledge about interventions whose success cannot be meaningfully assessed without considering their normative implications and distributional consequences.
3. **Systemic Long-Term Evaluation**: Moving beyond validation of local success metrics to rigorous, ongoing assessment of broader systemic effects, unintended consequences, and long-term evolutionary trajectories. This requires analytical frameworks capable of detecting emergent behaviors, cascade effects, and adaptive responses that may only become apparent over extended time horizons and across multiple scales of social organization.
4. **Systematic Practice-to-Theory Pipeline**: Formal mechanisms for transforming rich, contextual learning from interventionist practice into robust, transferable theoretical knowledge that can inform future inquiries across different domains. This involves structured processes for pattern abstraction, model refinement, and principle articulation that enable cumulative knowledge development rather than merely local problem-solving.

3. The Adaptive Interventionist Method (AIM)

The critique presented in the preceding analysis underscores a significant epistemological and methodological vacuum at the intersection of contemporary applied sciences and established frameworks for scientific inquiry. To address this gap, we propose the Adaptive Interventionist Method (AIM), a comprehensive framework specifically designed for generating and validating knowledge within 21st-century interventionist domains. AIM represents not merely an incremental improvement or synthesis of existing approaches, but a fundamental reconceptualization of scientific methodology grounded in the distinctive ontological and epistemological requirements of phygital intervention.

AIM emerges from the recognition that the methodological challenges facing interventionist sciences are not superficial problems of technique but profound questions about the nature of knowledge, the role of the researcher, and the criteria for validating claims in domains where inquiry and construction are inseparable. The method is structured around five core principles that collectively address the specific limitations identified in contemporary approaches, operationalized through an iterative, adaptive cycle designed for learning and knowledge generation within complex, dynamic systems. Crucially, AIM is designed not as a static methodological prescription but as an evolving framework capable of adaptation and refinement through its own application — a feature operationalized through the novel bootstrapping validation protocol we propose.

What AIM aims to be (in one line):

> *AIM is a philosophically **grounded**, ethically **integrated**, model-centric method for **generating** and **validating** knowledge through **intervention** in "phygital" systems (inseparable physical–digital–social contexts), with validation **balancing** pragmatic efficacy, systemic effects, and explicit ethics, and with a **meta-protocol** to bootstrap-validate the method itself.*

3.1. Philosophical Foundations

AIM derives its foundational philosophy directly from the SPA (Society, Politics, Advancement) framework [Meira 2025b], which provides the necessary conceptual architecture and normative orientation for methodology designed to navigate the complexities of contemporary interventionist inquiry. The SPA framework's embrace of phygital reality, its mandate for ethical adaptability, and its focus on long-term, systemic thinking form the normative backbone that distinguishes AIM from purely instrumental or technical approaches to methodology design.

To operationalize this philosophical foundation, AIM integrates insights from several key intellectual traditions that collectively provide the conceptual tools necessary for rigorous inquiry within complex, dynamic systems. The American pragmatist tradition serves as the primary epistemological engine for AIM's adaptive, learning-oriented approach. Charles Sanders Peirce's (1992) theory of inquiry proves particularly crucial, especially his analysis of abduction as the creative, hypothesis-generating phase that initiates genuine inquiry when confronted with surprising or anomalous phenomena [Peirce 1992]. Peirce's insight that abduction is "the only logical operation which introduces any new idea" makes it essential for confronting the novel challenges and emergent behaviors characteristic of phygital systems. William James's (1907) focus on practical consequences as the ultimate measure of truth provides the philosophical bedrock for AIM's emphasis on pragmatic validation [James 1907], while John Dewey's (1938) conception of inquiry as an active, experimental process directly links knowledge generation to action and experience, a connection fundamental to interventionist domains [Dewey 1938].

This pragmatist core is complemented and enriched by contemporary theories of design and reflective practice that address the specific challenges of intervention in ill-defined, complex problem spaces. Donald Schön's (1983, 1988) seminal concepts of "reflection-in-action" and "reflection-on-action" ground the iterative, responsive nature of the AIM cycle [Schön 1983, Schön 1988], while his analysis of design as a "conversation with the situation" captures the dynamic, interactive character of interventionist inquiry. Nigel Cross's (2011) empirical research on "designerly ways of knowing" provides insight into the cognitive strategies, such as solution-focused thinking and conjecture-analysis cycles, that enable effective intervention in problem spaces that resist traditional analytical decomposition [Cross 2011]. Finally, Peter Checkland's (1999) Soft Systems Methodology contributes crucial perspectives on framing "wicked problems" and defining system boundaries not as objective features of reality but as purposeful constructs negotiated among stakeholders, a practice essential for navigating the boundless interconnectedness and contested nature of phygital contexts [Checkland 1999].

3.2. Five Core Principles

Building upon its philosophical foundations, AIM operationalizes these theoretical commitments through five core principles that collectively define its unique methodological stance and distinguish it from existing approaches. These principles are not merely procedural guidelines but fundamental epistemological commitments that shape every aspect of the inquiry process. They function as both design constraints and evaluation criteria, ensuring that AIM applications remain faithful to the method's foundational philosophy while providing concrete guidance for navigating the complexities of interventionist research. Each principle addresses specific limitations identified in contemporary methodologies while contributing to AIM's integrated approach to knowledge generation in phygital contexts.

- **Principle 1: Pragmatic Validation**: Assessing knowledge claims and intervention effectiveness based on demonstrated utility, workability, and ability to achieve intended goals within specific contexts, while adhering to ethical principles. Drawing from James's (1907) focus on practical consequences [James 1907] and Peirce's (1992) pragmatic maxim [Peirce 1992], this principle shifts validation focus from truth-correspondence toward practical effectiveness, demanding structured and reflective approaches to pragmatic assessment.
- **Principle 2: Embedded Observation & Reflexivity**: Recognizing researcher inseparability from studied/changed systems, mandating embedded observation and systematic reflection on team influence, assumptions, and biases. Grounded in Schön's (1983) reflective practice [Schön 1983] and Pickering's (2010) "mangle of practice," [Pickering 2010] requiring multi-modal observation spanning physical, digital, and social dimensions while attending to both human and non-human agency.
- **Principle 3: Model-Centric Epistemology**: Building, testing, and refining useful models for complex system intervention rather than seeking universal laws, sup-

ported by van Fraassen's (1980) constructive empiricism [van Fraassen 1980] and Giere's (2006) perspectival realism [Giere 2006]. Models serve as tools for intervention guidance rather than universal truth claims, with knowledge accumulating through iterative refinement and context-specific validation.

- **Principle 4: Explicit Ethical Integration**: Moving ethics from periphery to center, treating ethical inquiry as epistemically necessary for valid knowledge generation. Operationalized through Value Sensitive Design [Friedman et al. 2008] and Responsible Innovation [Stilgoe et al. 2013] frameworks, framing interventions as enactments of sociotechnical imaginaries while fostering ethical adaptability through continuous governance and cultural responsiveness.
- **Principle 5: Phygital Contextualization**: Ontological commitment requiring holistic understanding of interconnected physical, digital, and social dimensions as inseparable reality, operationalized through Actor-Network Theory and Soft Systems Methodology. Rejecting reductionist approaches, this principle mandates analysis of cross-dimensional interactions as primary drivers of system behavior and intervention outcomes.

3.3. The AIM Inquiry Cycle: An Operational Framework

The theoretical commitments embodied in AIM's five core principles require systematic operationalization to guide actual research practice. This section presents the method's central contribution: a structured yet adaptive seven-phase inquiry cycle that translates abstract philosophical commitments into concrete methodological guidance. The cycle represents a carefully calibrated balance between procedural rigor and contextual flexibility, providing sufficient structure to ensure methodological coherence while maintaining the adaptability essential for navigating the unpredictable dynamics of complex phygital systems.

The cycle's design reflects AIM's fundamental recognition that interventionist inquiry cannot follow linear, predetermined paths but must remain responsive to emergent discoveries, stakeholder feedback, and evolving contextual conditions. Each phase builds systematically upon previous work while allowing for recursive loops, non-linear progression, and iterative refinement based on learning generated throughout the process. This adaptive structure ensures that the methodology remains faithful to the experimental, learning-oriented spirit of pragmatist inquiry while providing the systematic framework necessary for rigorous knowledge generation.

To demonstrate the cycle's practical application and illustrate how abstract principles translate into concrete research activities, we employ a running example throughout this section: *the development of an AI-powered code recommendation system designed to reduce bug injection rates at a large software company*. This example allows us to show how each phase generates specific outputs, how principles guide decision-making, and how the cycle's iterative nature enables adaptive learning in response to empirical discoveries and stakeholder feedback.

3.3.1. Contextualize & Frame

Purpose: Establish comprehensive, shared understanding of intervention context, goals, stakeholders, and ethical boundaries.

Core Activities: The team conducts *phygital system analysis*, mapping existing developer workflows and communication patterns (social), current codebase, development tools, and data infrastructure (digital), and physical office layouts or remote work infrastructure affecting collaboration (physical). *Stakeholder engagement* involves interviewing senior/junior developers, project managers, and QA teams. *Collaborative goal articulation* refines high-level goals into specific objectives like ”reduce critical bug rates in new check-ins by 15% within six months.” The team establishes *initial ethical protocol* with guidelines such as ”the recommender must not create chilling effects on experimental coding” and ”recommendation data cannot be used for individual performance evaluation.”

Outputs: `Context_Doc` detailing developer ecosystem; `Goals_Doc` with 15% reduction target; `EthicalProtocol_v0` outlining initial guidelines; `Framing_Doc` summarizing the problem.

3.3.2. Model & Hypothesize

Purpose: Translate contextual understanding into working models and testable hypotheses guiding intervention.

Core Activities: The team *develops dynamic models* of bug injection, perhaps statistical models linking code complexity metrics to bug frequency and qualitative models of junior developer cognitive load during complex tasks. They g*enerate hypotheses* like: ”`H1`: Providing real-time, context-aware recommendations for common API misuse patterns (digital intervention) will reduce cognitive load (social), leading to measurable critical bug decrease (pragmatic outcome), based on our developer error model.” They document uncertainties, such as risks of developers mindlessly accepting incorrect suggestions.

Outputs: `Models_Doc` detailing bug injection models; `Hypotheses_Doc` stating `H1` and disconfirmation criteria.

3.3.3. Design & Plan Intervention

Purpose: Create concrete, operational, observable intervention and evaluation plans.

Core Activities: The team designs the *intervention artifact* — the AI recommender — specifying architecture, machine learning models, and IDE integration. Concurrently, they *design the observation plan*, defining metrics (bug rates from version control, system performance logs) and methods (cognitive load surveys, developer interviews). They *refine the ethical protocol* with specific data anonymization procedures and developer consent protocols. A reflexivity plan schedules bi-weekly research team debriefs for observation and bias discussion.

Outputs: `Intervention_Spec` for AI tool; detailed `Observation_Plan`; finalized `EthicalProtocol_v1`; `Reflexivity_Plan`.

3.3.4. Intervene & Observe

Purpose: Execute plans, deploying intervention and systematically gathering real-world effects data.

Core Activities: The team *implements the intervention* by rolling out the AI recommender to pilot developer groups. They simultaneously *execute the observation plan*, collecting quantitative bug rate data and qualitative survey/interview data. *Embedded observation* involves team members participating in code reviews to observe tool usage in practice. They meticulously *document deviations* (e.g., developers finding unexpected workarounds) and maintain *reflexivity logs* capturing evolving understanding of tool impact.

Outputs: `Implemented_intervention` (live tool); rich `observational_dataset`; `deviation_documentation`, `reflexivity_records`.

3.3.5. Analyze & Evaluate (Pragmatic & Systemic)

Purpose: Transform raw data into multi-dimensional intervention effects assessment.

Core Activities: The team analyzes data performing three-part validation. *Pragmatic evaluation* assesses whether 15% bug reduction was achieved. *Systemic evaluation* analyzes interview data for unintended consequences, whether the tool led to over-reliance on AI suggestions, potentially deskilling junior developers, or created new "automation bias" bugs. *Ethical evaluation* assesses whether recommendations were equitable across developer experience levels and coding styles, and whether data collection respected privacy guidelines.

Outputs: `Analysis_Report` on bug rates; `Evaluation_Report` detailing pragmatic, systemic, and ethical findings; `Findings_Doc` synthesizing results.

3.3.6. Adapt & Theorize

Purpose: Integrate findings into existing knowledge base, refining models and abstracting transferable knowledge.

Core Activities: Based on evaluation, the team refines their models. If bug rates decreased but cognitive load did not, they revise their causal model. They *abstract transferable knowledge*, perhaps formulating new design principles: "For AI code recommenders, maximizing user trust may be more critical for bug reduction than minimizing raw cognitive load." They *evolve the ethical framework*, adding new automation bias mitigation guidelines. The team engages in *meta-methodological reflection*, noting that initial survey instruments weren't sensitive enough for nuanced developer workflow changes.

Outputs: `Models_v2_Doc` with revised theory; `Knowledge_Doc` containing new design principles; `EthicalProtocol_v2` with new guidelines.

3.3.7. Iterate or Conclude

Purpose: Make formal, evidence-based strategic decisions about inquiry future.

Core Activities: The team *conducts strategic trajectory decisions*. Finding the tool effective but carrying deskilling risks, they might decide to *iterate*, initiating a new AIM cycle focused on redesigning the UI to encourage critical thinking rather than blind acceptance. Alternatively, they could *scale* the current version to more teams while shifting to *continuation & monitoring* mode, closely tracking long-term skill development. Regardless, they perform *knowledge consolidation and dissemination*, documenting the entire cycle and sharing new design principles with other organizational teams.

Outputs: `Decision_Record` to iterate on UI; `Final_Report` of first cycle; `Dissemination_Plan` to share findings.

4. Bootstrapping AIM: Meta-Methodological Validation

Having proposed AIM as a comprehensive framework for interventionist inquiry, we now face an unavoidable meta-methodological question: How can AIM itself be validated? Proposing a new scientific methodology necessarily entails proposing a strategy for establishing its own credibility and utility.

This section outlines such a strategy, drawing inspiration from computer science's concept of "bootstrapping" to develop a reflexive validation approach where AIM systematically applies its own principles to test and refine its effectiveness as a research methodology. Rather than seeking external validation through classical criteria, we propose an adaptive, self-correcting process that transforms the apparent challenge of methodological self-evaluation into a productive mechanism for iterative improvement and empirical demonstration of AIM's practical value.

4.1. The Validation Challenge

Validating a scientific methodology presents unique challenges distinct from theory validation. Classical approaches relying on predictive accuracy or empirical confirmation become problematic when the validation object is the inquiry instrument itself. Risks include circularity (using method principles to justify the method), difficult comparative validation (AIM addresses contexts where classical methods are inappropriate), and the impossibility of absolute proof for any methodology.

Therefore, AIM validation cannot aim for absolute correctness proof but must focus on demonstrating pragmatic value, internal coherence, usability, and capacity to guide fruitful inquiry and facilitate critical reflection through adaptive, learning processes.

4.2. The Bootstrapping Analogy and Strategy

We borrow "bootstrapping" from computer science, addressing fundamental circularity through iterative self-construction. Compiler bootstrapping [Aho et al. 2006] resolves creating new language compilers by starting with minimal "seed" compilers in existing languages, then using each generation to compile more sophisticated versions. Operating system bootstrapping [Tanenbaum and Bos 2015] orchestrates progressively capable loaders from basic firmware to complex OS kernels.

Hofstadter's (1999) "strange loops" analysis provides theoretical foundations — systems giving rise to themselves through abstraction levels [Hofstadter 1999]. AIM's bootstrap protocol creates "tangled hierarchies" where methodology is simultaneously investigation object and means, generating novel methodological effectiveness insights impossible through purely external evaluation.

Applied to methodological validation, bootstrapping suggests a progressive development strategy that parallels these computational processes. Just as compiler bootstrapping begins with a minimal seed capable of basic functionality and iteratively builds toward full capability, AIM validation starts with an initial specification — a "seed methodology" — that embodies the core principles in their simplest operational form. This seed version is then systematically applied to real interventionist problems, generating evidence about its practical utility, theoretical adequacy, and areas requiring refinement.

Each application cycle serves dual purposes: it addresses the specific research problem at hand while simultaneously testing and improving the methodology itself. The insights gained from each application inform revisions to the method, creating progressively more sophisticated and empirically grounded versions. Like the constraint-driven evolution of bootstrapped systems, each iteration operates within the limitations discovered in previous cycles while systematically expanding the method's capabilities and reliability.

This iterative refinement process transforms what initially appears as problematic circularity — using AIM to validate AIM — into a productive spiral of improvement that generates increasingly robust evidence for the methodology's effectiveness while simultaneously enhancing its practical utility for future applications.

4.3. Multi-Phase Validation Protocol

Phase 0: Define Seed AIM (v0.1) and Meta-Validation Criteria

Formalize initial AIM cycle as "AIM v0.1" representing initial methodological hypothesis. Define explicit pragmatic validation criteria addressing "What counts as evidence that AIM is useful and effective?" These include Clarity and Understandability, Guidance Utility, Operational Feasibility, Model Generation Capability (Epistemic Fecundity), Ethical Guidance (Ethical Scaffolding), and Facilitation of Learning/Adaptation.

Phase 1: Application of Seed AIM

Apply AIM v0.1 to initial, well-defined research/development projects within target domains. Primary focus on using AIM v0.1 experience and process. Researchers meticulously document how AIM guided work, where it was helpful/ambiguous, and perceived shortcomings, collecting data on method performance in guiding projects, not just project outcomes.

Phase 2: Meta-Reflection and Evaluation of Seed AIM

Systematically evaluate AIM v0.1 performance using its own principles, applying embedded observation, pragmatic, systemic, and ethical analysis to the method itself. Analyze Phase 1 documentation against meta-validation criteria. Did AIM v0.1 meet its own standards? Where did it excel/fail? Conduct root cause analysis for shortcomings.

Phase 3: Refinement and Adaptation of AIM

Based on Phase 2 findings, revise and refine AIM methodology producing improved "AIM v1.1." This might involve clarifying definitions, adding/merging steps, modifying core principles, or providing better specific technique guidance, producing more robust, usable, and effective versions directly addressing identified weaknesses.

Phase 4: Iteration and Continued Validation

Repeat cycles by applying refined AIM (v1.1) to new, potentially more complex/diverse projects. This ongoing iterative process allows AIM evolution and adaptation based on accumulating practical utility and limitation evidence. The methodology becomes a living framework, continuously improved through its own application, mirroring knowledge evolutionary nature emphasized within AIM itself.

4.4. Expected Outcom

The bootstrapping protocol does not aim for final, static AIM validity "proof." Instead, its expected outcome is more dynamic and pragmatic: a methodology demonstrably valuable and trustworthy in practice, validated through very intervention, reflection, and adaptation processes it advocates for scientific inquiry itself, establishing AIM credentials through performance and evolution rather than solely abstract argument.

5. Discussion: Implications and Future Directions

5.1. Contributions to Philosophy of Science

AIM contributes to growing work on epistemology of practice and intervention, offering specific, structured methodological proposals for rigorous knowledge generation through intervention. It develops robust pragmatic validation forms, enriching epistemological debates dominated by truth-conditional theories. Most significantly, AIM attempts deep ethics and epistemology integration, challenging views where ethics are external constraints, suggesting that in interventionist sciences, ethical reflection is epistemically necessary for responsible and useful knowledge generation.

5.2. Implications for Practice

AIM provides tangible benefits for technology, innovation, marketing, and strategy practitioners through structured learning from practice, enhancing decision-making rigor by demanding explicit modeling, hypothesis formulation, and structured evaluation. For responsible AI development, AIM guides fair, accountable, transparent system creation by forcing integrated pragmatic, systemic, and ethical consequence evaluation. For large-scale socio-technical systems like smart city infrastructure, AIM's phygital contextualization and systems thinking manage immense development and evolution complexity.

5.3. Limitations and Challenges

AIM faces significant limitations requiring careful future development. **Robust pragmatic criteria definition** requires careful work operationalizing "utility" and "effectiveness" concepts measurably and non-arbitrarily. **Ethical adaptability** must avoid unchecked relativism through strong governance mechanisms and potential core, non-negotiable ethical constraints. Deeply embedded researcher nature increases **bias potential**, requiring ongoing struggle for sufficient critical distance despite built-in reflexivity. Full AIM cycles may be perceived as **complex and resource-intensive**, necessitating "scalable rigor" research. **Epistemological parochialism** risks exist; AIM's current philosophical underpinnings are largely Euro-American rooted, requiring active testing and adaptation in dialogue with non-Western frameworks to avoid methodological colonialism.

5.4. Research Agenda

Addressing limitations requires concerted research agenda: broad empirical testing via bootstrapping protocol involving diverse teams, problems, and cultural settings; further theoretical development including deeper engagement with diverse philosophical traditions; heuristics for pragmatic criteria research; ethical governance mechanisms investigation; comparative studies with other methods as AIM matures; computational support exploration for AIM cycles, from collaborative modeling platforms to AI-assisted tools for identifying potential systemic effects or ethical risks.

6. Conclusion

This paper addressed critical disjuncture between established scientific methodology canons and contemporary applied disciplines' epistemological needs. Fields like software engineering, innovation management, and strategic planning — characterized by interventionist nature, constructivist goals, and phygital reality operation — find traditional methods inadequate for inquiry guidance and knowledge claim validation.

We proposed AIM, a novel scientific inquiry framework navigating these challenges through five core principles: pragmatic validation balanced with systemic and ethical analysis; adaptive model building rather than universal law seeking; explicit and integrated ethical adaptability emphasis; holistic phygital contextualization mandate; and embedded observation and reflexivity processes.

Recognizing inherent new methodology validation challenges, we proposed a novel meta-methodological contribution: bootstrapping validation strategy using AIM's own principles to systematically test, evaluate, and refine methodology through real-world problem application. This reflexive, self-correcting process represents potential new pathways for establishing complex, interventionist domain methodology credentials.

Twenty-first century complex phygital landscape challenges demand scientific approaches both rigorous and relevant, capable of guiding effective action while remaining critically reflective and ethically attuned. The Adaptive Interventionist Method, grounded in SPA philosophy and validated through pragmatic bootstrapping processes, represents dedicated effort to conceptualize and operationalize such approaches. While acknowledging inherent limitations, AIM holds potential to significantly enhance artificial sciences' capacity to generate reliable knowledge, foster responsible practice, and contribute more effectively to navigating and shaping our shared future. It is offered not as final answer but as robust starting point for developing rigorous, relevant, and responsible applied science our complex times require.

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A. AIM v0.1 — Integrated Specification, Algorithm and Bootstrapping Protocol

A.1. Purpose and Grounding (Opening)

This appendix consolidates AIM's formal method into a single, navigable whole. It translates the paper's philosophical stance — interventionist science in a phygital ontology, model-centric and reflexive epistemology, and ethics as epistemically constitutive — into (i) a semi-formal, principle-to-phase specification with explicit gates and artifacts Section A.2, (ii) a commented pseudo-logic that is legible to technical and methodological readers Section A.3), and (iii) a formal bootstrapping protocol that validates and evolves AIM through its own application (Section A.4). This structure mirrors the main text (principles §3.1–3.2; cycle §3.3; bootstrapping §4), enabling a clean theory $\rightarrow$ specification $\rightarrow$ algorithm $\rightarrow$ bootstrapping flow.

This matters because in domains that create (rather than merely describe) institutional facts, the intervention ***is*** the phenomenon. Accordingly, AIM evaluates knowledge by pragmatic utility, systemic viability, and ethical desirability — not by correspondence alone — while keeping reflexivity first-class.

A.1.1. Unified Notation and Variable Dictionary

We define once and reuse everywhere:

C : Context/system description across P (physical), D (digital), S (social) dimensions.
St : Stakeholders, each with attributes (perspective, interests, influence).
G : Goals, each g with a measurable success criterion $g.\texttt{criterion}$.
E_0, E, E' : Ethical protocols (initial/current/evolved).
M, M' : Models of the system before/after adaptation.
H : Hypotheses linking intervention class I to outcomes O with $H.\texttt{falsify\_if}$ clause.
$Ispec$: Intervention specification (architecture, constraints).
$Oplan$: Observation plan.
$Rplan$: Reflexivity plan.
$Data\_raw$ / $Data\_processed$: Datasets.
V_p, V_s, V_e : Validation scores: Pragmatic, Systemic, Ethical.
$\{F\}$ Findings. K_t: transferable knowledge. K: general knowledge artifacts.
$Artifacts$: $Context\_Doc$, $Goals\_Doc$, $EthicalProtocol\_v0/v1/v2$, $Framing\_Doc$, $Models\_Doc$, $Hypotheses\_Doc$, $Intervention\_Spec$, $Observation\_Plan$, $Reflexivity\_Plan$, $Analysis\_Report$, $Evaluation\_Report$, $Findings\_Doc$, $Models\_v2\_Doc$, $Knowledge\_Doc$, $Decision\_Record$, $Final\_Report$, $Dissemination\_Plan$.
$Logs$ Log_dev, $Log\_context$, Log_reflex, Log_adapt, $Log\_ethical$.

A.2. Semi-Formal Specification (Principle → Phase)

A.2.1. Core Principles (operational form)

Phygital contextualization Treat P–D–S as inseparable co-producing reality; never analyze or intervene in one layer in isolation.
Embedded observation & reflexivity Observe from within interventions; continuously audit frames, biases, and role effects.
Model-centric epistemology Prefer **adaptive models** tuned for intervention over universal laws; abduction is essential.
Explicit, adaptive ethics Ethics is **epistemic infrastructure**; it shapes design, evidence, and claims, and must evolve with evidence.
Multidimensional validation Always balance **pragmatic** performance, **systemic** effects, and **ethical** desirability (V_p, V_s, V_e).

These principles embody the paper's interventionist stance (institutional facts; performative efficacy) and SPA's commitments (holism; long-termism; responsibility). They are encoded in every phase and gate below.

A.2.2. The AIM Cycle (Seven Phases

Each phase states **why** it exists (anchor), **inputs**, **core activities/constraints**, **outputs**, and **exit gates**. Phases are recursive/non-linear; gates discipline movement and make inquiry auditable.

Phase 1 — Contextualize & Frame

Why?

Establish a shared phygital situation model and ethical baseline; make tacit assumptions explicit; prevent short-termism. (Principles 1, 4, 5)

Inputs:

`Problem_Initial`, `Team_Initial`.

Core:

Map `C := {Elements_P, Elements_D, Elements_S, Relations(P,D,S)}`.

Enumerate `St` and record perspective, interests, influence.

Define `G` with measurable `g.criterion`.

Set E_0 (principles, risks, mitigations; initial governance).

Formalize `Problem_Formal := f(C, St, G,` E_0 `)` $\wedge$ `A(assumptions)` $\wedge$ `S_longterm`.

Outputs:

`Context_Doc; Goals_Doc; EthicalProtocol_v0; Framing_Doc`.

Gates:

`Coverage(St,G)=TRUE;` \verbCoherence(—`Problem_Formal, G,` E_0`)=TRUE; S_longterm` documented.

Phase 2 — Model & Hypothesize

Why?

Convert context into explanatory/abductive models and testable claims with uncertainty explicitly bounded. (Principles 2, 3, 4)

Inputs:

`Context_Doc`, Goals_Doc, Framing_Doc.

Core:

Build `{M}` with assumptions, uncertainty, `adapt_rules`.

Generate `{H}`: for class `I`, link `M` $\wedge$ `I` $\rightarrow$ `O` with `H.falsify_if` specified.

Outputs:

`Models_Doc; Hypotheses_Doc`.

Gates:

$\forall$`M`, assumptions/uncertainty/`adapt_rules` documented; $\forall$ —`H`, `testable` $\wedge$ `H.falsify_if` defined; trace `G` $\to$ `H`.

Phase 3 — Design & Plan Intervention

Why?

Produce an operational intervention and observation system that are ethically governed and reflexively instrumented. (Principles 2, 4, 5)

Inputs:

Models_Doc; Hypotheses_Doc; Goals_Doc; EthicalProtocol_v0.

Core:

`Ispec := Design({H}, G)` with architecture, constraints.

`Oplan :=` {Metrics, Methods, Instruments} with coverage of `{H}`, `G`.

`E := Refine(`E_0`, Ispec)` $\to$ `EthicalProtocol_v1`.

`Rplan :=` cadence/prompts/roles for reflexivity.

Outputs:

`Intervention_Spec; Observation_Plan; EthicalProtocol_v1; Reflexivity_Plan.`

Gates:

`Feasibility(Ispec)=TRUE; Coverage(Oplan,{H},G)=TRUE; Compliance(Ispec, EthicalProtocol_v1)=TRUE`

Phase 4 — Intervene & Observe

Why?

Act in the world and observe from within while logging deviations, context shifts, reflexive insights, and ethical posture. (Principles 1, 2, 4)

Inputs:

`Intervention_Spec; Observation_Plan; EthicalProtocol_v1; Reflexivity_Plan.`

Core:

`Execute Ispec`; run `Oplan` $\to$ `Data_raw`.

Maintain `Log_dev`, `Log_context`, `Log_reflex`, `Log_adapt`, `Log_ethical`.

Outputs:

`Data_raw`; all logs.

Gates:

`Execution_Complete(Ispec)` or documented stop;

`Data_Integrity(Data_raw)=TRUE`;

`Continuous_Reflexivity(Log_reflex)=TRUE`.

Phase 5 — Analyze & Evaluate (Pragmatic / Systemic / Ethical)

Why?

Transform evidence into multi-dimensional judgment: not just "did it work", but what it did to the system and for whom. (Principles 5, 4)

Inputs:

`Data_raw` + logs; `Goals_Doc`; `Hypotheses_Doc`.

Core:

`Data_processed := Process( Data_raw, Logs)`.

For each `H: Result(H)` ∈ `{Confirmed, Disconfirmed, Ambiguous}`.

Compute `Vp (vs. G)`, `Vs` (systemic/long-term—second-order effects, externalities), `Ve` (ethical desirability, distributional equity, protocol compliance).

`Synthesize {F} := Synthesize(Result({H}), Vp, Vs, Ve)`.

Outputs:

`Analysis_Report`; `Evaluation_Report` (`Vp`, `Vs`, `Ve`);

`Findings_Doc`.

Gates:

Justification exists for ∀`H Result(H)`; `Evaluation_Report` explicitly covers `Vp`, `Vs`, `Ve`.

Phase 6 — Adapt & Theorize

Why?

Close the practice → theory loop: revise models, abstract patterns, evolve ethics — turn situated learning into Kt. (Principles 3, 4)

Inputs:

`Findings_Doc`; `Models_Doc`; `EthicalProtocol_v1`.

Core:

If ∃`f`∈`{F}` contradicts `M` ⇒ `M' := AdaptiveRevise(M, f)`.

`Kt := Abstract({F}, C)` with scope/bounds (name, mechanism, forces, hazards).

E′ := Evolve(E, Ve) (ethics learned from outcomes).

Outputs:

Models_v2_Doc; Knowledge_Doc; EthicalProtocol_v2.

Gates:

For all $M' \neq M$: rationale + improved adaptability documented; $\forall k \in Kt$: scope conditions explicit.

Phase 7 — Iterate or Conclude

Why?

Make an explicit strategy choice: iterate, scale, or monitor; interventions rarely "end" — they change regime. (Principle 5)

Inputs:

Phase-6 outputs; Evaluation_Report.

Core:

Assess KnowledgeGap, Opportunity, Performance → Decision ∈ {ITERATE, SCALE, MONITOR}; prepare dissemination.

Outputs:

Decision_Record; Final_Report; Dissemination_Plan.

Gates:

Decision + rationale documented; Final_Report complete; Dissemination_Plan approved.

The phases concretize the main text's stance: interventions **constitute** institutional facts; validation therefore must weigh **performative efficacy** (Vp), **systemic viability** (Vs), and **ethical desirability** (Ve) together.

A.3. Pseudo Logic Operationalization (Commented)

The code mirrors A.2 exactly — same variables, artifacts, and gates — rendered as functions with short comments explaining purpose and epistemic rationale. It is a scaffold for governance and instrumentation, not machine code.

A.3.1. Main loop

```
FUNCTION Execute_AIM_Cycle(scope, entry_point="Phase1"):

  state := {
    cycle: 0,
    status: "ACTIVE",
    kb: { models: ∅, transferables: ∅, ethics: null }
  }
```

```
  WHILE state.status == "ACTIVE":
    state.cycle += 1

    // 1) Contextualize & Frame -- phygital grounding +
    // ethical baseline
    out1 := Contextualize_And_Frame(scope)

    // 2) Model & Hypothesize -- abduction + uncertainty
    // explicit
    out2 := Model_And_Hypothesize(out1)

    // 3) Design & Plan -- ethics-by-design + observability +
    // reflexivity
    out3 := Design_And_Plan(out2, out1)

    // 4) Intervene & Observe -- embedded observation,
    // disciplined logging
    out4 := Intervene_And_Observe(out3)

    // 5) Analyze & Evaluate -- triad Vp/Vs/Ve
    out5 := Analyze_And_Evaluate(out4, out2, out1)

    // 6) Adapt & Theorize -- models/ethics evolve; abstract Kt
    out6 := Adapt_And_Theorize(out5, out4)

    // Persist knowledge
    state.kb := update_kb(state.kb, out6)

    // 7) Iterate or Conclude -- explicit decision, with
    // rationale
    out7 := Iterate_Or_Conclude(out6, out5)

    IF out7.decision in {"ITERATE","SCALE"}:
      scope := adjust_scope(out7.decision)
    ELSE:
      state.status := "MONITORING"
    ENDIF

  ENDWHILE

  RETURN state.kb
END
```

Listing 1. Main AIM execution loop

A.3.2. Phase procedures (with gates)

```
FUNCTION Contextualize_And_Frame(scope):
```

```
  C  := map_phygital(P, D, S)
  St := enumerate_stakeholders(C)  // record perspective,
     interests, influence
  G  := define_goals_with_criteria()
  E0 := draft_initial_ethics(C, St, risks, mitigations)
  A  := elicit_assumptions()
  S_longterm := document_long_horizon_implications(C)

  Problem_Formal := f(C, St, G, E0, S_longterm) ∧ A

  REQUIRE coverage(St, G) AND coherence(Problem_Formal, G, E0)
          AND documented(S_longterm)

  RETURN {Context_Doc, Goals_Doc, EthicalProtocol_v0: E0,
     Framing_Doc}
END
```

Listing 2. Phase 1 — Contextualize & Frame

```
FUNCTION Model_And_Hypothesize(out1):
  {M} := build_models(out1.Context_Doc)
  {H} := generate_hypotheses(M, candidate_interventions)

  REQUIRE documented({M}.assumptions, uncertainty, adapt_rules)
  REQUIRE ∀H: testable(H) AND defined(H.falsify_if)
  REQUIRE traceability(G → {H})

  RETURN {Models_Doc, Hypotheses_Doc}
END
```

Listing 3. Phase 2 — Model & Hypothesize

```
FUNCTION Design_And_Plan(out2, out1):
  Ispec := design_intervention(out2.{H}, out1.Goals_Doc)
  Oplan := design_observation_plan(out2.{H}, out1.Goals_Doc)
  E     := refine_ethics(out1.EthicalProtocol_v0, Ispec)
  Rplan := design_reflexivity_plan()

  REQUIRE Feasibility(Ispec)
  REQUIRE Coverage(Oplan, out2.{H}, out1.Goals_Doc)
  REQUIRE Compliance(Ispec, E)

  RETURN {Intervention_Spec: Ispec, Observation_Plan: Oplan,
          EthicalProtocol_v1: E, Reflexivity_Plan: Rplan}
END
```

Listing 4. Phase 3 — Design & Plan

```
FUNCTION Intervene_And_Observe(out3):
  Data_raw := execute(out3.Ispec, out3.Observation_Plan)
  Log_dev, Log_context := record_deviations_and_context()
```

```
  Log_reflex := run_reflexivity(out3.Reflexivity_Plan)
  Log_adapt  := track_adaptive_actions()
  Log_ethical := monitor_ethics(out3.EthicalProtocol_v1)

  REQUIRE Execution_Complete(out3.Ispec) OR documented_stop()
  REQUIRE Data_Integrity(Data_raw)
  REQUIRE Continuous_Reflexivity(Log_reflex)

  RETURN {Data_raw, Logs: {Log_dev, Log_context, Log_reflex,
                           Log_adapt, Log_ethical}}
END
```

Listing 5. Phase 4 — Intervene & Observe

```
FUNCTION Analyze_And_Evaluate(out4, out2, out1):
  Data_processed := process(out4.Data_raw, out4.Logs)

  FOR H in out2.Hypotheses_Doc:
    Result[H] := evaluate_hypothesis(H, Data_processed)

  Vp := pragmatic_validation(Data_processed, out1.Goals_Doc)
  Vs := systemic_evaluation(Data_processed, out1.Context_Doc)
  Ve := ethical_evaluation(Data_processed, out4.Logs.Log_ethical
     ,
                           current_ethics())

  F := synthesize(Result, Vp, Vs, Ve)

  REQUIRE justification_exists(∀H, Result[H])
  REQUIRE evaluation_report_addresses(Vp, Vs, Ve)

  RETURN {Analysis_Report, Evaluation_Report: {Vp, Vs, Ve},
     Findings_Doc: F}
END
```

Listing 6. Phase 5 — Analyze & Evaluate

```
FUNCTION Adapt_And_Theorize(out5, out4):
  Mprime := adapt_models(prior_models(), out5.Findings_Doc)
  Kt     := abstract_transferables(out5.Findings_Doc, context=
     out4)
  Eprime := evolve_ethics(current_ethics(), out5.
     Evaluation_Report.Ve)

  REQUIRE documented_rationale(M → Mprime)
          AND improved_adaptability(Mprime)
  REQUIRE scope_conditions(Kt)

  RETURN {Models_v2_Doc: Mprime, Knowledge_Doc: Kt,
     EthicalProtocol_v2: Eprime}
END
```

Listing 7. Phase 6 — Adapt & Theorize

```
FUNCTION Iterate_Or_Conclude(out6, out5):
  KnowledgeGap := assess_gaps(out6.Models_v2_Doc)
  Opportunity  := assess_opportunities(out6.Knowledge_Doc, out5.
     Findings_Doc)
  Performance  := assess_performance(out5.Evaluation_Report)

  Decision := decide(KnowledgeGap, Opportunity, Performance)
  Final_Report := compile_full_record()
  Dissemination_Plan := plan_sharing(out6, out5)

  RETURN {decision: Decision, Decision_Record, Final_Report,
          Dissemination_Plan}
END
```

Listing 8. Phase 7 — Iterate or Conclude

A.4. Bootstrapping AIM v0.1 (Formal Meta Validation Protocol))

AIM's credibility must be established via its own use and improvement. This protocol treats the method as an object of inquiry: apply $Spec^v$, collect evidence, compute method metrics, propose changes, and version the spec — subject to SPA guardrails. See §4 in the main text.

A.4.1. Meta Notation (extends A.0.1)

`Spec`^{v} AIM specification in force at version v (e.g., v0.1 $\rightarrow$ v1.1).
$\mathcal{A}$ Set of AIM applications (cases).
`Tr` Tranche/batch of cases used for assessment.
`EP[a]` **Evidence Package** for case a: all artifacts/logs $+$ $V_p/V_s/V_e$ $+$ outcomes $+$ ambiguity incidents $+$ burden notes.
`Vm` Method-validation vector per tranche: `Vm` $= (V_{clar}, V_{guide}, V_{feas}, V_{fec}, V_{eth}, V_{adapt})$.
Each component:

- V_{clar}: Clarity
- V_{guide}: Guidance utility
- V_{feas}: Operational feasibility
- V_{fec}: Epistemic fecundity
- V_{eth}: Ethical scaffolding
- V_{adapt}: Adaptive learning

`MVS` Weighted aggregate score from `Vm` after normalization.
Δ**`Spec`** Set of Method Change Proposals (MCPs) derived from meta-analysis of $\{$`EP[a]`$\}$.
Γ meta-gates (acceptance conditions) per metaphase.

A.4.2. Meta Phases (M0–M4)

M0 — Seed and criteria

Inputs: Spec^v (v0.1), initial meta-criteria.
Activities: Fix V_m rubrics; set weights w; define EP schema; set Γ_{M0}.
Outputs: Bootstrapping Charter; V_m rubric; EP schema.
Gate $\Gamma M0$: Rubrics ratified; EP schema usable by case teams.

M1 — Apply Spec^v (Tr_1)

Inputs: Spec^v; diverse cases $Tr_1 \subset \mathcal{A}$.
Activities: Each case executes Phases 1–7; compile EP[a].
Outputs: $\{EP[a] \mid a \in Tr_1\}$.
Gate Γ_{M1}: ≥80% of cases deliver all seven phase artifacts + $V_p/V_s/V_e$ + Log_ethical.

M2 — Meta-analysis

Inputs: $\{EP[a]\}$, Spec^v.
Activities: Compute V_m (per case and aggregate); compute MVS; analyze failure modes (gates missed, ambiguity causes); extract cross-case $\Delta V_p/\Delta V_s/\Delta V_e$ patterns; propose ΔSpec.
Outputs: Meta-Evaluation Report; ΔSpec.
Gate Γ_{M2}: Each ΔSpec links to specific evidence; diagnostic traceability ensured.

M3 — Refine and version

Inputs: ΔSpec; Charter.
Activities: Prioritize ΔSpec; run SPA guardrails (no change weakens ethical vigilance or systemic evaluation); issue Spec^{v+1}; update rubrics if needed.
Outputs: Spec^{v+1}; Changelog with rationale; updated V_m rubric.
Gate Γ_{M3}: Changes preserve phygital holism, triad validation, ethical adaptability.

M4 — Iterate with $Tr_2, Tr_3, \ldots$

Inputs: Spec^{v+1}, next tranche(s), optional Baseline.
Activities: Repeat M1–M3; broaden contextual diversity; where feasible, compare Spec^v vs Spec^{v+1} or alternative methods.
Outputs: Series $\{V_m^t, MVS^t, \text{Spec}^{vt}\}$.
Stop/scale rules: Stabilization (MVS $\geq \theta$ and variance ↓ across ≥2 tranches), diminishing returns ($|MVS^t - MVS^{t-1}| < \varepsilon$ while burden ↑), or scope unlock (e.g., define an AIM-Lite profile). Decisions recorded in Method Decision Record.

A.4.3. `Vm` Metrics (Operational Sketch)

$$V_{\text{clar}} = 1 - \frac{\text{ambiguity incidents}}{\text{major decisions}}$$

$$V_{\text{guide}} = \frac{\#\text{decisions citing Spec guidance}}{\text{total material decisions}}$$

$$V_{\text{feas}} = \left(\frac{\text{gates passed first try}}{\text{total gates}}\right) \times \left(\frac{\text{planned}}{\text{actual artifact time}}\right)$$

$$V_{\text{fec}} = \text{Normalized yield of } M' \text{ revisions and } K_t \text{ per cycle}$$

$$V_{\text{eth}} = \text{Share of harms flagged } \textbf{ex-ante} \text{ vs. } \textbf{ex-post} \text{ ; severity-weighted compliance with } E/E'$$

V_{adapt} = Normalized reduction in lag fom issue $\rightarrow$ corrective adaptation, plus improvement in $\Delta\ Vp$, $\Delta\ Vs$, $\Delta\ Ve$ between Spec^v and Spec^{v+1}.

Aggregate: MVS $= \sum_i w_i \cdot z(V_{\text{m}_i})$ (where z is a normalization function). Keep raw Vm for transparency.

A.4.4. Evidence Package `EP[a]` (Minimum)

Artifacts: All listed in Section A.1.1.

Logs: `Log_dev`, `Log_context`, `Log_reflex`, `Log_adapt`, `Log_ethical`.

Meta-notes: Ambiguity incidents, gate failures, burden/time by role.

Comparators: If available — baseline outcomes or prior `Spec`^{v}.

Gate: `reject_incomplete` if any required element is missing (auditability and synthesis depend on completeness).

A.5. Bootstrapping PseudoLogic

```
FUNCTION Bootstrap_AIM(seed_spec, case_pool, weights w, theta,
   epsilon):

  v := "0.1"
  Spec := seed_spec
  history := []
  tranche := 0

  LOOP:
    tranche += 1
    Tr := select_tranche(case_pool, diversity=TRUE)
```

```
    // M1: apply Spec^v
    EPs := {}
    FOR a IN Tr:
      result := Execute_AIM_Cycle(scope_of(a))
      EPs[a] := build_EP(result)

    // M2: meta-analysis
    Vm_case := compute_Vm_per_case(EPs)
    Vm_tranche := aggregate(Vm_case)
    MVS := weighted_score(Vm_tranche, w)
    ΔSpec := derive_changes(EPs, Vm_case, Vm_tranche)

    // M3: refine (SPA guardrails)
    IF approve(ΔSpec, guardrails=SPA):
      Spec := apply(ΔSpec, Spec)
      v := bump_version(v, ΔSpec)

    history.append({v, Vm: Vm_tranche, MVS, ΔSpec})

    // M4: stop/scale conditions
    IF stabilized(history, theta) OR diminishing_returns(history
       , epsilon):
      BREAK

  ENDLOOP

  RETURN {Spec, history}
END
```

Listing 9. Bootstrapping AIM

A.6. Philosophical Alignment (Why This Appendix is of a Piece with the Main Text)

- **Interventionist science & institutional facts**. AIM assumes interventions **constitute** the realities under study (Searle's institutional facts); thus success includes **stabilizing desirable social realities** — not performance alone. The triad V_p (pragmatic utility), V_s (systemic viability), and V_e (ethical desirability) operationalizes this.
- **SPA and phygital holism**. The specification mandates cross-$P/D/S$ analysis at entry (Phase 1), integrated observability (Phase 3), and long-term/systemic evaluation (Phase 5).
- **Model-centric, abductive epistemology**. Phases 2 and 6 formalize model creation and revision, embedding abduction $\rightarrow$ deduction/induction $\rightarrow$ adaptation.
- **Ethics as epistemic infrastructure**. E evolves $E_0 \rightarrow E \rightarrow E'$ and is evaluated as Ve, making ethical vigilance a condition for valid claims, not an external add-on.
- **Bootstrapping legitimacy**. A.4 encodes the paper's strategy: method credibility accrues from performance-and-evolution across tranches, not assertion

A.7. Using this Appendix (Closing)

Use **Section A.2** to **plan and govern** (principles, phases, artifacts, gates). Use **Section A.3** to **run and instrument** (procedures, preconditions, decision points). Use **Section A.4** to **evolve the method responsibly**, versioning AIM via evidence from real applications under SPA guardrails. Together, these parts enforce the validation triad (Vp, Vs, Ve) that the paper argues is necessary for legitimate inquiry in interventionist sciences, and they anchor each move back to AIM's philosophical core. This appendix is intentionally operational and reflexive: it specifies how to act, observe, decide and learn, so that AIM's validity accumulates through disciplined practice.