

Knowledge-Capital Expansion in Modernity: Public Knowledge and Epistemic Capitalization in the Age of Artificial Intelligence

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Abstract

This paper examines knowledge-capital expansion under modern conditions, with particular attention to the transformation of public knowledge into recursively expanding epistemic capacity. Building on the concepts of knowledge capital and epistemic capitalization, the inquiry situates contemporary artificial intelligence within a longer historical development of writing, archives, universities, scientific publication, digital databases, computational infrastructure, and increasingly automated knowledge production. Artificial intelligence intensifies this trajectory by expanding epistemic absorption, accelerating recombination and inquiry, enabling machine-scaled empirical investigation, and increasing the extent to which knowledge-generating processes can be organized through models, agents, compute, data, robotic systems, and other infrastructures. The paper develops the political economy of this transformation through Marxian concepts of accumulation, means of production, relations of production, automation, and alienation. Particular attention is given to the emerging position of the epistemic proletariat, whose generative capacity may increase while dependence upon externally controlled epistemic infrastructure simultaneously deepens. The analysis further examines the growing separation among epistemic production, epistemic encounter, human knowing, and subject formation. Traditional models of inquiry, learning, experience, judgment, curiosity, and self-cultivation are considered alongside philosophical accounts of the value of knowing, including instrumental, autonomous, generative, formative, and existential dimensions. The paper also identifies justice problems arising from machine-scaled capitalization of public knowledge. These include unequal capitalization capacity, concentration of generative infrastructure, generative extraction, attention scarcity, epistemic crowding, recursive visibility advantage, and the emergence of framing and definitional power. A Generative Relational perspective is introduced to analyze the delegation of knowledge-generating relations and the possible redistribution of subject formation across epistemic and non-epistemic domains. The inquiry advances neither technological optimism nor technological pessimism. It treats AI-mediated epistemic capitalization as an historically unfolding transformation whose consequences remain contingent upon changing relations of access, control, attention, experience, circulation, and generativity.

Keywords: knowledge-capital expansion; epistemic capitalization; public knowledge; artificial intelligence; epistemic infrastructure; epistemic proletariat; alienation; epistemic formation; attention economy; generative justice; Generative Relational theory

Discussion Paper Note

This paper is a conceptual and exploratory inquiry into knowledge-capital expansion under modern conditions. It develops the foundational vocabulary of knowledge capital and epistemic capitalization through the contemporary transformation of knowledge production associated with artificial intelligence, automated research systems, computational infrastructure, and the increasing availability of public epistemic resources.

The central object of inquiry is broader than artificial intelligence. Epistemic capitalization has a longer history. Writing, archives, libraries, universities, scientific publication, databases, search systems, computational tools, and institutional research infrastructures have progressively enlarged the capacity to preserve, retrieve, combine, circulate, and reproduce epistemic resources. Artificial intelligence belongs to this historical trajectory while introducing changes of scale, speed, parallelism, automation, and infrastructural integration that can substantially transform the dynamics of knowledge-capital expansion.

The paper therefore treats contemporary artificial intelligence as an especially intensive configuration of modern epistemic capitalization. Artificial intelligence can enlarge the amount of public knowledge that becomes practically capitalizable, accelerate movement between questions and possible answers, support cross-domain recombination, automate parts of research workflow, coordinate multiple epistemic agents, and increasingly connect symbolic inquiry with physical experimentation through robotic laboratories, autonomous sensors, field systems, and other machine-operated infrastructures.

The possibility of automated physical inquiry is conceptually important. The argument does not depend upon a permanent boundary between machine processing and engagement with the physical world. A sufficiently developed epistemic infrastructure can potentially formulate hypotheses, design experiments, manipulate physical objects, collect measurements, conduct fieldwork, administer surveys, perform interviews, analyze resulting data, revise models, and initiate subsequent rounds of investigation. The relevant transformation therefore concerns the organization and control of epistemic encounter rather than the mere presence or absence of contact with empirical reality.

This distinction introduces a central problem of the paper. Epistemic encounter can increasingly be separated from the human subject who requests, controls, receives, or subsequently uses an epistemic output. A human actor may direct an inquiry while models, agents, instruments, robots, and automated laboratories perform much of the intermediate epistemic activity. Knowledge production, epistemic encounter, human knowing, and subject formation can therefore follow increasingly differentiated trajectories.

The paper examines this development through several philosophical and political-economic perspectives. Marxian political economy provides one major line of analysis. The concepts of capital accumulation, expanded reproduction, means of production, relations of production, division of labor, machinery, concentration, centralization, and alienation offer resources for examining a knowledge-production system in which control of epistemic production can become increasingly separable from direct participation in epistemic labor.

The analogy requires restraint. Knowledge capital is not assumed to reproduce every property of economic capital, and automated epistemic production is not treated as a simple duplication of industrial production. The purpose of the comparison is to identify structural relations that become analytically important when actors can organize and control models, compute, data, laboratories, agents, platforms, publication systems, and other conditions of knowledge generation without directly performing every epistemic operation through which resulting outputs emerge.

Within this framework, a knowledge-capitalist position concerns control over important means and conditions of epistemic production. An epistemic-proletarian position concerns generative capacity combined with insufficient control over the principal conditions required to reproduce and amplify that capacity. Artificial intelligence can intensify this relation in a form that may initially appear paradoxical. An independent epistemic producer can become substantially more productive through access to AI while becoming more dependent upon externally controlled models, compute, APIs, databases, platforms, institutional infrastructures, or robotic systems.

Greater individual generativity can therefore coexist with greater infrastructural dependency. Access to powerful epistemic tools does not by itself imply control over the means of epistemic production. Public access to knowledge likewise does not imply equal capacity to transform that knowledge into future generative power.

Public knowledge is consequently treated in this paper as generative infrastructure. Publicly available propositions, methods, datasets, theories, questions, software, records, and other epistemic resources can enter many subsequent knowledge-producing processes. Their practical generative effects, however, depend upon heterogeneous capitalization capacities.

Artificial intelligence can enlarge this asymmetry because actors with greater compute, stronger models, larger numbers of agents, better retrieval systems, greater financial resources, robotic infrastructure, and institutional access can explore more epistemic trajectories in parallel. Capital can thereby purchase more than access to existing information. Under sufficiently automated conditions, capital can purchase scalable capacities for generating questions, performing searches, testing hypotheses, conducting experiments, collecting data, evaluating results, and recursively initiating further inquiry.

The resulting political economy extends beyond ownership of completed knowledge products. Public knowledge can remain legally and technically accessible while the infrastructures capable of transforming it into machine-scaled generative capacity become concentrated. The paper therefore distinguishes enclosure of epistemic resources from enclosure of knowledge-generating capacity.

A further layer emerges from the economics of attention. Artificial intelligence can sharply reduce the cost of producing polished epistemic artifacts while human attention remains scarce. Machine-scaled systems can therefore generate large quantities of reports, articles, explanations, summaries, reviews, databases, visualizations, and other knowledge-like products. Even when individual outputs are produced without an intention to dominate public attention, aggregate production can alter the distribution of visibility within the public knowledge field.

This possibility motivates a distinction among public availability, retrievability, visibility, and effective epistemic presence. A work can remain publicly accessible while becoming increasingly unlikely to enter future epistemic relations. Long-term, high-cost, historically accumulated, or minority knowledge can therefore become difficult to encounter when the attention environment is saturated by rapidly produced and highly optimized artifacts.

The problem is intensified when visible properties of epistemic quality become cheap to reproduce. Fluent prose, extensive references, comprehensive structure, polished visual presentation, apparent breadth, and stylistic confidence can increasingly be generated at low marginal cost. Under severe attention constraints, readers and institutions may rely more heavily upon such surface indicators when evaluating epistemic artifacts. Perceived quality can consequently become increasingly separable from the generative history, difficulty, situated experience, or duration through which an artifact was produced.

Attention can also enter recursive capitalization processes. Visibility can generate recognition; recognition can generate symbolic and institutional authority; authority can increase future retrieval and attention; repeated visibility can influence which concepts and categorizations become standard interfaces through which a domain is encountered. The paper therefore examines the possibility of attention concentration, epistemic crowding, framing power, and definitional authority within formally open knowledge environments.

These phenomena create questions of justice that extend beyond access to information. The paper distinguishes provisionally among access justice, capitalization justice, and attention justice. Access justice concerns the distribution of access to epistemic resources. Capitalization justice concerns the distribution of capacities through which those resources can be transformed into further generative power. Attention justice concerns the conditions under which epistemic contributions retain a meaningful possibility of entering future inquiry and public recognition.

The paper does not claim to possess a settled institutional solution to these problems. Restrictions on automated production, ranking interventions, licensing rules, mandatory forms of recirculation, public infrastructure, attention-allocation mechanisms, and other possible responses create further normative and institutional questions. The present inquiry identifies the mechanisms and tensions while leaving their

governance open for subsequent ethical, jurisprudential, political-economic, and institutional analysis.

The paper also examines the relation between automated knowledge production and traditional accounts of knowledge emergence. Different epistemic processes are likely to exhibit different forms and degrees of susceptibility to automation. The relevant distinction cannot be reduced to a simple opposition between symbolic knowledge and empirical knowledge. Automated systems can increasingly interact with physical environments and conduct empirical inquiry.

A more useful distinction concerns the degree to which an epistemic process is operator-invariant, operator-sensitive, relation-dependent, or participant-constitutive. Some physical measurements may be highly delegable. Interview and observational processes can depend more strongly upon the identity and behavior of the investigator. Cultural knowledge, shared memory, community interpretation, and other forms of collectively emergent knowledge can depend even more deeply upon historically situated relations among participants.

The role of shared experience is therefore retained as an open and potentially important dimension of future knowledge systems. Some epistemic and cultural objects acquire significance through integration into a subject's spatiotemporal trajectory. An artwork, historical document, testimony, photograph, ritual, place, or cultural practice can derive part of its significance from the relations and historical circumstances through which it is encountered.

The transfer of a representation does not necessarily reproduce the experiential trajectory through which its significance emerged. An artificial system can reproduce the formal appearance of an artifact, and a machine can itself participate in empirical encounters, while the relational history of one subject cannot simply be transferred into another subject through the delivery of an informational residue.

This distinction becomes particularly important under conditions of abundant synthetic production. When sophisticated surface form becomes inexpensive, provenance, situated participation, shared history, lived encounter, and relational integration may acquire increasing significance for some forms of epistemic and cultural recognition. The paper treats this possibility as an historically open development rather than a general hierarchy between human and machine production.

The broader epistemological question concerns the value of knowing itself. Artificial intelligence makes this question newly visible because another epistemic agent may increasingly perform inquiry on behalf of a human subject. The practical success of such delegation raises a prior philosophical problem: what human good has traditionally been realized through knowing for oneself?

The paper surveys several philosophical responses. Aristotelian traditions connect knowing with the desire for knowledge and human flourishing. Kantian approaches emphasize judgment, autonomy, and the active conditions through which experience becomes intelligible. Hegelian accounts connect knowing with the transformation of consciousness through mediation and revision. Existential traditions relate encounter, contingency, possibility, and interpretation to the constitution of a situated self. Phenomenological approaches emphasize world-disclosure through situated engagement. Pragmatist accounts understand inquiry through problematic situations and the reconstruction of future capacity. Hermeneutic approaches emphasize transformation of interpretive horizons. Virtue epistemology connects knowing with intellectual agency and character. Traditions of self-cultivation and investigation of things connect engagement with the world to transformation of the knower.

These perspectives suggest several distinct values of knowing. Knowing can have instrumental value through prediction and action, autonomy value through independent judgment, generative value through the creation of capacities for future inquiry, formative value through transformation of the subject, and existential value through participation in the continuing constitution of a life and its relation to the world.

The distinction among these values prevents the paper from treating successful automation of epistemic production as sufficient evidence either for human epistemic progress or for human epistemic decline. Artificial intelligence can substitute for some instrumental functions of knowing, augment some forms of judgment and generativity, create new dependencies, and alter the processes through which subjects are epistemically formed. These effects require separate analysis.

Curiosity occupies a special position within this problem. Human inquiry has never been motivated exclusively by instrumental return. Children ask repeated questions before knowledge production be-

comes connected with employment, publication, reputation, institutional recognition, or economic value. Curiosity, wonder, uncertainty, surprise, and contingent encounter can themselves initiate epistemic trajectories.

Industrialized epistemic production creates the possibility that the continuation of knowledge production becomes progressively less dependent upon immediate human curiosity. Automated systems can generate questions, explore possibilities, evaluate results, and initiate subsequent rounds of inquiry. Knowledge production can therefore acquire stronger conditions for recursive continuation through accumulated epistemic and infrastructural capital.

The paper does not infer from this development that human curiosity becomes obsolete. It instead distinguishes the reproduction of knowledge production from the generative development of the human subject. A system can produce more epistemic outputs while the people controlling or consuming those outputs undergo very different degrees of epistemic transformation.

This distinction motivates the Generative Relational contribution of the paper. Within the Generative Relational framework, inquiry can be understood as a class of generative relations through which both epistemic objects and subjects are transformed. An epistemic encounter can generate propositions, questions, concepts, methods, capacities, memories, orientations, and future possibilities while also modifying the subject's relation to the world.

The paper provisionally distinguishes three dimensions of generativity: epistemic-output generativity, epistemic-capacity generativity, and subject-formative generativity. Epistemic-output generativity concerns the production of additional epistemic objects. Epistemic-capacity generativity concerns changes in the capacity for subsequent epistemic production. Subject-formative generativity concerns transformation of the knowing subject through inquiry and encounter.

Traditional human inquiry can couple these dimensions closely. Artificially mediated knowledge production makes their partial decoupling increasingly possible. Epistemic output and epistemic productive capacity can expand rapidly while the transformation of a particular human subject follows a slower, different, or weaker trajectory.

From a Generative Relational perspective, the central concern therefore cannot be reduced to maximizing the quantity of knowledge possessed by human beings. Human subjectivity can be generated through many relational domains, including epistemic inquiry, interpersonal relations, collective participation, art, music, place, bodily practice, care, religious experience, interaction with nature, and contingent encounters.

Delegation of epistemic relations can consequently produce several historical trajectories. It can contribute to alienation when the human subject becomes increasingly detached from the generative relations through which epistemic products emerge. It can also release time, attention, and cognitive resources for other forms of relational participation and subject formation. These possibilities can coexist within the same technological transformation.

The paper therefore adopts neither a technological-optimist nor a technological-pessimist position. Artificial intelligence is treated as part of an historically unfolding transformation whose consequences depend upon relations of access, control, production, attention, dependency, encounter, circulation, institutional organization, and subsequent generativity.

This methodological stance is compatible with the historical orientation of the inquiry. Contradictions generated by new productive arrangements are treated as elements of historical development rather than evidence of a predetermined final outcome. The analysis seeks to identify changing conditions, asymmetries, dependencies, possibilities, and forms of relational reorganization while preserving the revisability of judgments as those conditions continue to develop.

Several commitments therefore guide the discussion:

Knowledge-capital expansion is treated as a historical and relational process rather than an exclusively technological phenomenon.

Artificial intelligence is examined as an intensified contemporary infrastructure of epistemic capitalization rather than the origin of epistemic capitalization.

Public availability is distinguished from effective accessibility, capitalizability, visibility, and generative participation.

Growth in epistemic output is distinguished from growth in human epistemic formation.

Automation of epistemic encounter is distinguished from elimination of empirical engagement.

Machine-scaled generativity is examined together with the distribution and control of the infrastructures through which it becomes possible.

Justice problems are identified without presuming that their institutional solutions have already been established.

Human epistemic delegation is evaluated through multiple possible trajectories, including expanded generativity, dependency, alienation, redistribution of subject formation, and historically emergent configurations that remain unknown.

The paper consequently remains diagnostic and foundational in scope. It seeks to describe contemporary mechanisms, relate them to longer historical developments, examine their political-economic and philosophical implications, and formulate open problems produced by their interaction. Detailed normative criteria for generative exploitation, a complete jurisprudence of public knowledge, institutional solutions to attention concentration, and a full epistemology of knowing under delegated inquiry are reserved for subsequent work.

The later inquiry provisionally concerned with the investigation of things and the appearance of knowledge will examine the epistemological problem in greater depth. In particular, it will consider the separation between the subject who engages in investigation and the subject who receives its epistemic products. The present paper establishes the political-economic, technological, educational, and relational conditions through which that separation becomes increasingly possible.

The structure of the paper follows this scope. It begins with the relevant literatures and a Marxian political economy of epistemic production, then examines models of knowledge emergence and philosophical accounts of the value of knowing. It reconstructs the historical development of modern epistemic capitalization and the role of public knowledge, surveys contemporary AI research infrastructures, and analyzes the mechanisms through which AI can accelerate knowledge-capital expansion. Subsequent sections examine differential automation across epistemic processes, the conditions of the epistemic proletariat, attention and epistemic authority, alienation, epistemic formation, curiosity, the Generative Relational interpretation of epistemic delegation, and emerging questions of justice. The concluding discussion and open-problem sections preserve these tensions as a research programme rather than closing them through a predetermined account of the future of knowledge.

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Statement on the use of language models. The exploratory discussions and preparation of this paper involved OpenAI's ChatGPT. ChatGPT supported exploratory dialogue, formal reconstruction, source discovery followed by website verification, exact calculation, argumentative criticism, and drafting in $\text{\LaTeX}$. The author selected the research questions, directed and approved the theoretical commitments and epistemic status of the claims, and bears sole responsibility for the manuscript, including its definitions, formal constructions, taxonomy, calculations, arguments, conclusions, and errors. Authorship credit remains with the human author. The access level and claim limit for every cited source are recorded in the accompanying literature audit.

1 Introduction

This paper examines the transformation of knowledge-capital expansion under modern conditions, with particular attention to public knowledge, artificial intelligence, and the increasing automation of epistemic production. Its objective is to analyze how accumulated epistemic resources become convertible into further knowledge-generating capacity, how modern infrastructures enlarge the scale and speed of that conversion, and how contemporary artificial intelligence changes the relations among knowledge production, epistemic labor, human knowing, public knowledge, attention, and control. The inquiry is historical, political-economic, epistemological, and relational. It develops a diagnostic framework for an unfolding transformation while leaving its eventual institutional and normative resolution open.

The point of departure is the concept of *knowledge-capital expansion*. Knowledge can function as more than an informational stock. Existing propositions, questions, concepts, methods, datasets, instruments, archives, skills, and other epistemic resources can modify the conditions under which subsequent knowledge becomes possible. When accessible epistemic resources increase an actor's capacity to generate, evaluate, organize, or combine further epistemic resources, they acquire a capital-like generative property. The process through which resources are converted into enhanced subsequent generative capacity is described here as *epistemic capitalization*. Knowledge-capital expansion concerns the recursive development through which such capitalization contributes to further rounds of accumulation, inquiry, and productive capacity.

This process substantially predates contemporary artificial intelligence. Writing makes epistemic resources durable beyond an immediate encounter. Archives enable their intergenerational preservation. Printing increases the reproducibility and circulation of textual knowledge. Libraries organize access to accumulated epistemic resources. Universities institutionalize teaching, inquiry, specialization, and the reproduction of epistemic communities. Scientific journals distribute findings across geographically separated research networks. Databases, digital repositories, search engines, and computational systems increase the speed and range with which accumulated knowledge can be retrieved and recombined. Modern knowledge production can therefore be read as a history of expanding capacities to externalize, preserve, organize, access, and capitalize upon epistemic resources.

Public knowledge has a distinctive position within this history. A scientific article, theorem, dataset, method, software package, historical record, or other publicly accessible epistemic resource can enter many subsequent processes without being exhausted by one use. Knowledge commons consequently provide important generative infrastructure for collective inquiry [29]. Their generative consequences, however, depend upon the capacities through which different actors encounter and use them. Formal availability does not produce identical epistemic gains. Prior knowledge, language, time, funding, institutional position, networks, infrastructure, computational resources, and other complementary conditions affect the degree to which an accessible epistemic resource can be transformed into further productive capacity.

The resulting asymmetry is central to the political economy developed in this paper. Two actors can access the same public knowledge while acquiring very different future generative advantages from it. An actor with greater capitalization capacity can search a larger literature, explore more combinations, test more hypotheses, mobilize more instruments, employ more specialized labor, and transform successful results into additional financial, reputational, institutional, or infrastructural resources. Those resources can subsequently increase the capacity for another round of epistemic capitalization. Public knowledge can therefore support broad collective generativity while also participating in processes of recursive concentration.

Artificial intelligence intensifies several components of this dynamic. Contemporary systems can assist with literature retrieval, synthesis, hypothesis generation, programming, data analysis, experimental planning, writing, and evaluation. More integrated agentic systems have begun to connect multiple stages of research into partially or extensively automated workflows. The AI Scientist demonstrates end-to-end automation across idea generation, literature search, computational experimentation, analysis, manuscript production, and automated review within machine-learning research [37]. Multi-agent

systems in experimental biology have also connected literature-based hypothesis generation with experimental planning, analysis of laboratory results, and iterative hypothesis revision [23]. These developments indicate a movement from AI used for isolated research tasks toward AI organized as reusable epistemic infrastructure.

The physical boundary of automated inquiry is also becoming increasingly important. Self-driving laboratories integrate algorithmic experimental selection, automation, robotics, measurement, and iterative analysis into closed or partially closed research loops. Recent reviews describe their development from narrow automated platforms toward more general systems in which algorithms can propose, execute, and interpret experiments with reduced human intervention [14]. The relevant future possibility therefore extends beyond automated manipulation of previously recorded symbols. AI-mediated epistemic systems can increasingly be coupled to instruments, robotic laboratories, sensors, autonomous platforms, and other systems capable of acting within physical environments.

This development changes the location of the central epistemological problem. Empirical engagement can remain an essential condition of knowledge production while the human recipient of an epistemic output performs progressively less of that engagement. A person or organization can formulate a research direction and delegate literature search, hypothesis exploration, experimentation, measurement, analysis, and revision to an external infrastructure. The object of inquiry is still encountered. The epistemic work still occurs. The relation between the human subject and that work, however, can become increasingly indirect.

Such delegation introduces several distinctions that become important throughout this paper. Epistemic production concerns the generation of epistemic outputs. Epistemic encounter concerns the interactions with texts, data, objects, environments, persons, instruments, or other sources through which inquiry develops. Human knowing concerns the epistemic state and capacities of a particular human subject. Epistemic formation concerns the longer transformation through which a subject develops concepts, judgment, skills, questions, sensitivities, and capacities for subsequent inquiry. These processes have often been strongly coupled in human research, yet they are analytically distinct. AI-mediated production makes their partial separation increasingly visible.

The distinction becomes especially significant when epistemic infrastructure can be scaled through financial and organizational resources. Capital can support more compute, stronger models, larger agent populations, specialized databases, experimental instruments, robotic systems, and longer or more parallel search processes. The consequences extend beyond the ability to retrieve existing public knowledge. Under increasingly automated conditions, financial and infrastructural capital can purchase greater capacities to generate questions, explore hypotheses, interact with empirical systems, and select among large numbers of epistemic trajectories. Epistemic encounter itself can consequently become increasingly infrastructuralized and scalable.

A Marxian analysis becomes relevant at this point. Marx's account of capital concerns a dynamic process of valorization together with historically specific relations among labor, means of production, control, and accumulation [40]. The present inquiry does not identify knowledge production with industrial commodity production. It uses Marxian distinctions to examine an emerging configuration in which control over epistemic production can become increasingly separable from direct participation in epistemic activity. Models, compute, data infrastructure, laboratories, agents, publication systems, and platforms can operate as important means and conditions of epistemic production. Actors capable of controlling these conditions can organize epistemic activity at scales that exceed their own direct cognitive labor.

This perspective also brings alienation into the analysis. Automated epistemic production can increase the separation between a subject and the processes through which epistemic products are generated. An actor can receive a result without having performed much of the inquiry that produced it. A researcher can direct a system while remaining distant from many of its intermediate encounters. Institutions can optimize epistemic throughput according to publication, funding, competitive, or organizational imperatives whose relation to the curiosity and formation of individual researchers becomes increasingly indirect. The relevant problem therefore extends beyond employment displacement or productivity. It

concerns the changing relation among the producer, epistemic activity, epistemic products, objects of inquiry, and the organization of knowledge production.

The same political economy produces a distinctive problem for the *epistemic proletariat*. An individual can possess substantial conceptual ability, domain knowledge, creativity, curiosity, and research skill while lacking stable control over the principal infrastructures required to realize and recursively expand those capacities. AI can improve such an individual's productive ability substantially, yet the improvement can occur through increasing dependence upon externally controlled models, compute, APIs, databases, platforms, laboratories, or institutional systems. Greater generativity and greater dependency can therefore develop simultaneously.

This configuration differs from a simple inequality of access. Public knowledge may remain broadly accessible. AI services may also become widely available. The politically significant asymmetry can nevertheless persist at the level of control, scale, continuity, substitutability, and recursive capitalization. An actor with temporary access to an external model occupies a different relational position from an actor that controls the model, infrastructure, compute, data pipelines, agent systems, and resulting accumulation. The distinction between access and control is therefore essential for understanding modern knowledge-capital expansion.

The growing abundance of epistemic production also shifts attention toward a second scarce resource: human attention. When the marginal cost of producing polished articles, explanations, summaries, reports, visualizations, databases, and other epistemic artifacts declines, the volume of available material can increase much faster than the attention available to evaluate it. The political economy of knowledge then increasingly includes competition over visibility, retrieval, ranking, recognition, and interpretive authority.

This attention problem is structurally important even in the absence of deliberate manipulation. An organization that legitimately deploys large numbers of agents to reproduce, reorganize, summarize, and extend public knowledge can occupy a substantial share of searchable and recommendable epistemic space simply through productive scale. A slower work produced through years or decades of archival research, field experience, conceptual development, or sustained engagement can remain publicly available while becoming progressively less likely to be encountered.

Public availability must therefore be distinguished from effective epistemic presence. An artifact can exist, remain legally accessible, and remain technically retrievable while having little probability of entering future inquiry. Visibility can also become recursive. Frequently encountered sources receive more links, citations, references, and institutional recognition. They can consequently become more likely to appear in subsequent searches, recommendation systems, and AI-mediated retrieval. Attention can thereby convert into symbolic authority and further epistemic advantage, extending the cumulative processes already familiar from the sociology of science [43].

Artificial intelligence adds another difficulty to this evaluative environment. Many visible signals previously associated, however imperfectly, with costly epistemic production can become inexpensive to generate. Fluency, extensive citation lists, polished organization, comprehensive presentation, formal appearance, and rapid synthesis can increasingly be produced without a corresponding history of prolonged inquiry. Under attention scarcity, readers may have limited capacity to reconstruct the provenance and generative history behind every artifact. Surface quality, ranking, institutional authority, recency, and repeated visibility can consequently acquire greater weight in practical evaluation.

The resulting problem reaches beyond misinformation. A machine-generated artifact can be factually competent and aesthetically polished while contributing to an aggregate environment in which other epistemic resources become harder to encounter. Machine-scaled production can therefore produce epistemic crowding even when individual outputs remain useful. Repeated visibility can further influence the concepts and classifications through which a domain is ordinarily encountered. Attention concentration may consequently develop into framing power and, under stronger conditions, a practical capacity to shape which definitions appear authoritative.

These mechanisms raise questions of justice. Existing work on epistemic injustice examines inequalities affecting participation in practices of knowing [21], while generative justice emphasizes the

circulation of value through processes that sustain the generative capacities of participants and communities [19]. The present inquiry extends these concerns to the political economy of public knowledge under machine-scaled production. At least three provisional dimensions become relevant: access justice, capitalization justice, and attention justice.

Access justice concerns the ability to obtain epistemic resources. Capitalization justice concerns the distribution of capacities through which accessible resources can be converted into further generative power. Attention justice concerns the conditions under which contributions retain a meaningful possibility of entering future epistemic relations. These dimensions can diverge. A knowledge commons can remain formally open while capitalization capacity becomes concentrated. Epistemic resources can remain technically retrievable while attention becomes concentrated around a relatively narrow set of actors, infrastructures, or framings.

The transformation also creates a problem of enclosure with several layers. Conventional enclosure restricts access to epistemic resources themselves. A second form concerns concentration of the infrastructures through which public knowledge can be converted into machine-scaled generative capacity. A third concerns the distribution of attention and the interfaces through which public knowledge becomes visible. Under this third configuration, alternative knowledge can remain publicly available while losing practical participation in the generative field.

These justice problems are especially significant because machine-scaled capitalization can be recursive. Public knowledge can contribute to a privately controlled epistemic infrastructure. That infrastructure can generate further knowledge, data, reputation, authority, and financial resources. The resulting capacity can then capitalize upon the next round of public knowledge at still greater scale. Questions of generative extraction, recirculation, provenance, commons regeneration, and responsibilities toward publicly derived generative capacity therefore arise. The present paper formulates these problems without prescribing a complete solution. Their normative and jurisprudential treatment requires further work.

A parallel set of questions concerns education and the philosophy of knowing. Traditional accounts of learning and inquiry differ substantially, yet many assign an important role to some combination of encounter, observation, experience, practice, questioning, judgment, error, revision, social interaction, and sustained engagement. Education itself demonstrates that the value of inquiry cannot be measured exclusively by additions to society's stock of previously unknown propositions. A student who reproduces an experiment whose result has been known for centuries may contribute little to global epistemic output while undergoing substantial epistemic formation.

This distinction becomes increasingly important when an external system can produce the answer more efficiently than the learner. The relevant philosophical question then changes from whether AI can produce knowledge to why a human subject should know. Several traditions offer different responses. Knowledge can have instrumental value by enabling prediction and action. It can have autonomy value by supporting independent judgment. It can have generative value by increasing the capacity to formulate and pursue further inquiries. It can have formative value through transformation of the knower. It can also have existential value through the subject's continuing encounter with the world and the possibilities disclosed through that encounter.

These values need not respond identically to epistemic delegation. A machine may provide an instrumentally adequate answer while leaving the human subject's judgment largely unchanged. An AI system can enlarge a researcher's generativity by making previously inaccessible literatures practically usable. The same dependence can weaken independent verification under some conditions. A delegated inquiry can produce an excellent epistemic output while generating limited transformation in the person who receives it. Evaluation of AI-mediated knowledge production therefore requires attention to multiple epistemic trajectories rather than a single measure of output.

Curiosity makes the problem still more fundamental. Human beings engage in inquiry before knowledge production becomes connected to professional recognition, publication, institutional incentives, or financial return. Children repeatedly ask questions about phenomena that have little immediate instrumental value. Wonder, uncertainty, surprise, contradiction, and contingent encounter can initiate inquiry because the relation between the subject and the world itself generates questions.

Automated research systems make it possible for knowledge production to become less dependent upon immediate human curiosity. A system can generate candidate questions, search literatures, compare hypotheses, execute investigations, evaluate results, and generate subsequent questions. Epistemic production can therefore develop increasingly strong conditions for its own continuation. Accumulated knowledge and infrastructure can generate further production even when the human actor participates primarily through high-level direction, selection, authorization, or consumption of results.

This possibility resembles the recursive logic of capital while generating a distinct philosophical problem. Knowledge production can increasingly reproduce the conditions for further knowledge production while becoming partially decoupled from the curiosity, experience, and formation of particular human subjects. The result need not be interpreted as human decline. Automation can also release time and attention from routine epistemic labor, enabling different forms of inquiry, creativity, interpersonal relation, political participation, artistic engagement, or other modes of human development. The historical trajectory therefore remains open.

The Generative Relational framework provides one way to formulate this openness. Within a generative relational account, inquiry is understood as a class of relations through which epistemic resources, capacities, questions, and subjects can be transformed. Knowledge production can generate an output; it can also alter the capacity for subsequent production and transform the subject participating in the inquiry. These dimensions can be described provisionally as epistemic-output generativity, epistemic-capacity generativity, and subject-formative generativity.

AI-mediated delegation allows these dimensions to follow increasingly different trajectories. Society's epistemic output can grow rapidly. The productive capacity of research infrastructure can also expand. The epistemic and existential transformation of a particular human subject can proceed at a different rate and through different relations. The central Generative Relational concern is therefore broader than preservation of human performance in every epistemic task. It concerns the relations through which subjects retain opportunities for encounter, revision, agency, and further becoming.

This perspective also clarifies the importance of epistemic processes whose significance is strongly situated in shared or historically indexed experience. Different forms of knowledge exhibit different degrees of dependence upon the identity and relation of the participants through whom they emerge. Some measurements can be highly insensitive to the identity of the operator. Interviews, ethnographic encounters, cultural interpretation, collective memory, and other relational processes can be increasingly sensitive to the participants and circumstances through which they occur.

The distinction cannot be reduced to a permanent boundary between machines and humans. A machine can itself enter a physical or social relation and generate a genuine trajectory of interaction. The relevant question concerns whether a particular epistemic significance depends upon participation in a specific relation and historical configuration. The representation produced from an experience does not automatically reproduce that experience within another subject's trajectory.

This issue also matters for cultural and artistic objects. The significance of an artifact can emerge through its integration into a subject's accumulated spatiotemporal experience. A historical document can matter partly because it was produced within a particular historical relation. A work of art can become significant through memory, place, shared experience, cultural inheritance, or a contingent encounter whose meaning exceeds visible formal properties. When synthetic production makes sophisticated appearances abundant, relational provenance, situated experience, and historical integration may become increasingly important dimensions of recognition for some classes of epistemic and cultural objects.

The same observation reinforces the attention problem. Slow, situated, and historically accumulated knowledge can contain generative histories that are difficult to represent through rapidly evaluated surface signals. Machine-scale production can therefore create a field in which visible polish becomes abundant while the temporal and relational conditions underlying some forms of knowledge remain costly, difficult to communicate, and easy to overlook.

The paper approaches these developments without assigning a predetermined historical verdict. Contemporary AI can expand epistemic accessibility, increase the generative capacity of individuals and institutions, support new scientific discoveries, and make previously impractical investigations possible.

It can simultaneously intensify infrastructural dependency, concentration, alienation, attention competition, and separation between epistemic production and human formation. These tendencies can coexist and interact. Their eventual configuration depends upon technological development, institutional organization, political economy, educational practices, legal arrangements, cultural responses, and forms of collective governance.

The aim of the present inquiry is therefore diagnostic and generative. It seeks to identify mechanisms through which modern epistemic capitalization is being transformed, distinguish different dimensions of the resulting political economy, connect those mechanisms with philosophical accounts of knowing and formation, and formulate the justice problems that emerge when public knowledge enters machine-scaled productive systems. The paper does not attempt to settle the appropriate limits of automation, determine a final distribution of rights, establish a complete ethics of knowledge-capital accumulation, or decide which forms of human knowing must remain non-delegable.

The analysis proceeds through several stages. It first reviews the relevant literatures in political economy, knowledge commons, sociology of science, education, epistemology, attention, and contemporary automated research. It then develops the Marxian political-economic background and examines major models of knowledge emergence together with philosophical accounts of the value of knowing. The historical development of epistemic capitalization and the role of public knowledge establish the context for a detailed analysis of contemporary AI infrastructures and the mechanisms through which they can accelerate knowledge-capital expansion.

The subsequent analysis distinguishes different susceptibilities of epistemic processes to automation and examines the epistemic proletariat, infrastructural dependency, attention scarcity, authority, and alienation. It then considers epistemic formation, curiosity, and the possible separation between the reproduction of knowledge production and the continuing formation of human subjects. A Generative Relational analysis integrates these problems through the concepts of epistemic encounter, relational transformation, delegated generative relations, and subject-formative generativity. The justice analysis examines access, capitalization, attention, enclosure, generative extraction, and commons regeneration. The final discussion and open-problem analysis retain the historically unsettled character of these transformations.

The resulting position is intentionally provisional. Artificial intelligence is neither treated as the origin of modern epistemic capitalization nor reduced to another neutral productivity instrument. It constitutes an increasingly important configuration within a longer history through which the production of knowledge becomes externalized, infrastructuralized, scalable, and recursively capitalizable. The central problem is therefore the changing relation among public knowledge, generative capacity, productive infrastructure, human inquiry, attention, and subject formation.

The historical significance of this transformation will depend upon the relations that emerge through it. Knowledge can become more abundant while effective visibility becomes scarce. Human epistemic capacity can increase while infrastructural dependency deepens. Automated systems can expand empirical inquiry while human participation in epistemic encounter decreases. Delegation can generate alienation in some relations while releasing resources for new forms of human generativity in others. Public knowledge can support collective discovery while also feeding recursively concentrated productive capacity.

Understanding these simultaneous movements requires preserving their contradictions rather than resolving them in advance. The question is therefore broader than whether artificial intelligence will improve or diminish human knowledge. The emerging problem concerns how knowledge-capital expansion reorganizes the relations through which knowledge is produced, encountered, recognized, controlled, circulated, and integrated into human and collective becoming.

2 Literature Review

This section establishes the intellectual context required for analyzing knowledge-capital expansion under contemporary conditions. Its objective is to connect bodies of literature that usually examine separate

components of the problem: capital accumulation and productive relations, knowledge and information as economic resources, public knowledge commons, cumulative advantage, academic and platform capitalism, attention scarcity, epistemic inequality, theories of learning and epistemic formation, curiosity, and the rapidly developing literature on artificial intelligence in scientific production. The review proceeds from political economy toward epistemology and education, and then from these established literatures toward current AI-mediated research infrastructures. The method is comparative and conceptual. Each literature is examined for the analytical resources it provides and for the dimensions of modern epistemic capitalization that remain outside its principal object of analysis.

2.1 Capital, Accumulation, and Modern Political Economy

This subsection establishes the general political-economic background for the paper. Classical political economy provides several distinct meanings of capital that later become relevant when the term is transferred cautiously to epistemic production. Smith discusses stock employed in productive activity, while Ricardo places the distribution of social production among classes at the center of political economy [54, 48]. These traditions connect accumulated resources with productive capacity, distribution, and the organization of future production.

The importance of this literature for the present inquiry lies in its temporal orientation. Capital concerns resources whose significance extends beyond immediate possession or consumption because they participate in subsequent productive processes. Knowledge-capital analysis adopts this temporal concern while requiring additional distinctions appropriate to epistemic resources, whose reproducibility, non-rival characteristics, dependence upon human formation, and capacity for recombination differ substantially from many material productive assets.

2.2 Marxian Capital, Valorization, and Relations of Production

This subsection identifies the Marxian concepts that provide the principal political-economic vocabulary for later analysis. Marx develops capital through a dynamic relation of valorization, reproduction, accumulation, labor, and control over means of production [40]. Capital in this framework cannot be reduced to a static collection of useful assets. Its analytical significance emerges through a social and productive process in which accumulated value enters conditions for producing additional value.

The distinction between the dynamics of capital and the relational position of the capitalist is particularly important for the present paper. Recursive knowledge accumulation can display capital-like dynamics under many institutional arrangements, while a knowledge-capitalist position concerns an actor's relation to productive conditions, labor, infrastructure, control, and appropriation. This distinction allows the present inquiry to examine knowledge-capital expansion without presupposing that every instance of epistemic accumulation constitutes a capitalist relation.

2.3 Marxian Alienation and the Organization of Production

This subsection establishes the Marxian background for the later analysis of epistemic alienation. In the *Economic and Philosophic Manuscripts of 1844*, Marx examines estrangement in relation to the product of labor, the activity of production, human social existence, and relations among persons [39]. The analysis directs attention toward the relation between a producer and the productive process through which an output emerges.

The relevance to automated epistemic production concerns possible separations among epistemic workers, activities of inquiry, objects of inquiry, and resulting epistemic products. Contemporary automation also raises a further problem concerning the relation between production of knowledge and formation of the knower. The present paper treats this as an extension requiring careful argument rather than as a direct restatement of Marx's theory. Section 3 develops that translation in detail.

2.4 Machinery, Automation, and the Transformation of Labor

This subsection situates automation within a longer political-economic concern with machinery and productive organization. Marx's analysis of machinery and large-scale industry examines technological change together with division of labor, organization of production, dependence upon productive systems, and changes in the worker's relation to productive activity [40]. The analytical value of this literature lies in its treatment of technology as part of a changing productive relation.

AI-mediated epistemic automation similarly involves more than substitution of one task performer for another. Models, agents, compute, databases, instruments, robotic systems, and evaluation mechanisms can be assembled into productive infrastructures. Their significance therefore depends upon their relations with human labor, organizational authority, ownership, access, and control. This political-economic perspective complements technical measures of automation by examining how productive capacity is organized and distributed.

2.5 Knowledge Economy and Economics of Information

This subsection reviews economic traditions that place knowledge and information directly within production and growth. Machlup's study of the production and distribution of knowledge identified knowledge-producing activities as a major component of the modern economy [38]. Arrow emphasized distinctive economic properties of information and invention, including difficulties created by uncertainty and appropriability [3]. Romer's endogenous growth model later formalized the role of ideas in long-run economic growth and emphasized their distinctive relation to increasing returns and non-rival use [49].

These approaches establish the economic importance of knowledge while leaving a different analytical problem open. The present paper concerns the recursive capacity of epistemic resources to modify the conditions under which further knowledge can be produced. The relevant object is therefore the conversion of accessible knowledge into subsequent generative capacity, together with the distribution of the infrastructures through which that conversion occurs.

2.6 Human Capital, Intellectual Capital, and Knowledge Capital

This subsection distinguishes adjacent capital concepts from the conception of knowledge capital used in the present research programme. Becker's human-capital framework treats education, training, and related investments as means of developing productive capacities embodied in persons [5]. Research on organizational intellectual capital extends the analysis toward intangible organizational resources, including human, structural, and relational dimensions [7]. Work on research-and-development capital similarly examines accumulated R&D resources in relation to productivity [25].

Bourdieu's analysis of economic, cultural, social, and symbolic capital is especially relevant to processes of conversion among heterogeneous resources [8]. Recognition, credentials, networks, and economic resources can reinforce one another and thereby influence subsequent opportunities. The present concept of knowledge capital remains narrower in one respect and broader in another. It focuses specifically on epistemic resources through their consequences for future generativity while allowing their interaction with financial, reputational, institutional, network, and infrastructural forms of capital.

2.7 Knowledge Commons and Public Knowledge

This subsection establishes the literature through which public knowledge can be understood as a governed shared resource. Hess and Ostrom's knowledge-commons framework extends commons analysis to information and knowledge resources and emphasizes the institutional conditions governing their creation, access, preservation, and use [29]. The framework is especially important because digital knowledge can support widespread access while remaining subject to enclosure through intellectual property, licensing, pricing, preservation failures, and institutional arrangements.

The present inquiry builds upon this literature by shifting attention toward what actors can subsequently generate from accessible commons resources. Public availability provides an important condition for epistemic capitalization, while differences in knowledge, time, infrastructure, compute, networks, and organizational capacity can produce strongly heterogeneous generative gains. Commons governance and capitalization capacity therefore describe related dimensions of the public knowledge environment.

2.8 Cumulative Advantage and Scientific Production

This subsection introduces the sociological literature on recursive advantage within science. Merton’s account of the Matthew effect describes cumulative advantage in scientific careers and recognition, including processes through which prior standing affects the allocation of later recognition and resources [43]. Scientific production consequently develops within a field where contributions, visibility, institutional position, and reward can become recursively coupled.

This literature provides a direct precursor to the present concept of recursive epistemic advantage. Knowledge-capital analysis extends the problem from recognition toward the broader capacity to perform subsequent epistemic production. Prior knowledge, reputation, funding, networks, infrastructure, and attention can each alter the practical generative possibilities available in a later round of inquiry.

2.9 Academic Capitalism and Institutional Knowledge Production

This subsection reviews research on the market-oriented transformation of universities and academic production. Slaughter and Rhoades describe an academic capitalist knowledge and learning regime in which universities, faculty, administrative structures, public subsidies, intellectual property, and market relations become connected through new circuits of knowledge production and commercialization [53].

Academic-capitalism research demonstrates that knowledge production already operates within complex relations among public institutions, private markets, research labor, intellectual property, funding, and organizational strategy. The present inquiry extends this concern toward infrastructures capable of automating and scaling epistemic activity. AI can alter both the productivity of academic actors and the relative importance of control over computational, model, data, and platform resources.

2.10 Platform Capitalism and Infrastructural Power

This subsection establishes the relevance of platform-centered political economy. Srnicek analyzes digital platforms as business forms organized around data, network effects, infrastructural intermediation, and concentrated control over interactions [55]. Platform analysis directs attention toward actors whose power derives partly from controlling the infrastructure through which other actors interact and produce.

AI-mediated knowledge production intensifies the relevance of this infrastructural perspective. Researchers can receive substantial productive benefits from models, APIs, cloud services, retrieval systems, databases, and agent platforms while possessing limited control over their continuity, pricing, modification, or governance. Platform access can therefore enlarge immediate generative capacity while simultaneously establishing new forms of dependency.

2.11 Attention Economy, Search, and Epistemic Visibility

This subsection establishes attention scarcity as a political-economic constraint on abundant knowledge production. Simon’s analysis of information-rich environments identifies attention as a scarce resource whose allocation becomes increasingly important as information becomes abundant [52]. Later analyses of digital attention show how small advantages in attracting and retaining audiences can compound into substantial concentration [30]. Recent work also conceptualizes attention as a symbolic currency capable of participating in wider processes of social and economic conversion [28].

The literature becomes especially significant when AI lowers the cost of producing polished epistemic artifacts. An expanding supply of articles, summaries, reports, explanations, visualizations, and

other outputs encounters human attention whose temporal capacity remains constrained. Search, recommendation, ranking, and retrieval systems consequently participate in the allocation of effective epistemic visibility.

The present paper extends attention-economy analysis into the public knowledge commons. Its concern includes the possibility that machine-scaled production can create structural attention capture without deliberate manipulation. Public resources can remain available while their probability of entering future inquiry becomes highly unequal. Attention thereby becomes relevant to knowledge-capital expansion because visibility affects recognition, recombination, citation, retrieval, and subsequent generative participation.

2.12 Epistemic Inequality and Unequal Participation

This subsection identifies philosophical resources for analyzing unequal participation in epistemic practices. Fricker's account of epistemic injustice examines harms associated with credibility and interpretive resources and thereby establishes a framework in which power can shape a person's participation as a knower [21]. The literature directs attention beyond possession of information toward social conditions affecting whose testimony, concepts, and interpretations enter shared epistemic life.

Knowledge-capital analysis adds a future-oriented dimension. Unequal epistemic participation can influence the resources and relations from which subsequent generative capacity develops. Conversely, inequalities in generative capacity can influence whose questions, categories, and outputs become visible enough to shape future epistemic environments.

2.13 Generative Justice and Value Circulation

This subsection introduces generative justice as a framework for examining the circulation of value through productive systems. Eglash develops generative justice around processes through which value circulates back toward the people and communities whose generative capacities participate in its production [19]. The framework provides a useful alternative to evaluations focused exclusively on final distributions.

The concept is relevant to public knowledge because commons resources can enter private or institutional capitalization processes and generate substantial subsequent capacities. The present paper draws on generative justice when formulating questions of generative extraction, recirculation, and return. A complete normative account is reserved for later work.

2.14 Philosophy of Knowledge and Epistemic Formation

This subsection establishes philosophical traditions in which the significance of knowing extends beyond possession of correct propositions. Aristotle opens the *Metaphysics* from the premise of a human desire for knowledge and connects inquiry with wonder and forms of understanding pursued beyond immediate utility [1]. Kant's critical philosophy places the conditions and activities of cognition at the center of the possibility of experience and judgment [32]. Hegel's *Phenomenology of Spirit* develops knowledge through transformations of consciousness across successive forms of mediation [27].

Existential traditions provide another route to the significance of human knowing. Sartre's account of existence, freedom, choice, and self-constitution places human identity within an open field of possibilities rather than a completed essence [50]. Virtue epistemology further relates epistemic evaluation to intellectual agency and intellectual virtues [59]. Neo-Confucian traditions of self-cultivation, represented here through Zhu Xi's conversations, connect learning and the investigation of things with cultivation of the person [58].

These traditions differ substantially in ontology, method, and normative commitment. Their relevance to the present inquiry lies in a shared resistance to treating the value of knowing as exhausted by the external availability of an epistemic answer. They provide conceptual resources for distinguish-

ing instrumental, autonomous, generative, formative, and existential dimensions of knowing. Section 5 develops these distinctions comparatively.

2.15 Educational Philosophy and Models of Learning

This subsection reviews educational traditions in which learning emerges through activity, experience, social interaction, conceptual organization, and participation. Dewey's account of experience and education emphasizes continuity and interaction within educative experience [17]. Vygotsky's developmental framework places social interaction and culturally mediated activity within the development of higher psychological processes [56]. Bruner emphasizes the organization of disciplinary structure and the progressive development of understanding [10].

Experiential and situated approaches further emphasize relations between learning and participation. Kolb systematizes experiential learning around cycles connecting experience, reflection, conceptualization, and subsequent activity [34]. Lave and Wenger develop situated learning through legitimate peripheral participation and communities of practice [35]. These models differ in theoretical commitments, yet each assigns formative significance to processes through which the learner participates in an epistemic trajectory.

The AI challenge therefore concerns more than whether an external system can produce a correct educational output. Automated production can modify the sequence of activities through which a learner develops judgment, concepts, skills, questions, and future capacities. The later educational analysis uses these traditions as reference models for examining which components of epistemic formation can be delegated, compressed, transformed, or reorganized.

2.16 Curiosity, Inquiry, and Epistemic Motivation

This subsection establishes curiosity as a distinct component of knowledge generation. Loewenstein's information-gap account treats curiosity as arising from perceived gaps in knowledge and provides a psychological explanation for information-seeking behavior [36]. Kidd and Hayden review psychological and neuroscientific research that treats curiosity as an important motivation for learning, information seeking, decision-making, and development [33].

Curiosity is analytically important because knowledge production can be motivated by more than external rewards or immediate instrumental need. Questions can emerge from surprise, uncertainty, discrepancy, wonder, and encounters that disturb an existing understanding. AI systems capable of generating research questions introduce a new distinction between the production of further inquiries and the curiosity of particular human subjects. The distinction becomes central to the later analysis of self-continuing epistemic production.

2.17 AI for Science and Automated Knowledge Production

This subsection establishes the contemporary literature on AI-mediated scientific production and differentiates productivity-oriented applications from broader epistemic transformations. AI systems are now used across prediction, simulation, literature analysis, data interpretation, experimental design, and other scientific tasks. OECD's review of artificial intelligence in science describes both the opportunities for accelerating research and the institutional conditions required for responsible adoption [45].

The literature also identifies epistemic risks accompanying increased productivity. Messeri and Crockett argue that AI tools can create illusions of understanding and contribute to scientific monocultures when researchers become overconfident in outputs or converge on narrower families of methods and questions [44]. Hao and colleagues provide large-scale empirical evidence that AI adoption can increase individual scientific productivity and impact while coinciding with contraction in the collective topical range of science [26]. These findings are especially relevant to the distinction between actor-level generativity and field-level diversity developed later in this paper.

2.18 Scientific Foundation Models

This subsection examines scientific foundation models as reusable infrastructural components of knowledge production. Menon and colleagues survey scientific foundation models across scientific and engineering domains and develop criteria concerning domain adaptation, domain generalization, problem adaptation, and problem generalization [41]. The literature reflects a movement from task-specific computational tools toward models designed to transfer representational and problem-solving capacity across families of scientific problems.

For the present inquiry, the important property is reusability across future epistemic tasks. A scientific model can therefore function as infrastructural epistemic capital when its accumulated representations and capabilities reduce the cost or expand the range of later inquiry. The political-economic significance depends upon the resources required to build, access, adapt, operate, and govern such models.

2.19 Autonomous Research Agents

This subsection reviews systems that organize language models and tools into extended research workflows. Schmidgall and colleagues' Agent Laboratory connects literature review, computational experimentation, and report writing within an agent-based research process while retaining opportunities for human feedback [51]. Lu and colleagues subsequently demonstrate an AI Scientist architecture capable of carrying out idea generation, literature search, experimentation, analysis, manuscript production, and automated review within machine-learning research [37].

The movement from task assistance toward workflow organization is conceptually significant. Research agents can preserve state across multiple activities, select actions, use external tools, evaluate intermediate results, and initiate subsequent operations. Epistemic production therefore becomes increasingly representable as an orchestrated process whose components can be delegated to machine systems.

2.20 Multi-Agent Scientific Systems

This subsection examines the distribution of epistemic functions among multiple artificial agents. Ghareeb and colleagues present a multi-agent system for scientific discovery in which specialized agents perform literature research, develop hypotheses, propose experiments, analyze experimentally generated data, and revise hypotheses through iterative interaction [23]. The system connects computational reasoning with human-performed laboratory experimentation and demonstrates a form of laboratory-in-the-loop scientific production.

Multi-agent organization is relevant to the political economy of epistemic labor because division of research activity can increasingly be instantiated within computational infrastructure. Specialized roles, coordination, criticism, selection, memory, and synthesis can be distributed across agents whose number and operating duration depend partly upon available computational resources. This development makes the scale of epistemic organization itself a capital-sensitive variable.

2.21 Self-Driving Laboratories and Robotic Experimentation

This subsection establishes the literature connecting artificial intelligence with direct physical experimentation. Canty and Abolhasani describe self-driving laboratories as systems combining autonomous experimentation, robotics, reactor or instrument engineering, algorithmic decision-making, and AI-driven interpretation [14]. Their review also emphasizes scalability, generalizability, provenance, and structural asymmetries affecting the development of self-driving laboratories as shared scientific infrastructure.

Recent systems demonstrate increasingly direct agentic interaction with major scientific instruments. Chen and colleagues report an agentic AI X-ray scientist capable of planning and executing actions at a synchrotron instrument, interpreting observations, and adapting its behavior during experimental operations [15]. Such systems undermine a simple division between machine manipulation of representations and human engagement with empirical reality. The relevant analytical problem increasingly concerns who controls and participates in the infrastructure through which empirical encounters are performed.

2.22 Automated Literature Search and Knowledge Synthesis

This subsection examines automation at the interface between public scientific literature and subsequent inquiry. Asai and colleagues introduce OpenScholar, a retrieval-augmented system built around a data store containing tens of millions of open-access scientific papers and designed to generate citation-grounded scientific syntheses [4]. Their evaluation demonstrates that specialized retrieval, reranking, attribution, and iterative feedback can substantially improve coverage and citation accuracy relative to ungrounded language-model generation.

This literature is directly relevant to epistemic absorption capacity. The quantity of publicly available literature has long exceeded the amount that any individual researcher can read directly. Retrieval-augmented models can alter the practical relation between corpus size and usable knowledge by searching, ranking, comparing, and synthesizing resources at scales inaccessible to ordinary individual reading. Public knowledge consequently becomes capitalizable through an additional infrastructural layer.

2.23 Automated Hypothesis Generation and Evaluation

This subsection reviews the movement from information retrieval toward generation and testing of candidate explanations. Contemporary autonomous research systems increasingly combine literature-derived reasoning with hypothesis formation, experiment selection, computational evaluation, or revision. The AI Scientist explores candidate research ideas through experimentation and evaluation [37], while the multi-agent system reported by Ghareeb and colleagues generates biological hypotheses, proposes experiments, analyzes results, and updates subsequent inquiry [23].

The analytical importance of this literature concerns the expansion of question and hypothesis spaces. Automated systems can explore multiple candidate trajectories in parallel, compare intermediate results, discard unsuccessful branches, and continue promising ones. The scale of available compute and agentic infrastructure can therefore influence the number of epistemic possibilities that become practically explorable.

2.24 Automated Scientific Writing and Review

This subsection examines automation in the production and evaluation of scholarly artifacts. End-to-end research systems increasingly incorporate report or manuscript generation as a downstream component of research workflows [51, 37]. The development shifts writing from an isolated language-generation task toward a stage connected with literature retrieval, experimental records, analysis, and prior decisions within a larger workflow.

AI-assisted peer review is also receiving institutional experimentation. Perlis and colleagues describe the incorporation of AI into peer-review processes while emphasizing continuing human oversight, accountability, and editorial responsibility [46]. These developments are important because scholarly communication participates in the conversion of epistemic outputs into visibility, recognition, authority, and future research opportunities. Automation can therefore affect both production and the institutional mechanisms through which production is evaluated.

2.25 Models, Compute, Data, and Research Infrastructure

This subsection consolidates the infrastructural literature underlying AI-mediated knowledge production. Scientific foundation models require large-scale data, training procedures, computational resources, and adaptation mechanisms [41]. Autonomous agents additionally depend upon model access, tool interfaces, execution environments, retrieval systems, memory, and evaluation. Physical automation adds instruments, laboratory hardware, robotics, maintenance, and provenance infrastructure [14, 15].

The literature consequently supports analysis of AI research capacity as a layered infrastructure rather than a single model capability. Model quality, compute availability, corpus access, robotic capacity, orchestration systems, and institutional continuity can operate as complementary productive conditions.

Their distribution becomes politically significant when differences in infrastructure translate into differences in the scale, duration, diversity, and empirical reach of inquiry.

2.26 Verification, Reproducibility, and Epistemic Dependence

This subsection reviews constraints that accompany increasingly automated epistemic production. Open-Scholar's results demonstrate the importance of retrieval, attribution, reranking, and citation verification for scientific synthesis [4]. Messeri and Crockett emphasize the possibility that effective AI tools can increase confidence without corresponding increases in understanding [44]. Self-driving-laboratory research likewise places strong emphasis on provenance and reproducibility when autonomous systems generate long sequences of experimental decisions [14].

Verification therefore becomes an infrastructural problem alongside a cognitive one. As the number of machine-generated intermediate operations increases, direct human reconstruction of every step becomes increasingly costly. Epistemic dependence can consequently shift toward systems that store provenance, validate outputs, reproduce experiments, preserve logs, and evaluate other automated systems. This creates a recursive relation in which automation of production can increase demand for automation of verification.

2.27 Literature Synthesis and Analytical Positioning

This subsection integrates the reviewed literatures and identifies the analytical position of the present inquiry. Political economy explains accumulation, productive relations, machinery, control, and alienation. Economics of knowledge explains distinctive properties of information and ideas. Human-capital and intellectual-capital research examine productive capacities embodied in persons and organizations. Commons research examines shared knowledge resources and their governance. Sociology of science explains cumulative advantage and recognition. Academic- and platform-capitalism research identifies institutional commercialization and infrastructural control. Attention-economy research explains scarcity and concentration at the level of visibility. Epistemic-injustice and generative-justice frameworks provide resources for analyzing participation, circulation, and unequal generative conditions.

Philosophy and educational theory introduce a second family of problems. Knowing can participate in judgment, agency, inquiry, self-cultivation, experience, situated participation, and transformation of the subject. Curiosity research further establishes that information seeking can emerge from internally generated epistemic motivation. These literatures make it possible to distinguish the production of epistemic artifacts from the formation of human knowers.

The contemporary AI literature establishes a third family of developments. Scientific foundation models provide reusable computational capacities. Retrieval systems transform relations to large public corpora. Research agents organize extended workflows. Multi-agent systems distribute epistemic functions. Self-driving laboratories and instrument-controlling agents connect machine reasoning with physical experimentation. Automated writing and review extend AI mediation into scholarly communication. Large-scale empirical studies already indicate that gains in individual scientific productivity can coexist with contraction in collective research focus [26].

A conceptual gap remains across these literatures. Existing work rarely treats public knowledge, recursive epistemic capitalization, AI infrastructure, epistemic labor, attention scarcity, human epistemic formation, and justice as components of one evolving political-economic system. The present paper addresses that gap through the concept of knowledge-capital expansion. The framework examines how public epistemic resources enter recursively expanding productive capacities; how those capacities depend upon models, compute, institutions, robotics, attention, and other complementary resources; how control over those conditions produces differentiated relational positions; and how machine-scaled production changes the relation among epistemic output, epistemic encounter, human knowing, and subject formation.

The resulting analysis treats artificial intelligence as an intensified contemporary stage within a longer history of epistemic capitalization. It also preserves the heterogeneity of possible outcomes. Expanded

access can coexist with concentrated capacity. Greater individual productivity can coexist with greater infrastructural dependence. More abundant epistemic output can coexist with scarcer effective visibility. Automation of inquiry can reduce some forms of epistemic labor while reorganizing the conditions for human formation, curiosity, judgment, and other generative relations. These tensions establish the analytical transition to the Marxian political economy developed in Section 3.

3 Marxian Political Economy of Epistemic Production

This section develops the Marxian political-economic vocabulary required for the later analysis of AI-mediated knowledge-capital expansion. Its objective is to distinguish the dynamics of accumulation from positions within relations of production, clarify the significance of machinery and productive infrastructure, reconstruct several dimensions of alienation, and identify the conditions under which these concepts can be transferred cautiously to epistemic production. The discussion proceeds from Marx’s account of capital and reproduction toward productive relations and automation, then develops the epistemic translation and concludes by delimiting the analogy. The method is conceptual and comparative. Marxian categories are used where they reveal structural relations in knowledge production, while differences between economic and epistemic processes are retained explicitly [40, 39].

3.1 Capital and the Movement of Value

The present subsection establishes the dynamic character of capital that motivates its later comparison with knowledge-capital expansion. In Marx’s analysis, capital is intelligible through a movement in which accumulated value enters production and returns in an expanded form [40]. The analytical emphasis therefore falls on movement, reproduction, and expansion across time.

This dynamic orientation is important for epistemic analysis because a stock of knowledge becomes theoretically interesting when it changes the conditions of subsequent production. A concept, method, dataset, model, archive, or scientific instrument can participate in future epistemic processes and alter the range or efficiency of what can subsequently be generated. The analogy concerns this recursive productive role rather than an assertion that epistemic resources and monetary capital share an identical ontology.

A second distinction follows immediately. The existence of an expanding process does not by itself determine the social relation through which the process is organized. Capital dynamics and capitalist position therefore need to remain conceptually separable when the framework is transferred to knowledge production.

3.2 Accumulation and Expanded Reproduction

This subsection clarifies the temporal logic through which productive expansion can become self-reinforcing. Marx distinguishes simple reproduction from expanded reproduction and examines accumulation as a process through which part of the result of production re-enters subsequent production [40]. Accumulation therefore affects both the quantity of available resources and the scale of future productive activity.

An epistemic analogue appears when results of inquiry become resources for later inquiry. A published theorem can become a premise for further mathematics. A dataset can support later analysis. A trained model can reduce the cost of solving subsequent tasks. A successful laboratory can generate instruments, procedures, reputation, funding, and personnel that increase its future research capacity.

The relevant property is recursive reproduction of productive conditions. Knowledge-capital expansion therefore concerns more than growth in the number of epistemic artifacts. It includes growth in the capacity to produce, evaluate, combine, and mobilize further epistemic resources.

3.3 Means of Production and Relations of Production

This subsection establishes the distinction between productive resources and the social relations governing their use. Marxian political economy analyzes production through relations among labor, means of production, ownership, control, and the organization of productive activity [40]. Productive capacity is therefore inseparable from the institutional and social arrangements through which productive resources become available and are coordinated.

The epistemic translation requires a broad conception of means and conditions of production. Books, laboratories, instruments, databases, software, computational resources, models, archives, communication systems, research funding, institutional affiliation, and publication infrastructures can all participate in the production of knowledge.

Their political-economic significance depends upon relations of access and control. Temporary permission to use a model differs from control over its operation and future development. Access to a laboratory differs from authority over its research agenda. Public access to an article differs from control over the infrastructure capable of processing millions of such articles at scale.

The distinction between productive resources and productive relations therefore provides a basis for examining epistemic inequality beyond differences in individual intelligence or education.

3.4 Division of Labor and Productive Organization

This subsection examines the organizational distribution of productive activity. Modern production divides complex processes into differentiated tasks, coordinates specialized labor, and integrates individual operations into larger productive systems. Marx's analysis of cooperation, manufacture, and large-scale industry shows how productive organization can alter both aggregate capacity and the worker's relation to the whole process [40].

Scientific knowledge production has long displayed analogous forms of specialization. Researchers, technicians, statisticians, programmers, instrument specialists, librarians, editors, reviewers, administrators, and other participants contribute differentiated forms of epistemic and supporting labor. Large scientific collaborations demonstrate that no single participant needs to reproduce the complete epistemic trajectory through which a result is produced.

Artificial intelligence extends this organizational possibility. Literature search, hypothesis generation, coding, simulation, experimental planning, measurement, analysis, criticism, writing, and evaluation can increasingly be distributed among specialized artificial agents and automated systems. The division of epistemic labor can therefore become partly instantiated within computational infrastructure.

3.5 Machinery and Automation

This subsection identifies the significance of machinery for the organization of labor and productive capacity. Marx's analysis of machinery treats technological systems within relations of production and examines their effects on productivity, labor organization, dependence, and control [40]. Machinery changes the scale and coordination of production while altering the role performed by individual workers.

The epistemic relevance lies in the transition from tools that assist isolated cognitive operations toward infrastructures capable of coordinating extended productive sequences. A calculator performs a bounded operation. A database supports storage and retrieval. A contemporary agentic system can connect search, reasoning, experimentation, evaluation, and writing across a longer workflow.

Automation therefore changes the location of human participation within the epistemic process. Human activity can move from direct execution toward selection, supervision, evaluation, goal formation, exception handling, or control over infrastructure. The degree of this movement varies across domains and systems.

3.6 Capitalist Position and Direct Productive Activity

This subsection distinguishes control of production from direct participation in productive labor. Within Marxian political economy, the capitalist occupies a position defined through relations to capital, labor, and means of production. The position does not require personal execution of every productive operation through which value is generated [40].

This distinction becomes analytically useful in knowledge production. An actor can organize research by controlling funding, models, compute, laboratories, data infrastructure, personnel, publication systems, or automated agents while performing only a limited portion of the immediate epistemic labor. The resulting position is structurally different from that of a researcher whose productive capacity depends upon resources governed by another actor.

The concept of a knowledge-capitalist position therefore concerns relational control over important conditions of epistemic production. It does not identify every highly knowledgeable, productive, or successful individual with a capitalist position.

3.7 Concentration and Centralization

This subsection introduces two processes that become important when epistemic infrastructure acquires substantial scale. Marx distinguishes concentration through accumulation within existing capitals from centralization through the combination or redistribution of already existing capitals [40]. The distinction enables analysis of increasing productive scale through different historical mechanisms.

An epistemic analogue can occur when a research organization recursively accumulates models, data, compute, personnel, reputation, and infrastructure. A different process occurs when existing databases, laboratories, platforms, publishers, model providers, or research organizations become consolidated under fewer institutional centers.

These processes matter because the concentration of epistemic resources can change the practical scale at which public knowledge becomes capitalizable. The same public corpus can support very different productive trajectories when one actor possesses substantially greater computational, institutional, or experimental capacity.

3.8 Alienation from the Product

This subsection reconstructs the first dimension of alienation relevant to epistemic production. Marx's early analysis describes a condition in which the product of labor confronts the worker as something separated from the activity through which it was produced [39]. The concept concerns a relation between the producer, productive activity, and the resulting object.

In epistemic production, a comparable problem can arise when researchers contribute labor to outputs over which they possess little subsequent control, recognition, access, or interpretive authority. Large institutional and automated workflows can further increase the distance between individual contributors and completed epistemic products.

The analogy requires caution because knowledge can circulate, be copied, and remain cognitively available in ways that differ from many material products. The relevant concern is therefore relational separation rather than physical dispossession alone.

3.9 Alienation from Productive Activity

This subsection turns from the epistemic product toward the activity of inquiry itself. Marx's analysis of alienated labor concerns the worker's relation to productive activity and the conditions under which labor becomes externally organized and experienced [39].

The epistemic analogue concerns the organization of inquiry through objectives, metrics, workflows, technologies, and institutional demands that can become weakly connected to the researcher's own questions or judgment. Publication requirements, funding incentives, performance metrics, competitive pressures, and automated workflows can all influence the direction and pace of epistemic production.

AI introduces an additional possibility. A researcher can remain formally responsible for a project while substantial portions of questioning, investigation, analysis, and production occur through external systems. The human relation to epistemic activity can consequently become thinner even when the volume of resulting output increases.

3.10 Alienation and Human Self-Formation

This subsection identifies a deeper dimension of the alienation problem that connects political economy with the later epistemological analysis. Marx's early writings relate alienated labor to human activity and self-realization more broadly [39]. The present paper uses this dimension as a starting point for examining how participation in inquiry can contribute to the formation of the knower.

Epistemic activity can transform the subject who performs it. Encountering an unexpected result can alter conceptual expectations. Failed hypotheses can develop judgment. Sustained engagement with a difficult object can create new questions, sensitivities, and capacities. Inquiry therefore produces more than an external epistemic artifact.

When epistemic activity is extensively delegated, production of the external result can continue while some of these transformations occur elsewhere in the productive system. The resulting separation between epistemic output and human subject formation constitutes a major problem developed later in this paper.

3.11 Translation to Epistemic Production

This subsection consolidates the Marxian translation used throughout the remainder of the paper. The objective is to identify structural correspondences that support analysis while preserving differences between economic and epistemic production.

The principal correspondences concern productive relations. Epistemic labor includes activities through which questions, evidence, concepts, methods, interpretations, and other epistemic resources are generated or transformed. Means and conditions of epistemic production include the material, institutional, computational, informational, and relational resources required to perform such activity. Knowledge capital concerns epistemic resources whose availability or control modifies future generative capacity.

A knowledge-capitalist position arises when an actor possesses substantial control over the conditions through which epistemic production can be organized, scaled, directed, and recursively expanded. An epistemic-proletarian position arises when an actor possesses meaningful generative capacity while depending upon productive conditions controlled elsewhere.

These categories describe relational positions. They therefore remain analytically distinct from the amount of knowledge possessed by an actor. A highly knowledgeable researcher can occupy a dependent position, while an actor with limited direct expertise can control extensive epistemic infrastructure.

3.12 Knowledge-Capital Expansion and Relations of Epistemic Production

This subsection distinguishes the dynamic process of knowledge-capital expansion from the relations through which the process is organized. Knowledge-capital expansion can occur whenever epistemic resources recursively increase future generative capacity. Such dynamics can occur in private firms, universities, public research institutions, cooperatives, open-source communities, independent research practices, or other organizational forms.

The political-economic character of an expansion process depends upon relations of access, control, labor, appropriation, circulation, and dependency. Consequently, rapid epistemic accumulation does not determine a single institutional form.

This distinction is especially important for AI. An individual researcher can use AI to increase personal generativity without controlling the underlying model infrastructure. A public institution can deploy automated systems while maintaining broad recirculation of resulting knowledge. A private orga-

nization can use public knowledge to construct a highly concentrated generative infrastructure. Similar technologies can therefore participate in different relations of epistemic production.

3.13 Recursive Epistemic Accumulation

This subsection develops the recursive component that connects Marxian accumulation with knowledge-capital expansion. Epistemic production can generate resources that increase the capacity for subsequent epistemic production. Successful inquiry can produce new knowledge, methods, data, instruments, models, reputation, funding, institutional access, and technical infrastructure.

The resulting accumulation can cross several forms of capital. Epistemic success can generate reputation. Reputation can increase access to funding and collaboration. Funding can purchase compute, instruments, personnel, or robotics. These resources can enlarge the number and diversity of subsequent epistemic trajectories that become practically explorable.

AI can accelerate this recursive structure because parts of the conversion cycle can increasingly be automated. Public knowledge can be searched and synthesized at machine scale. Candidate hypotheses can be generated in parallel. Computational and physical experiments can be orchestrated automatically. Successful results can enter subsequent rounds of analysis with limited delay.

Recursive accumulation therefore becomes relevant at two levels. Epistemic resources can accumulate, and the infrastructure capable of capitalizing upon those resources can itself accumulate. The second process is particularly important for understanding concentration of machine-scaled generative capacity.

3.14 Epistemic Labor, Control, and Dependency

This subsection identifies the relational consequence of unequal control over accumulated epistemic infrastructure. A researcher can possess strong generative capacities while depending upon resources whose continuity, pricing, access conditions, or technical operation are determined elsewhere.

AI can intensify this condition because advanced epistemic production may depend upon layered infrastructures. Model access can depend upon a provider. Compute can depend upon cloud infrastructure. retrieval can depend upon databases and indexing systems. Automated experiments can depend upon laboratories, robotics, instruments, maintenance, and specialized engineering.

The resulting dependency is compatible with substantial increases in productivity. A researcher can become more capable in immediate practice while becoming more dependent upon externally controlled conditions for reproducing that capability.

The political-economic problem therefore concerns the distribution of control over future generative capacity. Differences in current output reveal only one dimension of this structure.

3.15 Alienation under Epistemic Delegation

This subsection develops the form of alienation most directly relevant to automated inquiry. Epistemic delegation allows execution of productive operations to move toward external systems while human participation is reorganized around direction, supervision, evaluation, or authorization.

Delegation itself does not establish alienation. A researcher can delegate substantial execution while remaining deeply involved in the generative trajectory through curiosity, problem formulation, criticism, interpretation, revision, and judgment. Extensive technological mediation can therefore coexist with substantial subject participation.

The stronger concern arises when the human relation to inquiry becomes progressively thinner. A limiting configuration can emerge in which an actor initiates a broad objective, repeatedly authorizes continuation, and receives completed outputs while participating minimally in the intervening processes of questioning, encounter, resistance, failure, revision, and conceptual transformation.

The relevant distinction is therefore between executional participation and generative participation. The quantity of operations manually performed by a human provides limited information about the de-

gree to which the human subject's history, curiosity, judgment, and transformation participate in the production of knowledge.

This distinction also prevents a simplistic opposition between human and machine production. A person who relies heavily upon assistive AI can remain deeply integrated into a generative process. Conversely, a person performing many operations manually can participate in a highly routinized process that produces little subjective transformation.

3.16 Knowledge Production and Productive Imperatives

This subsection examines the possibility that epistemic production can become increasingly organized around the continuation of production itself. Modern research institutions already connect publication, grants, reputation, employment, rankings, and organizational survival to continuing output. Knowledge production therefore participates in incentive structures that can operate independently of the immediate curiosity of individual researchers.

AI can strengthen this separation by reducing the marginal cost of producing additional epistemic artifacts and by automating parts of question generation, search, evaluation, and production. The productive system can consequently acquire stronger capacities for initiating subsequent rounds of epistemic activity.

The resulting structure resembles expanded reproduction at an abstract level. Accumulated epistemic and infrastructural resources enable additional production, which can generate further resources for continuing production. The analogy becomes especially relevant when output contributes to reputation, attention, funding, data, model improvement, or other capacities that feed back into the productive system.

The present paper leaves open whether such self-reinforcing production should be evaluated positively or negatively in particular cases. The analytical importance lies in distinguishing the continuation of knowledge production from the curiosity, formation, and purposes of particular human subjects.

3.17 Limits of the Marxian Analogy

This subsection defines the boundaries of the Marxian translation and prevents the political-economic vocabulary from becoming an unrestricted metaphor. The analogy developed in this paper concerns recursive accumulation, productive conditions, labor organization, control, dependency, concentration, centralization, and possible forms of alienation. Several characteristics of epistemic resources require independent treatment.

Knowledge can often be copied at low marginal cost. Multiple actors can use the same proposition simultaneously. Public circulation can increase the generativity of an epistemic resource. Epistemic production also depends upon judgment, interpretation, embodiment, social relations, historical context, and forms of subject formation whose dynamics cannot be reduced to conventional economic production.

The value produced through inquiry is also heterogeneous. Scientific validity, understanding, education, cultural significance, practical capability, reputation, public benefit, existential transformation, and financial return can follow different trajectories. Their conversion into one another is possible under some conditions and limited under others.

The concept of alienation likewise requires careful extension. Reduced manual participation does not establish alienation, and technological mediation does not determine the quality of a subject's generative relation. The later analysis therefore distinguishes executorial participation, epistemic encounter, reflective participation, subject formation, and relational generativity.

The Marxian framework is consequently used as one analytical layer within a broader account of modern epistemic capitalization. It reveals how accumulated resources, productive infrastructure, labor, control, and recursive expansion can reorganize knowledge production. The epistemological, educational, existential, relational, and justice dimensions of that transformation require additional conceptual resources developed in the subsequent sections.

4 Models of Knowledge Emergence and Epistemic Formation

This section establishes the epistemological and educational baseline required for evaluating automated knowledge production. Its objective is to identify major processes through which knowledge has traditionally been understood to emerge and through which human subjects develop capacities for subsequent inquiry. The section proceeds from experience, observation, experimentation, question formation, and conceptual revision toward practice, social participation, apprenticeship, shared experience, transmission, and temporal formation. The method is comparative rather than synthetic. The reviewed traditions differ substantially in their accounts of cognition, learning, and knowledge, while collectively revealing that epistemic formation frequently depends upon trajectories of encounter and transformation whose significance extends beyond possession of a final informational output.

4.1 Experience and Knowledge Formation

This subsection establishes experience as a foundational component in several accounts of epistemic formation. Dewey's educational philosophy treats experience through the principles of continuity and interaction, emphasizing that present experience modifies the conditions under which subsequent experience becomes possible [17]. Kolb later develops an experiential-learning framework in which concrete experience, reflective observation, abstract conceptualization, and active experimentation participate in an iterative learning process [34].

The importance of experience for the present inquiry lies in its temporal and generative character. An encounter can contribute information while also changing the capacities through which later encounters are interpreted. The epistemic consequence of experience therefore includes transformation of the subject's future possibilities of recognition, judgment, and inquiry.

This temporal structure distinguishes epistemic formation from simple information transfer. Two subjects can receive the same proposition while possessing different experiential histories and consequently different capacities to interpret, evaluate, connect, or extend it. Experience therefore enters knowledge production both as a possible source of epistemic content and as a condition shaping subsequent capitalization of that content.

4.2 Observation and Inquiry

This subsection examines observation as an epistemic activity situated within a wider process of inquiry. Observation can provide evidence, reveal discrepancies, generate questions, and modify existing expectations. Its epistemic significance depends partly upon the conceptual and practical capacities through which an observer identifies relevant features of a situation.

Dewey's account of inquiry is useful here because problematic or indeterminate situations generate processes of investigation through which conditions are examined and reorganized [17]. Observation therefore participates in a recursive relation among prior expectations, encountered conditions, emerging questions, and subsequent judgments.

The same physical environment can support different epistemic trajectories for different observers. Prior training can make a pattern visible to one observer and effectively absent to another. Repeated observation can also transform what the observer becomes capable of noticing. Observation consequently participates in epistemic formation through the development of perceptual, conceptual, and evaluative capacities.

4.3 Experimentation and Empirical Knowledge

This subsection identifies experimentation as a structured form of epistemic encounter. Experimental inquiry creates controlled or partially controlled conditions through which hypotheses, expectations, measurements, and physical responses can be brought into relation. The epistemic result therefore depends upon both the observed outcome and the design through which the outcome becomes interpretable.

Experimental activity also has a formative dimension. Designing an experiment requires decisions about variables, controls, measurement, uncertainty, and possible alternative explanations. Unexpected outcomes can reveal inadequacies in an existing conceptual structure and motivate revision. Repeated experimental engagement can consequently develop forms of judgment that are difficult to represent exhaustively as explicit propositions.

This distinction becomes important for later analysis of automated experimentation. Physical interaction with an object can be delegated to instruments or robotic systems while the epistemic consequences for different participants remain heterogeneous. The present subsection therefore treats experimental knowledge as a process involving empirical interaction, interpretation, and possible transformation of epistemic capacity.

4.4 Problem Formation and Question Generation

This subsection examines the formation of problems and questions as a constitutive component of inquiry. Knowledge production frequently begins before a well-defined research question exists. An anomaly, practical difficulty, conceptual tension, unexpected observation, or unfamiliar encounter can create a condition in which the existing epistemic organization becomes insufficient.

Question generation therefore depends partly upon prior knowledge and partly upon sensitivity to what remains unresolved. A highly developed conceptual framework can generate new questions by revealing relations that were previously unavailable for interrogation. Bruner's emphasis on disciplinary structure is relevant because understanding a field includes acquiring ways of organizing problems and identifying further possibilities of inquiry [10].

Questions consequently function as epistemic resources. A productive question can reorganize attention, determine what evidence becomes relevant, connect previously separate domains, and open a sequence of subsequent investigations. The capacity to generate questions is therefore part of epistemic formation rather than a preliminary operation external to knowledge production.

4.5 Concept Formation and Conceptual Revision

This subsection addresses the role of concepts in organizing epistemic experience. Concepts enable subjects to classify, relate, compare, and interpret encountered phenomena. Epistemic development can therefore involve changes in the conceptual structures through which experience becomes intelligible.

Bruner's account of learning emphasizes the importance of grasping structural relations within a domain rather than accumulating isolated facts [10]. Vygotsky likewise places conceptual development within socially mediated processes in which language and culturally organized activity participate in higher psychological development [56].

Conceptual revision becomes especially important when existing categories fail to accommodate new evidence or relations. Inquiry can then alter the organization through which the subject subsequently interprets the world. Knowledge formation consequently includes changes in conceptual possibility, including the capacity to recognize new distinctions and formulate new questions.

4.6 Practice and Embodied Learning

This subsection establishes practice as a source of epistemic capacities that develop through repeated activity. Practical competence frequently involves coordination among perception, action, timing, judgment, and response. Such capacities can develop through sustained engagement even when the practitioner cannot provide an exhaustive propositional description of every operation involved.

Experiential-learning approaches emphasize the recursive relation among action, experience, reflection, and subsequent action [34]. Situated approaches further demonstrate that learning can be inseparable from participation in the practices through which competence is recognized and reproduced [35].

The epistemic significance of practice therefore extends beyond acquisition of instructions. Practice alters the subject's capacity to perceive relevant differences, anticipate consequences, respond to

irregularities, and evaluate the quality of performance. These transformations become especially important when later sections examine the degree to which execution can be delegated while human practical formation follows a different trajectory.

4.7 Social Interaction and Collaborative Knowing

This subsection examines knowledge formation through interaction among multiple subjects. Vygotsky's account of development emphasizes the formative role of social interaction and culturally mediated activity [56]. Knowledge can emerge through explanation, disagreement, imitation, correction, negotiation, and participation in shared practices.

Collaborative inquiry also distributes epistemic capacities across persons. One participant can possess technical knowledge, another historical knowledge, another practical experience, and another access to relevant communities or resources. The epistemic process can therefore depend upon relations among heterogeneous capacities rather than their concentration within a single subject.

This relational structure matters for the present paper because automation can alter the composition of collaborative epistemic systems. Artificial agents can enter processes previously performed by human collaborators, while the epistemic significance of such substitution depends partly upon the role played by interaction itself in the formation of knowledge and participants.

4.8 Apprenticeship and Situated Learning

This subsection examines learning through sustained participation in a social practice. Lave and Wenger's account of situated learning describes learning through legitimate peripheral participation within communities of practice [35]. The learner develops competence through changing participation in an organized field of activity.

Apprenticeship is significant because access to explicit knowledge does not exhaust the resources involved in formation. The learner observes standards of judgment, encounters irregular cases, receives correction, develops practical sensitivities, and gradually becomes capable of participating with greater independence.

The relation between experienced practitioner and learner can therefore operate as a generative infrastructure. Transmission occurs through interaction, observation, correction, imitation, interpretation, and accumulated shared experience. These processes provide an important reference point for later analysis of cultural, professional, and religious transmission under conditions of extensive public access to codified knowledge.

4.9 Inquiry-Based Learning

This subsection identifies educational models in which learning develops through active engagement with questions and problems. Dewey's educational philosophy links learning with experience, inquiry, and reflective engagement [17]. Bruner similarly emphasizes active engagement with the structure of a discipline and the learner's development of capacities for further discovery [10].

Inquiry-based learning is important because the pedagogical objective includes development of the capacity to investigate. The educational value of a task can therefore remain substantial even when its final answer is already known to the teacher, textbook, or scientific community.

A student who reconstructs a familiar result can develop question-forming capacity, evidential judgment, conceptual organization, and tolerance for uncertainty. The global stock of knowledge may remain approximately unchanged while the student's epistemic capacities undergo significant transformation. This asymmetry between societal epistemic output and individual epistemic formation becomes central to the later analysis of AI-assisted education.

4.10 Experiential and Discovery-Oriented Learning

This subsection consolidates educational approaches that emphasize learning through exploration and progressive reconstruction. Kolb's experiential model organizes learning around cycles of experience, reflection, conceptualization, and active experimentation [34]. Bruner's work emphasizes the development of understanding through engagement with underlying structures and processes of discovery [10].

The significance of discovery within education concerns the learner's trajectory. A discovery can be epistemically old at the level of civilization and epistemically new at the level of the learner. Reconstructing a known relation can still transform the learner's concepts and future capacities.

This distinction provides an important boundary for later analyses of automation. Reduction in the cost of obtaining answers does not directly determine the educational value of the processes through which a learner becomes able to recognize, evaluate, and regenerate those answers.

4.11 Shared-Experience Knowledge

This subsection introduces shared-experience knowledge as a provisional analytical category for epistemic processes in which overlapping experience among multiple subjects participates materially in the emergence of knowledge. The objective is to identify a form of epistemic generation that extends beyond individual experience and beyond simple aggregation of independently produced propositions.

Shared experience can arise within families, communities, professional groups, religious communities, cultural traditions, historical events, fieldwork, or long-term collective practices. Participants can encounter overlapping events while developing different interpretations, memories, and responses. Knowledge can emerge through later comparison, narration, disagreement, correction, and integration of these heterogeneous trajectories.

The resulting knowledge is relationally structured. The epistemic content can depend partly upon the fact that participants occupied positions within the historical process being interpreted. A record generated outside that process can contribute important evidence while possessing a different relation to the events and participants.

Shared-experience knowledge therefore introduces a distinction between representation of an experience and participation in the relational history through which its epistemic significance becomes available.

4.12 Collective Epistemic Emergence

This subsection develops the collective dimension of knowledge formation. Collective knowledge can emerge through interaction among partial, heterogeneous, and sometimes conflicting perspectives. The resulting epistemic configuration can exceed the informational contribution of any single participant because relations among testimonies, practices, interpretations, and disagreements generate additional structure.

Situated-learning theory provides one model in which knowledge and competence develop through participation in communities of practice [35]. Vygotskian approaches likewise emphasize the social mediation of cognitive development [56]. These traditions support an analysis in which epistemic formation can be distributed across social relations.

Collective epistemic emergence is particularly relevant to cultural preservation and historiography. Historical understanding can develop through relations among archival records, oral testimony, inherited practices, institutional memory, material environments, and later interpretation. Preservation of individual informational fragments therefore provides only one condition for preservation of the wider generative field.

4.13 Transmission and Relational Continuity

This subsection examines transmission as a sustained relation through which epistemic capacities and practices are reproduced across persons and generations. Its objective is to distinguish access to codified

representations from participation in a formative trajectory.

Apprenticeship provides a clear secular example. A manual can describe a practice while the learner still requires observation, correction, repeated performance, and participation with experienced practitioners. Religious and self-cultivation traditions provide another important case. Zhu Xi's conversations repeatedly connect learning, investigation, practice, and self-cultivation within an extended process of formation [58].

The existence of a public text therefore does not imply equivalent access to the capacities historically associated with its practice. A person can acquire a definition of a concept while remaining at an early stage in the formation required to interpret or enact it competently.

Transmission can consequently function as a relational generative condition. The teacher, learner, practice, community, historical context, and duration of participation jointly influence what becomes epistemically available. This structure is especially important for later analysis of traditions in which lineage, mentorship, or sustained participation retains significance even when canonical texts are widely accessible.

4.14 Temporality of Epistemic Formation

This subsection establishes time as a constitutive variable in many processes of epistemic formation. Dewey's principle of continuity emphasizes that experience modifies the conditions of later experience [17]. Experiential and situated approaches likewise describe learning through trajectories whose later stages depend upon earlier participation [34, 35].

Some epistemic capacities can develop rapidly. Others require repeated encounters, long-term comparison, gradual conceptual reorganization, or sustained participation in a practice. The temporal requirement can arise from the structure of the object, the limits of the learner, or the relational conditions through which relevant differences become recognizable.

Temporality therefore resists reduction to informational quantity. Providing more representations within a shorter period can increase accessible information while leaving other dimensions of formation unchanged. The possibility of accelerating epistemic output consequently needs to be distinguished from the possibility of accelerating every form of epistemic development.

4.15 Spatiotemporal Situatedness of Epistemic Experience

This subsection develops the relation between epistemic formation and the subject's accumulated spatiotemporal trajectory. Its objective is to identify cases in which the significance of an epistemic or cultural object depends partly upon the historical position from which it is encountered.

An artifact, testimony, place, ritual, document, or event can acquire different epistemic significance for subjects with different histories. The relevant difference can involve memory, prior relationships, cultural participation, earlier knowledge, bodily experience, or participation in related events. The object contributes to knowledge through its integration into an already developing trajectory of relations.

This structure is particularly important for art, cultural knowledge, and historical interpretation. Formal properties of an artifact provide only one component of its possible significance. Provenance, historical position, shared memory, and the circumstances of encounter can materially alter the meaning that becomes available to a subject or community.

Spatiotemporal situatedness therefore provides a conceptual basis for distinguishing representational equivalence from experiential equivalence. Two artifacts can display similar observable properties while occupying different historical and relational positions. Likewise, two subjects can receive the same informational representation while integrating it into substantially different epistemic trajectories.

4.16 Representational Preservation and Generative Continuity

This subsection distinguishes preservation of epistemic representations from preservation of the processes capable of regenerating understanding and practice. Its objective is to clarify a problem that

becomes especially important in cultural preservation, archival work, education, and the transmission of specialized knowledge.

A text, image, recording, database, or technical description can preserve important epistemic material across time. Such preservation enlarges the possibility of later recovery and reinterpretation. The continuation of a practice can additionally depend upon communities, skills, places, rituals, relationships, interpretive traditions, and opportunities for participation.

Representational preservation and generative continuity can therefore diverge. A tradition can possess extensive documentation while losing many of the relations through which its practices and interpretations were previously reproduced. Conversely, a living community can maintain significant practical and relational knowledge even when explicit documentation remains limited.

The distinction is relevant to modern public knowledge because digital availability greatly enlarges representational preservation. The persistence of generative continuity depends upon additional relational and institutional conditions.

4.17 Encounter, Inquiry, Knowledge, and Formation

This subsection synthesizes the models reviewed in this section and establishes the analytical baseline for the later examination of automation. Experience, observation, experimentation, questioning, conceptual revision, practice, social interaction, apprenticeship, shared experience, and transmission describe heterogeneous processes. Their common analytical importance lies in the possibility that epistemic production and transformation of the subject occur within the same trajectory.

An epistemic encounter can alter what a subject knows. It can also alter what the subject notices, which questions become available, how evidence is evaluated, which distinctions become meaningful, and what forms of future participation become possible. The epistemic result therefore includes both an output dimension and a formative dimension.

The reviewed models also reveal substantial heterogeneity. Some epistemic processes depend heavily upon explicit representation. Others depend upon practice, social interaction, long-term participation, shared history, or situated experience. Some empirical operations can be delegated extensively without substantial changes in the object being investigated. Other epistemic processes are sensitive to the identity, history, or relation of the participants.

These differences establish the basis for a later distinction among operator-invariant, operator-sensitive, relation-dependent, and participant-constitutive epistemic processes. They also prevent automation from being treated as a uniform intervention into an undifferentiated category of knowledge.

The principal conclusion of the present section is consequently structural. Knowledge emergence can produce epistemic artifacts, develop capacities for future inquiry, and transform the subjects and relations participating in the process. These effects frequently occur together while remaining analytically distinct. Contemporary artificial intelligence makes their possible decoupling increasingly important because execution, empirical encounter, analysis, and production can be distributed across human and machine agents.

Section 5 therefore turns from the mechanisms through which knowing and learning can emerge to the philosophical significance of knowing for the subject. That analysis is required before the paper can assess what may change when increasingly capable artificial systems perform larger portions of inquiry on behalf of human participants.

5 Philosophical Accounts of the Value of Knowing

This section examines philosophical accounts of the value realized through knowing. Its role is to establish a conceptual basis for evaluating epistemic delegation under artificial intelligence, especially in cases where an external system can generate reliable answers, conduct investigations, or produce epistemic artifacts on behalf of a human subject. The section proceeds through Aristotelian, Kantian, Hegelian,

existential, phenomenological, pragmatist, hermeneutic, virtue-epistemological, and self-cultivation perspectives. It then synthesizes these traditions into several analytically distinct values of knowing and considers how those values can follow different trajectories under delegated inquiry. The method is comparative. The traditions are treated as distinct philosophical resources whose differences should be preserved while identifying dimensions of knowing that exceed the external availability of epistemic outputs.

5.1 Aristotle and the Desire to Know

This subsection establishes an early philosophical account in which inquiry possesses significance beyond immediate instrumental use. Aristotle opens the *Metaphysics* by connecting human beings with a desire for knowledge and develops an account of inquiry in which understanding can be pursued for its own sake [1]. The resulting orientation gives knowledge a place within human activity that cannot be exhausted by its capacity to solve an externally specified problem.

The importance of this position for contemporary epistemic automation concerns the status of inquiry itself. If an artificial system can efficiently provide an answer, the instrumental demand for human investigation can decline while the human desire to understand can persist. The value realized through inquiry can therefore remain even when another agent possesses greater productive efficiency.

The Aristotelian perspective also provides a useful starting point for distinguishing epistemic production from epistemic life. A society can possess large quantities of knowledge while particular subjects participate only weakly in inquiry. The amount of available knowledge and the degree to which knowing forms part of human activity therefore require separate analysis.

5.2 Knowledge and Human Flourishing

This subsection develops the relation between intellectual activity and a broader conception of human flourishing. Aristotle's ethical philosophy places activities of reason within an account of the human good and gives contemplative activity a particularly important position [2]. Knowledge consequently acquires value through its participation in a form of life as well as through its external consequences.

The relevance to AI-mediated inquiry lies in the distinction between receiving the benefits generated by knowledge and participating in the activity of understanding. A technological system can increase safety, productivity, medical effectiveness, or material welfare while leaving open the degree to which intellectual activity remains part of the flourishing of particular persons.

This perspective therefore introduces a question that recurs throughout the paper: changes in the social production of knowledge can improve the outcomes available to human beings while simultaneously reorganizing the role that inquiry occupies within human life.

5.3 Kantian Judgment and Conditions of Cognition

This subsection examines the value of knowing through Kant's analysis of the conditions under which experience becomes intelligible. The *Critique of Pure Reason* describes cognition through an active relation among sensibility, concepts, and judgment, thereby placing the organization of experience within the capacities of the knowing subject [32].

The significance of this account for the present inquiry lies in the difference between receiving a proposition and possessing the capacities through which its object can be judged. Access to an answer can increase the information available to a subject while leaving open the subject's ability to identify the relevant concepts, examine grounds, recognize conditions of application, and determine when a judgment should be revised.

AI-mediated knowledge production makes this distinction increasingly important. External systems can supply conclusions at scales that exceed the capacity of an individual to reconstruct every intermediate operation. Judgment consequently becomes a separate epistemic capacity whose development and exercise require analysis alongside the productivity of the delegated system.

5.4 Kantian Autonomy and Epistemic Agency

This subsection develops a contemporary epistemic implication from the Kantian emphasis on active judgment. The term *epistemic autonomy* is used here analytically to describe a subject's capacity to evaluate claims, relate them to grounds, identify relevant limits, and revise judgments without complete dependence upon an external epistemic authority.

The concern is especially important under conditions of highly capable artificial assistance. A person can possess immediate access to sophisticated answers while relying upon systems whose reasoning, evidence selection, model architecture, or institutional governance remain only partly accessible. Epistemic access and epistemic autonomy can consequently develop along different trajectories.

Autonomy in this sense does not require reconstruction of every calculation or experimental operation. Modern knowledge already depends upon testimony, specialization, instruments, institutions, and distributed expertise. The analytical issue concerns the preservation of sufficient judgment for a subject to interrogate, compare, contest, contextualize, and responsibly act upon epistemic outputs.

5.5 Hegelian Mediation and Formation of Consciousness

This subsection examines knowing through a philosophical tradition in which the development of consciousness occurs through successive encounters with the limitations of its own forms of understanding. Hegel's *Phenomenology of Spirit* presents consciousness as undergoing transformations through experience, mediation, contradiction, and revision [27].

The importance of this perspective lies in the formative structure of inquiry. An epistemic difficulty can reveal an inadequacy in an existing conceptual organization. Resolution of that difficulty can transform the standpoint from which later objects become intelligible. Knowledge therefore appears together with a trajectory through which the knower changes.

This account provides a particularly useful reference point for automated knowledge production. A system can generate a result after traversing a long sequence of hypothesis formation, counterexample, correction, and revision. The human recipient can receive the result through a much shorter trajectory. The epistemic product can consequently travel across subjects without reproducing the formative sequence through which it emerged.

5.6 Existentialism, Contingency, and Self-Constitution

This subsection examines knowing through the relation between situated existence and self-constitution. Sartre's existential philosophy emphasizes human existence, freedom, choice, and the continuing constitution of the self through situated activity [50]. The present paper draws from this tradition a limited epistemic insight: encounters with the world can disclose possibilities and participate in changes in how a subject understands both the world and the subject's own position within it.

From this perspective, inquiry can carry existential significance when encounters with unfamiliar, resistant, surprising, or consequential phenomena modify the subject's orientation. A question can therefore have a history within a particular life. Its significance can depend upon the circumstances through which the problem became salient to that subject.

Epistemic delegation changes the distribution of these encounters. An external agent can investigate a problem and deliver a result while the human subject experiences only part of the trajectory. The relevant philosophical issue concerns the degree to which inquiry continues to participate in the subject's own process of orientation and self-constitution.

5.7 Phenomenology and World-Disclosure

This subsection introduces phenomenological resources for analyzing the relation between knowing, embodiment, and situated encounter. Merleau-Ponty's *Phenomenology of Perception* develops perception through the lived body and the phenomenal world, emphasizing the embodied structure through which a world becomes available to a subject [42].

The relevance to automated inquiry concerns the difference between an epistemic representation and the trajectory through which an object becomes disclosed within experience. A representation can communicate substantial information while the recipient's perceptual, bodily, and situational relation to the object remains different from that of the investigator.

This difference establishes no permanent prohibition against machine encounter. Artificial agents coupled to sensors, robotic bodies, and physical environments can participate in increasingly extensive empirical relations. The philosophical problem concerns the distribution of those relations across agents and the consequences for the human subjects who receive their outputs.

5.8 Pragmatism and Transformative Inquiry

This subsection examines knowing through pragmatist accounts of inquiry. Dewey's theory of inquiry begins from problematic or indeterminate situations and analyzes inquiry through operations that transform such situations into more determinate configurations [18]. Inquiry therefore has a practical and reconstructive structure.

The value of inquiry within this perspective includes the development of capacities for dealing with subsequent situations. Inquiry changes available knowledge while also reorganizing habits, concepts, expectations, and possible courses of action. The consequence is generative: successful inquiry can increase the capacity for future inquiry.

This structure closely approaches the concept of epistemic-capacity generativity developed later in this paper. The significance of an answer therefore includes the future capabilities produced through the process of reaching and using it.

5.9 Hermeneutics and Interpretive Transformation

This subsection examines understanding through hermeneutic transformation. Gadamer's *Truth and Method* develops understanding through historically situated interpretation and the encounter between different horizons [22]. Interpretation occurs within inherited linguistic, historical, and cultural conditions whose transformation participates in the event of understanding.

The relevance to contemporary knowledge production is especially strong for historical, cultural, legal, religious, and textual inquiry. A synthesis can represent the conclusions of an interpretive process while omitting substantial parts of the trajectory through which assumptions were exposed, alternative interpretations encountered, and an initial horizon revised.

Hermeneutics therefore provides a philosophical basis for treating interpretation as a formative relation. The value of understanding can include the transformation of the interpretive standpoint through which future encounters become possible.

5.10 Virtue Epistemology and Intellectual Agency

This subsection examines knowing through the qualities and agency of the knower. Zagzebski develops an epistemology centered on intellectual virtues and the normative significance of intellectual motivation and agency [59]. Epistemic evaluation thereby extends from the properties of individual beliefs toward the capacities and dispositions through which a subject conducts inquiry.

The perspective becomes relevant when epistemic execution is extensively delegated. A system can produce a reliable result while the human participant exercises varying degrees of attentiveness, intellectual courage, humility, care, discrimination, and critical judgment. The epistemic qualities of the result and the intellectual formation of the user can therefore diverge.

Virtue epistemology consequently supplies a vocabulary for analyzing the development of epistemic agents under automation. It directs attention toward the kinds of subjects produced through repeated practices of accepting, questioning, checking, revising, and acting upon machine-generated outputs.

5.11 Self-Cultivation and Investigation of Things

This subsection introduces a self-cultivation perspective in which engagement with things and learning participate in transformation of the person. Zhu Xi's recorded discussions connect investigation, learning, reflection, practice, and moral cultivation within a sustained process of becoming capable of understanding and acting appropriately [58].

The analytical relevance lies in the distance between possessing a textual description and undergoing the formation associated with a practice. A canonical text can be publicly accessible while the capacities required for its interpretation and enactment develop through study, repeated practice, correction, reflection, and sustained participation.

This structure is especially important for traditions organized around teacher–student transmission. The teacher contributes more than informational delivery. Interpretation, correction, example, shared practice, and temporal continuity can operate as generative conditions through which the learner's capacities develop.

The later epistemological paper devoted to the investigation of things will examine this problem in greater depth. The present inquiry uses the tradition to establish a narrower distinction between access to epistemic representations and formation of the subject capable of realizing their significance.

5.12 Instrumental Value of Knowing

This subsection begins the analytical synthesis by identifying instrumental value. Knowing can support prediction, decision, intervention, coordination, and effective action. A medical diagnosis can guide treatment. Engineering knowledge can support construction. Legal knowledge can guide institutional action. Scientific models can support prediction and technological design.

Instrumental value is particularly amenable to delegation. A person can benefit from reliable knowledge without personally reconstructing the inquiry through which it was generated. Modern societies already depend extensively upon such distributed epistemic specialization.

AI can therefore increase instrumental epistemic value substantially by lowering the cost of obtaining, processing, and applying relevant information. The existence of this benefit provides one reason for avoiding a general presumption against epistemic delegation.

5.13 Autonomy Value of Knowing

This subsection identifies the value associated with a subject's capacity for independent epistemic judgment. Knowing can reduce dependence upon external authorities by enabling a person to evaluate claims, compare alternatives, recognize uncertainty, and determine when further inquiry is required.

Autonomy value differs from informational possession. A person can receive an accurate recommendation while possessing little capacity to determine why it is appropriate, where its limits lie, or when changing circumstances undermine it. Conversely, a person can rely extensively upon external expertise while retaining substantial capacity for critical evaluation.

AI can therefore augment autonomy by making evidence, explanations, competing interpretations, and expert resources more accessible. The same infrastructure can create dependency when practical judgment becomes tightly coupled to systems whose operation or continued availability lies outside the subject's control. The resulting effect depends upon the organization of the epistemic relation.

5.14 Generative Value of Knowing

This subsection identifies the value of knowing through its consequences for future inquiry. Knowledge can create new questions, reveal previously hidden relations, enable new methods, and enlarge the range of epistemic possibilities available to a subject.

This value directly connects philosophical analysis with knowledge-capital expansion. A resource possesses generative significance when its acquisition changes what can subsequently be investigated,

understood, or produced. The value of knowing therefore includes future epistemic possibilities generated through the present epistemic state.

AI can increase generative value by allowing subjects to absorb unfamiliar literatures, test ideas rapidly, identify counterexamples, translate across domains, and explore larger possibility spaces. Generative enhancement becomes especially significant when the human participant continues to formulate, evaluate, and transform questions through interaction with the system.

5.15 Formative Value of Knowing

This subsection identifies the transformation of the knower as a distinct value of inquiry. The traditions reviewed above differ substantially, yet several provide resources for understanding inquiry as a process through which concepts, judgment, habits, skills, interpretive horizons, intellectual character, or practical sensitivities develop.

Formative value can therefore exist even when an inquiry contributes little new information to society. A student reconstructing an established proof, a trainee repeating a familiar experiment, or an apprentice practicing a known technique can undergo substantial epistemic development while producing a result already familiar to others.

The distinction becomes central under automation because high-quality epistemic outputs can increasingly be produced without a corresponding transformation in every human recipient. Social knowledge production and individual epistemic formation can consequently follow different rates and trajectories.

5.16 Existential Value of Knowing

This subsection identifies the value of inquiry through its participation in a subject's continuing relation to existence. Knowledge can arise through encounters that change how a subject understands the world, available possibilities, other persons, and the subject's own position within those relations.

Existential value is therefore strongly situated. The significance of a question can depend upon the history through which it became meaningful to a particular subject. Two people can possess the same proposition while its integration into their lives produces substantially different consequences.

This dimension also connects knowledge with contingency. Unanticipated encounters can interrupt an established orientation and open previously unavailable questions. Inquiry can then become part of the process through which a subject reinterprets and continues to constitute a life.

5.17 Delegated Knowing under Artificial Intelligence

This subsection integrates the preceding philosophical accounts into the problem of AI-mediated epistemic delegation. Its objective is to distinguish the value of an epistemic output from the different human values that can be realized through participation in inquiry.

An artificial system can increasingly retrieve literature, construct arguments, generate hypotheses, conduct computational analysis, coordinate experiments, and synthesize conclusions. Successful delegation can therefore increase the quantity, speed, and practical value of knowledge production. The philosophical consequences depend upon which dimensions of knowing are being considered.

Instrumental value can often be realized through highly delegated processes. Generative value can also increase when AI expands the questions, concepts, evidence, or methods available to a human subject. Autonomy value depends more strongly upon whether the resulting arrangement develops or weakens capacities for judgment and critical evaluation. Formative value depends upon the transformations that occur within the participating subject. Existential value depends upon how inquiry enters the subject's situated trajectory and relation to the world.

These dimensions can move independently. Extensive AI use can coexist with strong human judgment, curiosity, revision, and subject formation. Limited AI use can coexist with highly routinized hu-

man activity and weak formative effects. The proportion of operations executed by a machine therefore provides an inadequate measure of human participation in the generative process.

The resulting distinction is important for both knowledge production and creative activity. Execution can be delegated extensively while a subject's history, questions, judgments, commitments, and revisions remain deeply integrated into the trajectory. A different configuration can reduce human participation largely to initiation, authorization, and reception of outputs. The later Generative Relational analysis develops these differences through executorial, directional, reflective, existential-generative, and relational forms of participation.

The philosophical literature reviewed in this section therefore supports a plural account of the value of knowing. Knowledge can contribute to action, autonomy, future generativity, formation of the knower, and the continuing constitution of a situated life. AI-mediated epistemic production can redistribute these values across human and artificial participants without determining a single historical outcome.

The analytical consequence is a distinction between the expansion of knowledge-producing capacity and the preservation of particular forms of human epistemic participation. Their future relation remains contingent upon educational practices, technological design, institutional incentives, social relations, and the ways in which human subjects choose to integrate delegated inquiry into their lives.

Section 6 next places these philosophical distinctions within the longer historical development through which epistemic resources and knowledge-producing capacities became progressively externalized, preserved, organized, and scalable.

6 Historical Development of Modern Epistemic Capitalization

This section situates contemporary AI-mediated knowledge production within a longer history of epistemic capitalization. Its objective is to identify major changes in the infrastructures through which knowledge can be externalized, preserved, reproduced, organized, retrieved, combined, and converted into future generative capacity. The section proceeds from durable externalization and writing through archives, printing, libraries, universities, scientific publication, specialization, databases, networked information, search systems, platforms, and computational knowledge production. Artificial intelligence is then positioned within this historical trajectory. The method is selective and analytical. The section does not attempt a comprehensive history of knowledge; it examines historical transformations that materially altered the conditions for recursive epistemic accumulation.

6.1 Durable Externalization of Knowledge

This subsection establishes durable externalization as a foundational condition for large-scale epistemic accumulation. Knowledge embodied exclusively in the memory, practice, or immediate relations of living subjects is constrained by the continuity, mobility, and transmissive capacity of those subjects. Durable representations allow portions of an epistemic process to persist beyond the particular encounter in which they emerged.

Writing is a particularly consequential form of such externalization. Goody's analysis of writing emphasizes its effects on social organization, administration, religion, law, and the development of specialized literate practices [24]. The importance of writing for the present framework lies in its capacity to stabilize epistemic residues across time and thereby make them available for later interpretation, comparison, correction, and recombination.

Externalization changes the temporal structure of epistemic production. A later subject can encounter a representation produced by an earlier subject without reproducing the original experience through which it emerged. This creates conditions for intergenerational accumulation while simultaneously introducing the distinction between preservation of a representation and preservation of the generative relation that produced it.

6.2 Writing and Epistemic Accumulation

This subsection examines writing as an infrastructure for cumulative epistemic organization. Written records permit propositions, classifications, instructions, measurements, narratives, laws, and other symbolic resources to be compared across times and locations. Their persistence enables subsequent actors to begin inquiry from a historically accumulated epistemic field.

Goody's analysis also shows that writing participates in institutional differentiation by supporting administrative records, legal codification, religious textual traditions, and specialized literate roles [24]. Epistemic accumulation therefore develops together with social arrangements governing who can produce, preserve, interpret, and authorize written records.

From the perspective of knowledge capital, writing enlarges the temporal reach of epistemic resources. A written representation can enter many later generative processes, although its practical value remains dependent upon literacy, interpretation, preservation, accessibility, and relevant background knowledge. Durable externalization consequently enlarges potential capitalizability while leaving effective capitalization heterogeneous.

6.3 Archives and Intergenerational Knowledge

This subsection examines archives as infrastructures that organize durable epistemic resources across generations. Archival accumulation involves more than preservation of individual records. Selection, classification, cataloguing, provenance, institutional custody, and retrieval practices shape which traces of earlier activity remain available for later inquiry.

The social history of knowledge demonstrates that institutions of collection and classification participate actively in the organization of what later actors can know [11]. Archives therefore influence the future possibility space of historical, legal, scientific, administrative, and cultural inquiry.

The generative significance of an archive depends upon both preservation and retrievability. A record that physically survives while remaining practically undiscoverable has a different epistemic trajectory from a record incorporated into searchable and interpretable systems. Archival infrastructure can therefore be understood as an early mechanism for increasing the future capitalizability of accumulated knowledge.

Archives also illustrate the limits of representational preservation. Historical records preserve selected traces of past relations while many experiences, practices, silences, and unrecorded perspectives remain absent. Intergenerational epistemic accumulation is consequently conditioned by the historical processes through which records entered the archive.

6.4 Printing and Reproducible Knowledge

This subsection examines the transformation produced by reproducible print. Eisenstein's historical analysis treats the shift from manuscript copying to printing as a major change in the conditions of textual transmission and intellectual activity [20]. Printing increased the capacity to reproduce texts in larger numbers and supported new forms of comparison, circulation, preservation, and scholarly coordination.

The consequences of print were institutional as well as technical. Johns emphasizes that credibility, authorship, piracy, commercial practice, and the social organization of print were historically constructed rather than automatically determined by the printing technology itself [31]. Reproducibility therefore expanded epistemic circulation while creating new problems of trust, authority, control, and provenance.

For knowledge-capital analysis, printing substantially reduced the cost of reproducing certain epistemic resources and increased the number of actors who could potentially encounter the same textual object. The same argument that later appears in digital knowledge already has an earlier form here: expansion of reproducibility changes the scale of epistemic circulation while leaving the distribution of effective use dependent upon institutions, literacy, markets, language, and interpretive capacity.

6.5 Libraries and Organized Epistemic Access

This subsection examines libraries as infrastructures that convert accumulated representations into organized possibilities of encounter. Collection alone does not determine effective accessibility. Cataloguing, classification, reference systems, preservation, spatial organization, and professional practices influence which resources can be discovered and connected.

Burke's social history of knowledge treats libraries, curricula, encyclopaedias, and other classificatory systems as part of the historical organization of knowledge [11]. Commons scholarship likewise shows that shared knowledge resources depend upon institutional arrangements governing access, preservation, contribution, and use [29].

Libraries therefore increase epistemic capitalization capacity through organized retrieval. They reduce the cost of locating previously accumulated resources and enable individual inquiry to draw upon collections that exceed the memory or possessions of a single subject.

This development also creates a recurrent historical pattern. As the quantity of preserved knowledge increases, additional infrastructures become necessary to select and navigate it. Growth in epistemic resources consequently generates demand for new forms of epistemic intermediation.

6.6 Universities and Institutional Knowledge Production

This subsection examines universities and related institutions as durable organizations for reproducing epistemic capacities. Universities connect teaching, disciplinary specialization, scholarly communities, archives, libraries, laboratories, credentials, and research practices across generations. Their historical significance therefore includes both production of epistemic outputs and reproduction of people capable of further knowledge production.

Burke's account of the social organization of knowledge emphasizes the role of universities, academies, cities, states, and markets in structuring intellectual activity [11]. Modern analyses of academic capitalism further show that university knowledge production operates within relations involving public funding, markets, intellectual property, institutional strategy, and external organizations [53].

The university is consequently a particularly important example of institutional epistemic capital. Its productive capacity cannot be reduced to a collection of texts or individual scholars. It depends upon accumulated relations among people, material infrastructure, disciplinary standards, institutional memory, training systems, and access to complementary resources.

The university also illustrates the coupling between epistemic production and epistemic formation. Research and education coexist within the same institutional structure, allowing production of new knowledge to interact with the formation of future knowers. Later AI-mediated transformations may alter this coupling without eliminating the institutional functions from which it developed.

6.7 Scientific Publication and Distributed Accumulation

This subsection examines scientific publication as an infrastructure for distributed epistemic accumulation. Journals and related scholarly communication systems allow results produced within localized research environments to enter wider communities of evaluation, criticism, replication, citation, and recombination.

Print culture contributed to the emergence of new relations among technical writing, scientific exchange, and reproducible scholarly records [20]. The later organization of scientific communication also created systems of recognition through which publication, priority, reputation, and institutional position became recursively connected. Merton's analysis of cumulative advantage demonstrates how prior recognition can influence subsequent allocation of attention and resources within science [43].

Scientific publication therefore performs at least two functions relevant to knowledge capital. It circulates epistemic resources across distributed research communities, and it converts successful epistemic production into forms of recognition that can affect future productive capacity.

Publication also establishes a persistent tension between dissemination and selection. The value of a distributed literature depends upon mechanisms for discovering, evaluating, and relating contributions. Growth in publication therefore continually produces new demands for indexing, reviewing, citation, classification, and retrieval.

6.8 Specialization and Division of Epistemic Labor

This subsection examines specialization as a mechanism for increasing productive depth while distributing knowledge across heterogeneous actors. Modern knowledge systems contain disciplinary, methodological, technical, and institutional divisions that allow participants to develop highly specialized capacities.

Burke's historical account emphasizes changing groups, institutions, practices, and classifications involved in the production and organization of knowledge [11, 12]. Specialization expands collective epistemic capacity because different actors can develop forms of expertise that would be difficult for a single person to reproduce comprehensively.

The same process increases dependence. A researcher can rely upon instruments designed by others, statistical methods developed elsewhere, datasets collected by distant institutions, software maintained by specialized communities, and findings whose experimental histories cannot be personally reconstructed.

Modern epistemic production is therefore already distributed before the arrival of artificial intelligence. AI intensifies an existing organizational principle by allowing some specialized epistemic functions to be delegated to machine systems and coordinated at computational scale.

6.9 Databases and Digital Knowledge Infrastructure

This subsection examines the transition from predominantly document-centered storage toward computationally organized data. Digital databases allow epistemic resources to be structured for repeated querying, updating, comparison, and integration.

Codd's relational model was foundational for database systems that separate logical relations among data from aspects of their physical representation [16]. The importance of this development for epistemic capitalization lies in the transformation of stored information from a collection primarily encountered through sequential reading into a resource that can be computationally queried and reorganized.

Digital databases therefore increase the range of operations that can be performed over accumulated epistemic resources. Large collections can support filtering, aggregation, joining, statistical analysis, and subsequent machine-mediated processing.

The transition also changes the relevant infrastructure of control. Database schemas, access permissions, query systems, interfaces, maintenance, and computational resources influence which actors can transform stored data into further knowledge. Digital accumulation therefore increases both capitalizability and dependence upon technical infrastructure.

6.10 Networked Information and Distributed Hypertext

This subsection examines the transition from locally organized digital resources toward networked information spaces. Bush's 1945 discussion of the growing scientific record anticipated systems that would support rapid consultation and associative navigation across accumulated information [13]. Several decades later, Berners-Lee's CERN proposal described a distributed hypertext system designed to address information management problems in complex and changing organizational environments [6].

Networked hypertext substantially increased the possibility that epistemic resources stored in different locations could become part of a common navigable environment. Links created relations among documents while network access reduced geographical constraints on retrieval.

The epistemic significance extends beyond faster communication. Networked information allows the practical knowledge environment of a subject to include resources distributed across institutions,

countries, and domains. It thereby enlarges the external epistemic field available for subsequent capitalization.

The growth of such fields produces a familiar consequence: abundance increases the importance of discovery mechanisms. Once the accessible network exceeds the scale through which individuals can navigate directly, search and ranking become central epistemic infrastructures.

6.11 Search Systems and Machine-Mediated Retrieval

This subsection examines search as a mechanism for converting large information spaces into practically accessible epistemic resources. Search systems reduce the cost of locating potentially relevant information and thereby alter the relation between the size of an external corpus and the amount of it that can enter an individual inquiry.

Brin and Page's description of a large-scale hypertextual search engine illustrates the shift toward computational crawling, indexing, and ranking of large web collections [9]. Search therefore performs more than retrieval from a known location. It algorithmically mediates which resources become visible in response to a query.

This mediation has direct consequences for epistemic capitalization. A resource that exists within a public corpus contributes little to a particular inquiry when it remains practically undiscoverable. Search increases the probability that relevant resources enter subsequent epistemic relations.

The same mechanism creates a distributional problem. Ranking systems influence the probability of encounter and therefore participate in the allocation of attention. Machine-mediated retrieval consequently connects public availability, effective visibility, and future generative capacity.

6.12 Platforms and Epistemic Intermediation

This subsection examines the consolidation of multiple epistemic functions within digital platforms. Contemporary knowledge environments increasingly depend upon infrastructures that combine hosting, indexing, recommendation, identity, metrics, communication, collaboration, and access control.

Srnicek's analysis of platform capitalism emphasizes the economic significance of infrastructures that mediate interactions while accumulating data and network advantages [55]. The same structural insight is relevant to epistemic environments. Platforms can reduce coordination and discovery costs for users while acquiring significant influence over the conditions through which knowledge is circulated and encountered.

Epistemic intermediation therefore becomes a source of productive power. Control over search, recommendation, access, ranking, metrics, or distribution can influence which resources enter subsequent inquiry even when the underlying knowledge remains distributed across many producers.

Platformization also strengthens the distinction between access and control. A researcher can obtain substantial generative value from an infrastructure while possessing limited influence over its persistence, rules, ranking mechanisms, interfaces, or future development.

6.13 Computational Knowledge Production

This subsection examines computation as a transition from digital storage and retrieval toward machine-executed epistemic operations. Computational systems can transform data, simulate processes, estimate parameters, search large spaces, test formal relations, and execute procedures whose scale exceeds ordinary unaided human calculation.

Bush's earlier concern with extending access to accumulated knowledge already identified mechanization of intellectual work as a response to information abundance [13]. Database systems subsequently made large structured collections computationally manipulable [16]. Search systems extended machine processing toward selection within very large networked corpora [9].

Computational knowledge production changes epistemic capitalization because prior knowledge can increasingly be encoded into reusable procedures. A statistical package, simulation environment, soft-

ware library, scientific workflow, or computational model can preserve operational capacities that later users can mobilize without reconstructing every underlying procedure.

This creates a further form of externalized epistemic capital. What is preserved is increasingly a capacity to perform epistemic operations in addition to a representation of previously produced knowledge.

6.14 Artificial Intelligence within the Historical Trajectory

This subsection positions contemporary artificial intelligence within the historical transformations examined above. AI inherits infrastructures created through writing, archives, print, institutional science, digital databases, networked communication, search, computational models, and platform systems. Its epistemic productivity therefore depends upon a historically accumulated field rather than an isolated technological discontinuity.

The distinctive contemporary development concerns the increasing integration of previously separated epistemic functions. AI systems can retrieve literature, transform representations, generate candidate explanations, produce code, analyze data, evaluate outputs, and participate in extended research workflows. Agentic research systems increasingly coordinate several of these functions within a common computational process [37, 23]. Self-driving laboratories further connect algorithmic decision-making with robotic experimentation and physical measurement [14].

Artificial intelligence therefore intensifies a historical movement from externalization of epistemic products toward externalization of epistemic operations and productive capacities. Writing preserves a symbolic result. Libraries and archives organize accumulated representations. Databases make structured resources computationally queryable. Search systems automate selection from large corpora. Contemporary AI increasingly operates across retrieval, synthesis, generation, evaluation, and execution.

The historical continuity is analytically important because many contemporary questions precede AI. Unequal access to institutions, specialization, dependency upon infrastructures, concentration of publication and visibility, and cumulative advantage have earlier forms. AI can transform their magnitude, speed, coupling, and recursive structure.

The historical discontinuity concerns the degree to which the infrastructure can participate directly in producing the next epistemic state. Earlier information systems primarily increased preservation, access, organization, or specific forms of calculation. Contemporary agentic and autonomous systems can increasingly select and execute sequences of epistemic operations whose outputs become inputs to subsequent operations.

Modern epistemic capitalization can consequently be understood as a progressive expansion of the external conditions through which knowledge becomes durable, circulable, searchable, operational, and recursively productive. This trajectory does not establish a predetermined endpoint. Each historical expansion in epistemic infrastructure has interacted with institutions, markets, norms, education, political authority, and existing forms of inequality.

Artificial intelligence enters the same historical field while substantially expanding the scale at which accumulated public knowledge can be transformed into further generative capacity. The resulting political-economic problem therefore concerns both technological capability and the relations governing the infrastructures through which that capability becomes available.

Section 7 develops this problem by examining public knowledge as a generative field and distinguishing formal availability from practical capitalizability, capitalization capacity, recursive advantage, and commons regeneration.

7 Public Knowledge and Modern Epistemic Capitalization

This section develops the role of public knowledge within modern epistemic capitalization. Its objective is to distinguish formal availability from practical capitalizability, identify the conditions through which shared epistemic resources are converted into future generative capacity, and analyze how openness can

coexist with unequal accumulation. The section proceeds from public knowledge as generative infrastructure toward accessibility, capitalization capacity, capitalization asymmetry, commons-to-private capitalization, recursive advantage, cross-capital reinforcement, and commons regeneration. The method is relational and dynamic. Public knowledge is treated as part of a generative field whose effects depend upon the capacities, infrastructures, and institutional positions through which different actors encounter it.

7.1 Public Knowledge and Generative Infrastructure

This subsection establishes public knowledge as a shared condition of future epistemic production. Knowledge commons scholarship emphasizes that information and knowledge can be organized through institutional arrangements supporting shared access, preservation, contribution, and use [29]. The significance of such resources extends beyond their immediate informational content because publicly accessible knowledge can enter many subsequent trajectories of research, education, interpretation, and innovation.

A public theorem can support later proofs. An open dataset can enable independent analyses. A published method can be adapted to another domain. A public historical archive can support new interpretations. Open software can become a component of subsequent research infrastructure. Public knowledge therefore contributes to a field of possible future generation.

The term *generative infrastructure* is used here to emphasize this future-oriented function. Public epistemic resources increase the range of materials from which later actors can construct questions, methods, arguments, models, and other epistemic products. Their social significance therefore includes the capacities they make possible in subsequent rounds of inquiry.

7.2 Expansion of Accessible Epistemic Resources

This subsection examines the historical increase in the quantity and diversity of epistemic resources available beyond their original sites of production. Printing, libraries, scientific publication, digital repositories, networked information systems, and open-access practices have progressively enlarged the external epistemic field from which individual and institutional actors can draw.

Digital knowledge intensifies this development because the same informational resource can often be accessed by multiple actors without physical depletion. Arrow's analysis of information already identified economic properties that differentiate informational goods from many conventional commodities [3]. Romer's treatment of ideas similarly emphasizes non-rival properties relevant to their role in growth [49].

Expansion of accessible resources therefore increases the potential scale of epistemic recombination. The practical consequences depend upon whether actors can discover, interpret, evaluate, and integrate those resources into ongoing inquiry.

7.3 Accessibility and Practical Capitalizability

This subsection distinguishes formal accessibility from the capacity to convert an accessible resource into further epistemic production. A resource can be legally public and technically reachable while remaining difficult to use because of language, disciplinary complexity, computational requirements, search costs, missing contextual knowledge, or incompatible infrastructure.

The concept of *practical capitalizability* refers to the extent to which an accessible epistemic resource can realistically enter a subsequent generative process for a particular actor. Practical capitalizability is therefore actor-relative and context-dependent.

A mathematical article can be publicly downloadable while remaining practically unusable to a reader lacking the required formal background. A large dataset can be openly licensed while remaining difficult to analyze without sufficient compute or technical infrastructure. A historical archive can be public while its effective use depends upon language skills, paleographic competence, institutional access, or substantial time.

Public accessibility consequently provides one condition of epistemic capitalization while leaving other generative conditions unresolved.

7.4 Epistemic Absorption Capacity

This subsection introduces epistemic absorption capacity as the ability to locate, interpret, evaluate, integrate, and productively mobilize external knowledge. Its role is to explain why expansion of public knowledge can produce different effects across actors even when legal access is comparable.

Absorption requires more than reception. New knowledge must enter relations with existing concepts, questions, methods, memories, and objectives. A subject with substantial prior knowledge can recognize connections or implications that remain invisible to another subject encountering the same resource.

Epistemic absorption capacity can therefore depend upon prior knowledge, language, disciplinary training, attention, time, search infrastructure, institutional support, and access to complementary tools. Artificial intelligence later becomes important because it can reduce some of these costs through translation, retrieval, synthesis, comparison, and explanation.

The concept also has a temporal dimension. Successful absorption can increase future absorption capacity by creating concepts, vocabulary, methods, and questions through which later resources become easier to interpret.

7.5 Capitalization Capacity

This subsection develops the broader capacity through which accessible epistemic resources become future generative power. Capitalization capacity includes absorption while extending toward the ability to convert acquired resources into new questions, methods, experiments, interpretations, tools, infrastructure, or other productive conditions.

For an actor i , capitalization capacity can be represented provisionally by a function of complementary resources, as shown in Equation 1.

$$\kappa_i(t) = \kappa(K_i(t), T_i(t), F_i(t), N_i(t), I_i(t), S_i(t), L_i(t)), \quad (1)$$

where K_i represents prior epistemic resources, T_i available time, F_i financial resources, N_i relevant networks, I_i infrastructure, S_i institutional position, and L_i linguistic and interpretive capacities. Equation 1 is a conceptual representation rather than an empirical production function.

The formulation emphasizes complementarity. Access to public knowledge can produce limited generative effects when the complementary conditions required for use remain weak. Conversely, strong capitalization capacity can transform a modest external resource into substantial future epistemic advantage.

7.6 Capitalization Asymmetry

This subsection examines unequal generative gains under shared access. Capitalization asymmetry occurs when actors encountering comparable epistemic resources obtain substantially different changes in future productive capacity.

For two actors A and B drawing upon a common public resource C , the basic asymmetry can be represented by Equation 2.

$$\Delta G_A(C, t) \neq \Delta G_B(C, t), \quad (2)$$

where ΔG_i denotes the change in subsequent generative capacity. Equation 2 does not imply that the difference is unjust or permanent. It identifies a structural possibility arising from heterogeneous complementary conditions.

Capitalization asymmetry can originate from prior knowledge, compute, time, institutional position, language, network access, research infrastructure, or ability to convert epistemic gains into other forms of capital. Such differences can become recursive when one round of advantage improves the conditions for the next.

7.7 Public Inputs and Private Generative Capacity

This subsection examines a configuration in which publicly accessible epistemic inputs contribute to capacities that remain under private or restricted control. The process is compatible with continued public access to the original knowledge.

An actor can use public research to construct a proprietary database, model, workflow, experimental platform, or specialized body of organizational knowledge. The source material can remain public while the resulting infrastructure becomes difficult for others to reproduce.

The political-economic significance therefore concerns the transformation of shared inputs into asymmetrically controlled future productive capacity. Private generative capacity can arise partly from public epistemic resources without requiring legal privatization of those resources themselves.

This distinction becomes increasingly important under AI because large public corpora can contribute to models and agentic infrastructures whose operation depends upon privately controlled compute, engineering, data pipelines, and organizational resources.

7.8 Commons-to-Private Capitalization

This subsection formalizes the preceding process as *commons-to-private capitalization*. The term describes a trajectory in which public or shared epistemic resources enter a process that produces subsequent generative capacity under comparatively restricted control.

The structure is shown in Equation 3.

$$K_{\text{commons}} \rightarrow C_A \rightarrow G'_A \rightarrow K'_A, \quad (3)$$

where K_{commons} denotes accessible commons resources, C_A the capitalization process controlled or organized by actor A , G'_A the resulting increase in generative capacity, and K'_A the subsequent epistemic resources produced. Equation 3 describes a direction of conversion and contains no normative judgment by itself.

Commons-to-private capitalization can coexist with socially valuable innovation. Public research frequently contributes to private products, organizational expertise, technologies, and services that generate additional social benefits. The normative issue depends upon the relations of control, dependency, circulation, return, and effects on the future generativity of the commons.

7.9 Recursive Epistemic Advantage

This subsection examines how capitalization asymmetry can become self-reinforcing. Merton's analysis of cumulative advantage in science shows how prior recognition can influence later access to attention and resources [43]. Knowledge-capital analysis extends this recursive structure toward generative capacity itself.

A successful round of epistemic capitalization can produce more than a new result. It can create reputation, funding, collaborators, infrastructure, datasets, models, methods, or institutional authority. These resources can increase the actor's capacity to capitalize upon subsequent public knowledge.

Recursive advantage therefore involves a temporal coupling between current epistemic gain and future capitalization capacity. The initial difference need not be large. Repeated feedback can generate substantial divergence across longer trajectories.

AI can strengthen this mechanism when computational resources allow some actors to process larger corpora, explore more hypotheses, run more experiments, or deploy more agents. The resulting outputs can then contribute to further financial, reputational, and infrastructural accumulation.

7.10 Openness and Concentration

This subsection examines the possibility that expansion of public access and concentration of effective generative capacity can occur simultaneously. Knowledge commons can enlarge the total field of resources available for inquiry while actors differ substantially in their capacity to absorb and capitalize upon those resources.

The coexistence of field-level expansion and actor-level divergence is represented conceptually in Equation 4.

$$\Delta G_{\text{field}} > 0 \quad \text{and} \quad \Delta(G_A - G_B) > 0. \quad (4)$$

Equation 4 represents a condition in which aggregate generative capacity increases while the difference between two actors' capacities also increases.

This configuration can be described as an openness–concentration tension. Openness enlarges the pool of resources available for capitalization. Actors with stronger complementary capacities can sometimes exploit the larger pool more rapidly and at greater scale.

The analytical consequence is important for public-knowledge policy. Expansion of access can improve collective generativity while leaving questions of capacity distribution unresolved. Access and concentration therefore require separate empirical analysis.

7.11 Cross-Capital Reinforcement

This subsection examines the conversion of epistemic advantage into complementary forms of capital and the return of those resources to epistemic production. Bourdieu's analysis of capital conversion provides an important reference point for understanding relations among economic, cultural, social, and symbolic resources [8].

Within knowledge production, epistemic success can generate reputation. Reputation can generate network access, institutional position, or funding. Funding can purchase compute, instruments, personnel, or data. Infrastructure can increase the scale of later knowledge production.

The process therefore extends beyond accumulation within a single resource category. Modern epistemic capitalization can operate through coupled cycles linking knowledge, attention, recognition, finance, institutions, networks, and infrastructure.

These conversions also affect the public knowledge commons. An actor that successfully transforms public knowledge into reputational or financial capital can return to the commons with substantially greater capacity to absorb and process the next generation of public resources.

7.12 Recirculation and Commons Regeneration

This subsection examines the reverse movement through which privately or institutionally generated resources return to shared epistemic fields. Knowledge-capital accumulation can support commons regeneration when resulting knowledge, methods, datasets, tools, infrastructure, teaching, documentation, or other productive resources become available for subsequent collective use.

A regenerative circulation can be represented by Equation 5.

$$K_{\text{commons}} \rightarrow C_A \rightarrow K'_A \rightarrow K'_{\text{commons}}, \quad (5)$$

where K'_{commons} represents the commons after the contribution of additional resources generated through actor A 's capitalization process. Equation 5 represents one possible circulation pattern and does not imply that every capitalization process produces such a return.

Generative justice provides a useful conceptual reference because it directs attention toward the circulation of value back toward the people and communities participating in its production [19]. Within public knowledge systems, generative return can include open publication, reusable tools, infrastructure, financial support, training, maintenance, or other contributions that enlarge future shared generativity.

The appropriate form and magnitude of such return remain normative and institutional questions. The present paper identifies recirculation as a structural variable rather than establishing a universal obligation.

7.13 Public Knowledge and Attention Allocation

This subsection introduces attention as an additional condition affecting the effective use of public knowledge. Expansion of accessible information creates a selection problem because human attention remains temporally constrained. Simon identified this relation between information abundance and attention scarcity in early analyses of information-rich environments [52].

A public epistemic resource can therefore possess several different statuses. It can exist, remain legally accessible, be technically retrievable, and still receive little effective attention. Search, recommendation, citation, institutional prestige, language, presentation, and ranking can all influence the probability that a resource enters subsequent inquiry.

Attention is therefore relevant to capitalization because resources that are rarely encountered have fewer opportunities to contribute to future generative processes. Publicness alone does not determine effective epistemic presence.

This problem becomes more significant under machine-scaled production, where the supply of polished epistemic artifacts can expand much faster than human attention. Section 12 develops the resulting political economy of visibility in detail.

7.14 Public Knowledge and Recursive Advantage

This subsection integrates the mechanisms developed throughout the section. Public knowledge enlarges the external epistemic field available to multiple actors. Practical capitalizability depends upon heterogeneous absorption, interpretive, computational, institutional, and financial capacities. Successful capitalization can then create additional epistemic and complementary resources that increase future capitalization capacity.

The resulting process is recursive. An actor that extracts greater generative value from one round of public knowledge can enter the next round with stronger resources. Differences in capitalization capacity can therefore become historically cumulative.

The process remains compatible with substantial field-level benefit. Public knowledge can generate discoveries, technologies, education, and institutional capacity across many actors. The central analytical point concerns the distribution of the resulting generative conditions.

This distinction prevents publicness from being treated as a complete theory of epistemic equality. Public access concerns the availability of inputs. Knowledge-capital analysis additionally concerns the capacities through which those inputs become future productive power.

7.15 Public Knowledge within Modern Epistemic Capitalization

This subsection synthesizes the role of public knowledge within the wider historical process of epistemic capitalization. Public epistemic resources provide a shared field from which multiple actors can construct later knowledge. Their generative effects are mediated by absorption capacity, capitalization capacity, infrastructure, attention, institutional position, and cross-capital conversion.

The resulting system contains several simultaneous tendencies. Expanded openness can increase collective generativity. Heterogeneous capitalization capacity can produce recursive advantage. Public inputs can contribute to privately controlled generative infrastructure. Successful private capitalization can also generate resources that recirculate into the commons. Attention and ranking can alter which formally public resources remain effectively present in later inquiry.

These tendencies establish the political-economic context for artificial intelligence. AI does not enter an undifferentiated public knowledge space. It enters a historically accumulated field already structured by differences in access, interpretation, visibility, institutions, capital, and productive infrastructure.

Artificial intelligence can alter several of these relations simultaneously. It can increase epistemic absorption, reduce search and translation costs, expand the practically capitalizable portion of public knowledge, accelerate cross-domain recombination, and enable larger numbers of epistemic trajectories to be explored. The same systems can increase the importance of compute, models, data pipelines, agent orchestration, robotics, and other resources whose distribution remains unequal.

Section 8 therefore turns from public knowledge as a generative field toward the contemporary infrastructures through which artificial intelligence increasingly converts that field into machine-scaled epistemic capacity.

8 AI Infrastructure for Epistemic Capitalization

This section examines the infrastructural components through which artificial intelligence increasingly participates in epistemic capitalization. Its objective is to distinguish the principal technical and organizational layers that convert accessible knowledge, computational resources, empirical systems, and research objectives into reusable capacities for subsequent knowledge production. The section proceeds from models, compute, data, and retrieval toward scientific foundation models, research agents, multi-agent systems, automated experimentation, field and survey infrastructures, analysis, scientific writing, review, and integrated autonomous research systems. The method is functional and infrastructural. Each component is considered through the epistemic operations it enables, the complementary resources it requires, and the forms of productive capacity that can persist across multiple rounds of inquiry.

8.1 Models and Epistemic Infrastructure

This subsection establishes models as reusable components of contemporary epistemic infrastructure. Modern AI models can encode capacities for language processing, pattern recognition, representation, prediction, code generation, reasoning support, and interaction with external tools. Scientific foundation models extend this logic toward domains in which a common model architecture or representation can be adapted across multiple scientific tasks [41].

The infrastructural significance of a model lies in persistence across tasks. A model trained or adapted for one family of epistemic operations can reduce the cost of subsequent retrieval, classification, prediction, synthesis, or problem solving. Its productive consequence therefore extends beyond the immediate output generated in one interaction.

Models also concentrate prior epistemic and technical investment. Training data, architectural choices, optimization procedures, evaluation systems, engineering labor, and computational expenditure become incorporated into an artifact that can later be invoked repeatedly. A deployed model can therefore function as a machine-mediated repository of productive capacity.

The generative value of this infrastructure depends upon complementary conditions. Access interfaces, context construction, retrieval systems, specialized tools, domain adaptation, compute, and human judgment influence the extent to which model capabilities become practically useful within research.

8.2 Compute and Machine-Scaled Generative Capacity

This subsection examines computation as a condition governing the scale, duration, and parallelism of AI-mediated inquiry. Model capabilities become practically available through computational resources required for training, inference, search, simulation, agent execution, and repeated evaluation.

Compute influences epistemic production through more than raw processing speed. Greater computational capacity can support larger models, longer contexts, additional sampling, parallel agent populations, more extensive simulations, larger search spaces, repeated verification, and sustained autonomous workflows.

The resulting relation makes compute a complementary form of productive infrastructure. Two actors can possess access to similar public knowledge and similar model architectures while differing substantially in the number of epistemic trajectories they can afford to explore.

Compute therefore participates directly in capitalization capacity. Its distribution affects which actors can convert large public corpora, complex models, and automated workflows into sustained machine-scaled epistemic production.

8.3 Data and Machine-Accessible Knowledge

This subsection examines data as both an epistemic resource and an infrastructural condition of artificial intelligence. Training corpora, scientific datasets, observational records, experimental results, images, software repositories, structured databases, and other machine-readable resources can enter model development and downstream research workflows.

The historical expansion of public digital knowledge substantially enlarges the pool of epistemic material available for machine-mediated processing. Publicly accessible papers, repositories, datasets, and software can support retrieval, synthesis, adaptation, evaluation, and new forms of model-assisted inquiry.

Machine accessibility introduces requirements beyond formal openness. File formats, metadata quality, indexing, licensing, documentation, interoperability, data cleanliness, and computational accessibility influence the extent to which a resource can enter automated pipelines.

The distinction between public availability and machine accessibility is therefore important. A resource can remain publicly readable while being difficult to incorporate into automated workflows. Conversely, highly structured and well-indexed resources can become unusually valuable inputs for machine-scaled epistemic capitalization.

8.4 Retrieval and Literature Intelligence

This subsection examines retrieval infrastructure as the interface between large external corpora and model-mediated inquiry. Retrieval systems locate, rank, filter, and supply potentially relevant resources to downstream models. Their role becomes increasingly important when the available literature exceeds the scale at which a human researcher can perform direct comprehensive review.

OpenScholar demonstrates one contemporary architecture in which retrieval, reranking, citation grounding, and iterative refinement are organized around a large corpus of open-access scientific literature [4]. The system illustrates how specialized retrieval infrastructure can substantially alter the practical relation between corpus size and usable knowledge.

Retrieval therefore contributes to epistemic absorption capacity. It can reduce search costs, increase coverage, identify connections across distant literatures, and supply evidence for later synthesis.

The same infrastructure also performs selection. Ranking decisions influence which documents enter the effective context of an inquiry. Retrieval systems therefore participate simultaneously in epistemic expansion and attention allocation.

8.5 Scientific Foundation Models

This subsection examines scientific foundation models as infrastructures designed for reuse across related scientific domains and tasks. Menon and colleagues distinguish scientific foundation models through their capacities for adaptation and generalization across domains and problems [41].

The capital-like property of such models lies in their ability to preserve productive capability across future inquiries. A model that can be adapted across multiple scientific tasks represents accumulated computational and epistemic capacity that can enter subsequent research without reconstruction from first principles.

Scientific foundation models can therefore alter the cost structure of epistemic production. Once a sufficiently capable model exists, later users can build additional workflows through prompting, adaptation, retrieval, fine-tuning, tool use, or agentic orchestration.

Their distribution remains important. Construction and operation can require substantial data, compute, engineering expertise, and institutional resources. The resulting infrastructure can therefore expand

scientific capacity while also creating differences in who can build, adapt, or control the most capable systems.

8.6 Research Agents and Agentic Workflows

This subsection examines the transition from isolated model outputs toward systems that preserve state, select actions, use tools, and execute extended research processes. Agent Laboratory demonstrates an architecture in which language-model agents participate in literature review, experimentation, and report generation within a structured workflow [51]. The AI Scientist further integrates idea generation, literature search, computational experimentation, analysis, manuscript production, and automated review [37].

Agentic organization is epistemically significant because a research problem can be decomposed into multiple operations whose outputs condition later operations. The system can retain intermediate results, revise plans, call external software, and continue inquiry across multiple stages.

Research agents therefore externalize part of the procedural organization of inquiry. What becomes reusable is not only a model capability but also a workflow capable of repeatedly coordinating model calls, tools, memory, data, and evaluation.

This shift enlarges the scale at which epistemic labor can be organized without requiring continuous human execution of every intermediate step.

8.7 Multi-Agent Research Systems

This subsection examines the distribution of epistemic functions among multiple artificial agents. Multi-agent systems can assign different roles to literature search, hypothesis formation, criticism, planning, analysis, evaluation, and synthesis.

Ghareeb and colleagues demonstrate a multi-agent scientific-discovery system in which specialized agents conduct literature research, generate hypotheses, propose experiments, analyze experimentally generated results, and revise subsequent hypotheses [23]. The architecture illustrates a computational form of distributed epistemic labor.

Multi-agent systems can increase parallelism and internal differentiation. Several candidate explanations can be explored simultaneously, distinct agents can criticize one another's outputs, and evaluation can occur before a result enters the next stage of inquiry.

The productive scale of such systems depends upon available compute, model access, orchestration software, memory, tool infrastructure, and evaluation resources. Multi-agent epistemic organization therefore creates a direct link between computational capital and the number of parallel epistemic trajectories that can be sustained.

8.8 Automated Hypothesis Generation

This subsection examines infrastructures capable of producing candidate hypotheses from accumulated knowledge, observations, or prior experimental results. Automated hypothesis generation moves AI participation from retrieval and synthesis toward the expansion of possible research trajectories.

The AI Scientist generates candidate research ideas and evaluates them through computational experimentation [37]. The multi-agent system developed by Ghareeb and colleagues similarly generates and revises biological hypotheses in interaction with experimental results [23].

The epistemic value of hypothesis-generation infrastructure lies in breadth and parallelism. A system can produce multiple candidate explanations, compare them against literature or data, and select subsets for further investigation.

The resulting capability can enlarge the practically explorable question space. Its value depends upon evaluation quality, diversity of generated candidates, access to relevant evidence, and the capacity to distinguish productive novelty from superficial variation.

8.9 Automated Experimental Design

This subsection examines the translation of hypotheses into structured empirical interventions. Experimental-design systems can select variables, conditions, measurements, candidate parameter values, or subsequent experiments based upon previous results.

Self-driving laboratory research demonstrates the increasing integration of algorithmic decision-making with automated experimental execution [14]. Such systems can implement iterative loops in which the result of one experiment informs the design of the next.

Automated design is epistemically significant because it moves machine participation closer to the organization of empirical encounter. The system determines which portions of a physical possibility space become experimentally sampled.

The generative capacity of this infrastructure depends upon instruments, robotics, domain models, uncertainty estimation, control software, and evaluation procedures. Experimental design therefore illustrates the coupling between symbolic computation and material productive infrastructure.

8.10 Robotic Experimentation

This subsection examines robotic systems as means through which epistemic operations can be executed in physical environments. Robotics can automate sample handling, instrument control, material preparation, measurement, inspection, and other experimental operations.

The significance for the present inquiry concerns the scalability of empirical encounter. Capital investment in robotic systems can increase the number, duration, precision, and parallelism of physical experiments that an organization is able to conduct.

Robotic experimentation therefore weakens any simple association between empirical inquiry and continuous human manual execution. The relevant political-economic question increasingly concerns control over the infrastructure that performs the empirical operations.

This development also clarifies the distinction between execution and participation developed later in the paper. A human researcher can remain deeply involved in question formation, interpretation, and revision while delegating physical execution to robotic systems.

8.11 Self-Driving Laboratories

This subsection examines self-driving laboratories as integrated infrastructures that connect experimental selection, robotic execution, measurement, analysis, and iterative decision-making. Canty and Abolhasani describe contemporary self-driving laboratories through the combination of automation, robotics, algorithmic control, and AI-mediated interpretation [14].

The distinctive property of a self-driving laboratory lies in closure of the experimental loop. Experimental outcomes can become machine-readable inputs for the selection of subsequent experiments, allowing the system to continue exploration across multiple rounds.

This configuration creates a reusable means of empirical knowledge production. The laboratory embodies physical, computational, and epistemic capacities that can be directed toward successive research problems.

Its political-economic significance follows from capital intensity and reproducibility. Construction, maintenance, instrument access, robotic hardware, calibration, software integration, and specialist engineering can require substantial resources. Control over such systems can therefore produce large differences in machine-scaled empirical capacity.

8.12 Automated Field Observation and Data Collection

This subsection extends automated epistemic infrastructure beyond controlled laboratories. Sensors, autonomous vehicles, drones, robotic platforms, remote instruments, and networked monitoring systems can collect data across physical environments over extended periods.

The conceptual importance of such systems lies in their capacity to scale observation across space and time. Environmental, astronomical, agricultural, urban, geological, and ecological inquiry can increasingly rely upon automated systems that collect observations continuously or across locations difficult for individual researchers to monitor directly.

Automated field observation therefore transforms empirical access into an infrastructural property. The amount of reality that can be sampled becomes partly dependent upon the number, persistence, mobility, and sensing capacity of deployed systems.

The resulting epistemic advantage can be capital-intensive. Organizations with greater ability to deploy and maintain observational infrastructure can produce larger proprietary or semi-proprietary streams of empirical data even when the theoretical knowledge guiding collection is publicly available.

8.13 Automated Survey and Interview Infrastructure

This subsection examines the extension of automated inquiry into social research. Language-capable agents can support survey administration, standardized interviewing, transcription, translation, coding, and initial analysis. Future systems can also combine conversational models with embodied or mobile platforms for more extensive field deployment.

The epistemic structure of interview-based research differs from many physical measurements because the identity and behavior of the interviewer can influence the responses generated. Automation therefore changes both productive capacity and the relational configuration through which the data emerge.

Machine-scaled survey and interview systems can increase the number of participants, languages, locations, or iterative follow-up interactions that become practically manageable. They can also create new methodological requirements concerning disclosure, response effects, representativeness, privacy, interpretation, and relational context.

These differences motivate the later distinction between operator-invariant, operator-sensitive, relation-dependent, and participant-constitutive epistemic processes.

8.14 Automated Analysis and Evaluation

This subsection examines systems that transform observations and intermediate research outputs into assessments capable of directing subsequent inquiry. Automated analysis can include statistical processing, pattern detection, comparison with prior literature, error identification, model selection, and evaluation of candidate explanations.

End-to-end and multi-agent research systems already incorporate forms of machine-mediated evaluation into iterative workflows [37, 23]. Automated evaluation increases the possibility that one machine-generated output becomes the basis for selection among later machine-generated operations.

The epistemic importance of this layer is recursive. Production at machine scale creates more intermediate outputs than a human participant can inspect directly. Evaluation infrastructure becomes necessary to filter those outputs and determine which trajectories continue.

Automation of evaluation therefore increases both productive capacity and epistemic dependence upon the criteria embedded in the evaluating system. Verification, provenance, diversity of evaluative procedures, and human oversight remain important conditions of reliability.

8.15 Automated Scientific Writing

This subsection examines writing as a downstream component of integrated epistemic workflows. Research agents can increasingly transform literature reviews, experimental logs, analyses, figures, and intermediate conclusions into structured reports or manuscripts [51, 37].

Automated writing lowers the cost of converting internal research processes into externally communicable epistemic artifacts. It can support rapid documentation, consistency, translation, summarization, and adaptation to different audiences.

This capacity has political-economic consequences because publication is one route through which epistemic production becomes visible, citable, and convertible into reputation. Reduction in the cost of producing polished artifacts can therefore affect the volume of material entering scholarly and public attention environments.

The quality of surface presentation can also become less informative about the duration or difficulty of the generative process underlying the artifact. This issue becomes central to the later analysis of attention, visibility, and epistemic authority.

8.16 Automated Review and Criticism

This subsection examines the use of artificial intelligence in evaluation, criticism, and review. Automated research systems increasingly incorporate internal reviewer roles, while scholarly institutions are experimenting with AI-assisted peer-review processes [37, 46].

Review functions are epistemically important because they influence which outputs are accepted, revised, prioritized, or circulated. Automation of review therefore extends AI-mediated production into the mechanisms through which epistemic artifacts acquire institutional credibility.

AI-assisted review can increase throughput and provide additional checks across large volumes of material. Its reliability depends upon provenance, evaluation quality, transparency, domain expertise, institutional accountability, and appropriate human responsibility.

The political-economic significance is recursive. When both production and evaluation become increasingly scalable, the volume of epistemic material that can pass through organized workflows can expand substantially. Attention and verification then become increasingly important constraints.

8.17 Integrated Autonomous Research Systems

This subsection synthesizes the infrastructural components examined throughout the section. Integrated autonomous research systems connect models, retrieval, memory, tools, data, agent orchestration, evaluation, and potentially physical experimental infrastructure within extended epistemic workflows.

The AI Scientist demonstrates substantial integration across computational research stages [37]. Ghareeb and colleagues demonstrate multi-agent coordination linked to experimental biology [23]. Self-driving laboratory research extends automation into iterative physical experimentation [14]. Agentic control of scientific instruments further demonstrates direct machine participation in experimental operations [15].

These developments suggest a transition from isolated AI assistance toward systems capable of preserving and reproducing organized epistemic capacity. The productive unit increasingly becomes an infrastructure containing models, data access, tools, agents, evaluation procedures, and empirical interfaces.

Such systems can remain partially supervised, highly interactive, or substantially autonomous. The degree of autonomy is less important for the present political-economic analysis than the persistence and scalability of the productive capacity. An infrastructure that can repeatedly convert questions and public epistemic resources into further inquiry possesses capital-like significance even when human direction remains substantial.

The integration of symbolic and empirical infrastructure also changes the meaning of epistemic capitalization. Capital can support access to existing knowledge, computational processing, and increasingly the capacity to conduct large numbers of physical epistemic encounters. Models, agents, robots, laboratories, sensors, and evaluators can become components of a common productive system.

The resulting configuration establishes the technical basis for machine-scaled knowledge-capital expansion. Section 9 therefore turns from the components of AI epistemic infrastructure toward the mechanisms through which their combination can expand epistemic absorption, accelerate capitalization cycles, increase cross-domain recombination, enlarge question spaces, scale empirical access, and automate portions of recursive epistemic reproduction.

9 Mechanisms of AI-Mediated Knowledge-Capital Expansion

This section develops the principal mechanisms through which artificial intelligence can accelerate knowledge-capital expansion. Its objective is to explain how the infrastructures described in Section 8 modify the conversion of existing epistemic resources into future generative capacity. The analysis proceeds through epistemic absorption, practical capitalizability, cross-domain recombination, question-space expansion, parallel exploration, compression of epistemic cycles, scalable empirical encounter, automated evaluation, recursive reuse, and cross-capital reinforcement. The method is mechanistic and relational. AI-mediated knowledge-capital expansion is treated as a process arising from interactions among models, public knowledge, human questions, compute, data, institutional resources, experimental systems, and the organizational control of these elements.

9.1 Expansion of Epistemic Absorption

This subsection examines the capacity of AI systems to enlarge the portion of external knowledge that an actor can practically absorb. Public knowledge can exceed the linguistic, disciplinary, temporal, and attentional capacities of individual researchers. Retrieval-augmented systems, translation, automated summarization, comparison, explanation, and literature synthesis can reduce several of these barriers.

OpenScholar provides a contemporary example of AI-mediated scientific literature synthesis grounded in retrieval over a large research corpus [4]. Such systems allow users to interrogate bodies of literature that would require substantial manual effort to search and organize.

The resulting mechanism can be represented conceptually by Equation 6.

$$K_{\text{accessible}} \xrightarrow{\text{AI mediation}} K_{\text{practically absorbable}}^i \uparrow, \quad (6)$$

where the superscript i indicates that practical absorption remains actor-relative. Equation 6 represents an increase in the portion of accessible knowledge that can enter the active epistemic field of a particular actor.

AI therefore changes the relation between corpus size and individual cognitive limits. A researcher can use external systems to identify terminology, translate unfamiliar material, reconstruct disciplinary context, compare competing positions, and locate relevant evidence.

The effect can be especially large for cross-disciplinary inquiry, where the cost of entering an unfamiliar literature has traditionally constrained the range of practically available questions.

9.2 Expansion of Practical Capitalizability

This subsection extends epistemic absorption toward the productive use of knowledge. AI can reduce the distance between encountering an external resource and converting that resource into a method, experiment, model, argument, program, or new research question.

A publicly available article may contain an unfamiliar mathematical technique. A model can explain the method, translate notation, produce an implementation, test examples, compare alternative formulations, and assist integration into a new project. Similar processes can occur with statistical methods, software libraries, legal concepts, scientific protocols, and historical materials.

The practical effect is an increase in the capitalizable portion of the public knowledge field. The same corpus can therefore possess greater productive significance after the arrival of infrastructures capable of interpreting and operationalizing its contents at lower cost.

This mechanism also increases the importance of complementary infrastructure. Effective capitalization can depend upon model quality, context length, retrieval, compute, tools, access permissions, evaluation capacity, and the user's ability to identify productive questions.

9.3 Acceleration of Cross-Domain Recombination

This subsection examines AI-mediated recombination across disciplinary and conceptual boundaries. Modern knowledge is distributed across specialized languages, literatures, methods, and communities. These boundaries can impose substantial search and translation costs on interdisciplinary inquiry.

Language models can lower some of these costs by identifying analogies, translating terminology, summarizing unfamiliar frameworks, generating candidate correspondences, and proposing ways in which methods from one domain might be applied in another.

The mechanism is represented schematically by Equation 7.

$$K_A \oplus K_B \xrightarrow{\mathcal{M}} \{Q_{AB}, M_{AB}, H_{AB}, K'_{AB}\}, \quad (7)$$

where K_A and K_B denote epistemic resources from two domains, $\mathcal{M}$ denotes AI-mediated recombination, Q_{AB} new questions, M_{AB} candidate methods, H_{AB} hypotheses, and K'_{AB} resulting knowledge. Equation 7 is a conceptual model of possible recombination rather than a claim that every generated connection is valid or productive.

Cross-domain recombination can substantially increase generative possibility because many useful relations remain difficult to identify under disciplinary specialization. AI can therefore function as an interface among previously weakly connected epistemic regions.

The epistemic value of this mechanism depends upon evaluation. Superficial analogy can be generated as easily as productive analogy. Human or machine criticism, empirical testing, formal verification, and disciplinary judgment remain important for determining which recombinations merit continuation.

9.4 Expansion of Question Space

This subsection examines the transformation of questions into a scalable epistemic resource. A productive research program depends upon the set of questions that can be formulated, recognized as meaningful, and pursued with available resources.

Agentic systems can generate candidate questions from literature gaps, anomalies, conceptual combinations, experimental results, or previously generated hypotheses. The AI Scientist and multi-agent scientific systems already demonstrate forms of automated idea and hypothesis generation [37, 23].

The relevant expansion can be represented by Equation 8.

$$Q_t \xrightarrow{\text{AI generation}} Q_{t+1}, \quad |Q_{t+1}| > |Q_t|, \quad (8)$$

where Q_t denotes the practically available set of candidate questions at time t . Equation 8 represents an increase in accessible question space and does not imply an increase in the quality of every candidate question.

This mechanism is important because questions themselves can function as knowledge capital. A productive question changes what evidence is sought, which methods become relevant, and which relations among existing resources become visible.

AI can therefore expand epistemic generativity even before producing a new answer. Its contribution can occur through multiplication and restructuring of the possible directions of inquiry.

9.5 Parallelization of Epistemic Exploration

This subsection examines the conversion of computational resources into parallel research trajectories. Human inquiry is constrained by time, attention, memory, and the number of experiments or arguments that can be pursued simultaneously. Agentic infrastructures can distribute candidate questions or hypotheses across multiple concurrent processes.

Multi-agent research systems illustrate this possibility by assigning specialized roles or alternative hypotheses to different agents [23]. Parallel execution can increase the number of candidate trajectories explored before a human researcher needs to intervene.

The mechanism can be represented through Equation 9.

$$Q \rightarrow \{\tau_1, \tau_2, \dots, \tau_n\} \rightarrow \mathcal{E} \rightarrow K', \quad (9)$$

where τ_j denotes an epistemic trajectory and $\mathcal{E}$ denotes an evaluation process. Equation 9 describes the distribution of one problem across several candidate investigative paths.

The scale of n depends partly upon compute, model access, experimental resources, and evaluation costs. Parallel epistemic exploration therefore creates a direct route through which financial and infrastructural resources can become differences in future knowledge-generating capacity.

9.6 Compression of Epistemic Cycles

This subsection examines the temporal compression of recurrent research operations. Traditional inquiry can involve delays between literature search, hypothesis generation, implementation, experimentation, analysis, criticism, revision, and documentation. AI systems can reduce several of these delays when the relevant operations become integrated into a common workflow.

Agent Laboratory and the AI Scientist illustrate computational workflows that connect several stages of research within a persistent agentic process [51, 37]. Self-driving laboratories extend similar recursive organization toward physical experimentation [14].

A simplified cycle is shown in Equation 10.

$$Q_t \rightarrow H_t \rightarrow E_t \rightarrow A_t \rightarrow R_t \rightarrow Q_{t+1}, \quad (10)$$

where Q_t denotes a question, H_t a hypothesis, E_t an experimental or investigative operation, A_t analysis, and R_t revision. Equation 10 represents a recursive epistemic cycle whose elapsed time can decrease as successive operations become automated and integrated.

Temporal compression matters because the result of one cycle can become an input to the next more rapidly. Knowledge-capital expansion therefore depends upon the number of productive cycles that can occur within a given period as well as the amount generated within any single cycle.

9.7 Scaling of Empirical Encounter

This subsection examines the increasing capacity to scale encounters with empirical reality. AI-mediated epistemic expansion extends beyond symbolic processing because robotic laboratories, sensors, scientific instruments, autonomous platforms, and automated experimental systems can interact with physical environments.

Self-driving laboratories demonstrate iterative integration among algorithmic decision-making, robotic execution, measurement, and subsequent experiment selection [14]. Agentic control of scientific instruments similarly illustrates machine-mediated participation in physical experimentation [15].

The resulting mechanism can be described as *capitalization of epistemic encounter*. Financial and infrastructural resources can purchase the means for increasing the number, diversity, duration, or precision of empirical interactions that can be conducted.

A conceptual representation appears in Equation 11.

$$C \rightarrow I_{\text{emp}} \rightarrow \{E_1, E_2, \dots, E_n\} \rightarrow K', \quad (11)$$

where C denotes mobilizable capital, I_{emp} empirical infrastructure, and E_j individual epistemic encounters. Equation 11 shows how capital can be converted into scalable empirical exploration.

This mechanism complicates any account that treats direct contact with reality as a permanent boundary of artificial knowledge production. The increasingly important distinction concerns which agents perform the encounter, which actors control the infrastructure, and how resulting knowledge enters human and institutional epistemic trajectories.

9.8 Expansion of Empirical Trajectory Space

This subsection extends scalable empirical encounter toward the number of alternative experimental histories that can be explored. A research problem can permit many combinations of parameters, samples, environments, procedures, or sequential interventions. Human time and laboratory capacity traditionally restrict the subset that can be investigated.

Automation increases the number of trajectories that can be sampled. A self-driving laboratory can choose successive experiments based upon previous results, while parallel automated systems can explore different regions of an experimental space.

The productive consequence is therefore greater than faster execution of an unchanged protocol. Automated infrastructure can enlarge the empirical region within which hypotheses can be tested and revised.

This expansion creates an additional form of capitalization asymmetry. Organizations possessing more robots, instruments, sensors, compute, or automated laboratories can convert the same theoretical question into a larger set of empirical trajectories.

9.9 Automated Counterargument and Falsification

This subsection examines the use of AI systems to generate objections, counterexamples, alternative explanations, and tests against provisional claims. Multi-agent architectures can assign critic or reviewer roles, while end-to-end research systems can evaluate intermediate results before allowing a trajectory to continue [37, 23].

Counterargument can increase generativity by revealing assumptions or weaknesses that would otherwise remain unnoticed. Automated systems can search large spaces of possible objections and compare a proposed explanation against multiple alternatives.

The mechanism can also support human inquiry. A researcher can use an AI system as an intellectual opponent, requesting counterexamples, rival interpretations, or possible failures. In such cases automation expands the field against which human judgment operates.

The epistemic consequences depend upon whether criticism becomes sufficiently diverse and reliable. Large quantities of internally generated criticism can still reproduce shared assumptions embedded in the models or source material. Automated counterargument therefore increases the scale of possible testing while preserving a need for heterogeneous evaluative relations.

9.10 Automated Evaluation and Selective Continuation

This subsection examines evaluation as a mechanism required by machine-scaled epistemic abundance. Parallel generation creates more hypotheses, analyses, documents, and experimental outputs than human participants can inspect individually. Automated evaluation can rank candidates, reject weak trajectories, and allocate further resources toward selected alternatives.

The productive advantage arises because generation and selection can be coupled. A system can produce many candidate paths while continuing only a smaller subset. This reduces the amount of direct human attention required for each intermediate operation.

Selective continuation also creates a new concentration of epistemic influence. Evaluation criteria determine which possibilities receive additional compute, experimental resources, or visibility. The evaluator therefore participates in the evolution of the question space rather than merely assessing completed outputs.

This mechanism anticipates the later analysis of attention and epistemic authority. When machine-generated possibilities become abundant, control over selection can become as important as control over production.

9.11 Recursive Reuse of Epistemic Outputs

This subsection examines the conversion of one round of machine-assisted knowledge production into inputs for subsequent rounds. A generated dataset, model, method, hypothesis, benchmark, software tool, literature map, or experimental result can become part of the infrastructure used in later inquiry.

The recursive structure is shown in Equation 12.

$$K_t \rightarrow \mathcal{I}_t \rightarrow K_{t+1} \rightarrow \mathcal{I}_{t+1} \rightarrow K_{t+2}, \quad (12)$$

where $\mathcal{I}_t$ denotes the epistemic infrastructure available at time t . Equation 12 represents a process in which epistemic outputs contribute to the productive conditions of later epistemic production.

AI can accelerate this recursion because generated outputs can often be immediately machine-readable. New code can enter later workflows, new experimental results can update subsequent decisions, and synthesized literature can become context for further hypothesis generation.

The distinction between epistemic product and epistemic infrastructure therefore becomes increasingly fluid. An output can rapidly acquire a productive role within the next generative cycle.

9.12 Machine-Scaled Reproduction of Epistemic Capacity

This subsection examines the reproduction of epistemic capacity itself. Traditional knowledge transfer frequently requires education, apprenticeship, institutional continuity, or recruitment of additional skilled persons. Machine-readable procedures and model-mediated workflows allow some capacities to be duplicated or deployed across additional computational instances.

A research agent configuration can be executed repeatedly. A trained model can serve many users. Software pipelines can be copied. Robotic procedures can be replicated across compatible equipment. Epistemic operations therefore acquire forms of reproducibility whose scaling properties differ from those of human training.

The resulting mechanism can be described as machine-scaled reproduction of epistemic capacity. Productive knowledge becomes encoded within infrastructure that can be instantiated across additional tasks or locations with relatively low marginal organizational effort once the underlying system has been constructed.

This property strengthens the capital-like character of AI infrastructure. Accumulated investment can produce a reusable system whose productive capacity extends across many later inquiries.

9.13 Cross-Capital Reinforcement under Artificial Intelligence

This subsection examines the interaction between epistemic capacity and other forms of capital under AI-mediated production. A successful model or research system can generate epistemic outputs, reputation, market value, institutional authority, data, users, and financial resources. These gains can finance additional compute, model development, laboratories, recruitment, and data acquisition.

The resulting cycle can be represented by Equation 13.

$$K \rightarrow G_{\text{AI}} \rightarrow (K', R', F', I') \rightarrow G'_{\text{AI}}, \quad (13)$$

where G_{AI} denotes AI-mediated generative capacity, K' additional epistemic resources, R' reputational resources, F' financial resources, and I' expanded infrastructure. Equation 13 represents a possible reinforcement cycle across multiple resource domains.

This structure can produce rapid divergence because gains generated in one domain increase the conditions for future accumulation in another. Epistemic advantage can attract funding, funding can purchase compute, compute can increase exploration, exploration can generate additional epistemic output, and output can create further recognition.

AI therefore strengthens the potential coupling among epistemic, financial, infrastructural, and symbolic accumulation.

9.14 Public Knowledge and Private Recursive Infrastructure

This subsection examines a particularly important contemporary configuration: public epistemic resources entering privately controlled recursive infrastructures. Public papers, code, datasets, standards, textbooks, and other open resources can contribute to systems whose later productive capacity depends upon privately controlled models, compute, robotics, orchestration, or organizational integration.

The process is represented conceptually by Equation 14.

$$K_{\text{public}} \rightarrow I_{\text{private}} \rightarrow E \rightarrow K'_{\text{private}} \rightarrow I'_{\text{private}}, \quad (14)$$

where I_{private} denotes controlled generative infrastructure, E denotes symbolic or empirical epistemic operations, and I'_{private} denotes the enhanced infrastructure produced after another capitalization cycle. Equation 14 highlights the possibility that public inputs support increasingly differentiated private productive capacities.

The original public knowledge can remain openly available throughout this process. The concentration therefore occurs at the level of capitalization capacity rather than through removal of the original resource from the commons.

This mechanism is central to the possibility of an openness–concentration dynamic under AI. Public knowledge can become more accessible globally while the capacity to process, test, and extend that knowledge at machine scale becomes increasingly differentiated.

9.15 Industrialization of Epistemic Capitalization

This subsection integrates the preceding mechanisms through the concept of *industrialized epistemic capitalization*. The term refers to a condition in which conversion of existing knowledge into further epistemic production becomes increasingly organized through scalable, repeatable, capital-intensive, and partially automated infrastructures.

Industrialization in this sense involves several simultaneous changes. Larger portions of public knowledge become machine-processable. Questions can be generated and explored in parallel. Experimental encounters can be automated. Evaluation can filter machine-generated possibilities. Outputs can become inputs to subsequent cycles with limited delay. Productive capacities can be reused across many inquiries.

The resulting system can achieve levels of epistemic throughput that exceed the productive capacity of individual researchers or conventional research teams. The relevant unit of analysis therefore shifts toward integrated epistemic infrastructures containing models, agents, databases, compute, laboratories, sensors, evaluators, and human participants.

Industrialized epistemic capitalization does not imply the disappearance of human inquiry. Human participants can continue to formulate questions, interpret results, exercise judgment, provide contextual knowledge, establish normative priorities, and participate deeply in generative trajectories. The organizational relation between these activities and machine-executed operations becomes increasingly variable.

9.16 Expansion without Uniform Epistemic Formation

This subsection distinguishes growth in epistemic production from the distribution of epistemic formation among participating subjects. AI-mediated systems can expand output, question-space exploration, empirical coverage, and recursive generative capacity while human participants undergo highly heterogeneous degrees of learning and transformation.

One researcher can use AI-generated counterarguments to deepen conceptual understanding. Another can receive a completed synthesis with little engagement with the underlying literature. A third can delegate execution extensively while remaining strongly involved in problem formulation, interpretation, and revision.

The degree of automation therefore does not determine the degree of human epistemic participation. This distinction becomes important for evaluating alienation, education, curiosity, and subject formation in later sections.

Knowledge-capital expansion consequently operates across at least two analytically separate trajectories: expansion of externally organized epistemic capacity and transformation of the subjects who participate in or benefit from that capacity.

9.17 Mechanisms of Recursive Epistemic Expansion

This subsection synthesizes the mechanisms developed throughout the section. Artificial intelligence can expand epistemic absorption, increase practical capitalizability, accelerate cross-domain recombination, enlarge question spaces, parallelize inquiry, compress research cycles, scale empirical encounter, automate criticism and evaluation, and convert outputs rapidly into resources for subsequent production.

The combination of these mechanisms creates a recursive system. Public knowledge supplies an expanding epistemic field. Models and retrieval systems increase the portion that can be absorbed. Agentic infrastructures convert absorbed resources into larger spaces of questions and hypotheses. Compute enables parallel exploration. Robotic and scientific infrastructure connect machine reasoning with empirical environments. Automated evaluation selects among proliferating trajectories. Successful outputs can then strengthen the infrastructure available for the next cycle.

The cumulative structure can be represented by Equation 15.

$$K_t \rightarrow A_t \rightarrow Q_t \rightarrow T_t \rightarrow E_t \rightarrow K_{t+1} \rightarrow A_{t+1}, \quad (15)$$

where K_t denotes available epistemic resources, A_t capitalization capacity, Q_t the practically available question space, T_t the set of explored epistemic trajectories, and E_t the relevant evaluative or empirical encounters. Equation 15 represents a recursive architecture in which newly produced knowledge can increase the capacity, question space, and infrastructure available for later inquiry.

The political-economic consequence is that differences in infrastructure can become differences in the speed and breadth of epistemic recursion. Actors with stronger models, compute, data access, experimental systems, and institutional resources can capitalize upon the same public knowledge field through a larger number of simultaneous and successive trajectories.

The epistemological consequence is equally important. Increased production does not establish that every form of knowledge emergence can be automated in the same way. Experimental measurement, interpretation, apprenticeship, shared experience, cultural transmission, social interaction, and participant-dependent inquiry possess different relations to the agents performing them.

Section 10 therefore examines the heterogeneity of knowledge-emergence processes and develops a distinction among operator-invariant, operator-sensitive, relation-dependent, and participant-constitutive forms of epistemic production.

10 Differential Automation of Knowledge-Emergence Processes

This section develops a differentiated account of automation across knowledge-emergence processes. Its objective is to identify how the epistemic consequences of delegation vary according to the role played by the investigator, the relation between participants, the history of the encounter, and the practical or cultural conditions through which knowledge emerges. The section proceeds from comparatively codified and formal processes toward experimental, observational, embodied, situated, relational, shared, historical, and participant-constitutive forms of knowing. It then introduces a four-part analytical classification comprising operator-invariant, operator-sensitive, relation-dependent, and participant-constitutive processes. The method is comparative and relational. The classification concerns the structure of particular epistemic processes rather than fixed properties of entire disciplines.

10.1 Heterogeneity of Epistemic Processes

The mechanisms examined in Section 9 can increase the scale and speed of epistemic production. Their significance depends, however, upon what kind of epistemic process is being automated. Knowledge emerges through heterogeneous relations among representations, formal operations, instruments, physical objects, embodied practices, investigators, communities, and historical situations.

A calculation can remain stable across many competent operators. An interview can change according to the person conducting it. An apprenticeship depends upon sustained participation in a practice. Testimony concerning a shared historical event can depend upon the fact that particular persons occupied positions within that event. These cases involve different relations between the epistemic process and the agent performing it.

Automation should therefore be analyzed through the structure of delegation. The central issue concerns which components of an epistemic process can change operators while preserving the epistemically relevant relations, which components are sensitive to the characteristics of the operator, and which forms of knowledge partly emerge through the participation of particular subjects.

Table 1 summarizes the provisional classification developed throughout this section.

Table 1: Analytical Classes of Differential Epistemic Automation

Class	Operator Relation	Illustrative Processes	Automation Implication
Operator-invariant	Relevant result remains comparatively stable across competent operators under specified conditions	Formal computation, standardized measurement, some routine analytical procedures	Execution can often be delegated extensively
Operator-sensitive	Characteristics or conduct of the operator influence the resulting evidence or inference	Interviewing, observational coding, some field measurement	Delegation changes a variable within the epistemic process
Relation-dependent	Knowledge depends materially upon interaction among participating agents	Collaborative interpretation, ethnographic interaction, mentorship, dialogical inquiry	Changing participants can change the generative relation
Participant-constitutive	Participation or historical position contributes to the epistemic object or significance itself	Shared experience, lived testimony, lineage-based practice, collective memory	Delegation can alter the conditions through which the knowledge emerges

These classes form an analytical gradient rather than mutually exclusive containers. A single research project can contain operations belonging to several classes, and the same operation can move between classes when its epistemic purpose changes.

10.2 Codified and Combinatorial Knowledge

This subsection examines epistemic processes organized primarily around explicitly represented resources. Codified knowledge includes propositions, formulae, classifications, written procedures, structured datasets, software, legal texts, and other resources whose relevant content can be represented in forms available for repeated inspection and manipulation.

Such resources are especially compatible with machine-mediated retrieval, comparison, translation, synthesis, and recombination. Contemporary retrieval systems can already search large scientific corpora and construct grounded literature syntheses [4]. Agentic systems can combine retrieval with subsequent reasoning and production [51, 37].

Automation can therefore increase the number of codified resources that enter a single inquiry and the number of combinations that can be examined. Epistemic reliability still depends upon source quality, interpretation, context, and evaluation, yet direct continuity between the biological identity of the operator and the result is often comparatively weak.

Codified knowledge consequently represents one region in which substantial executional delegation can occur while preserving many of the informational relations relevant to the task.

10.3 Formal and Symbolic Knowledge

This subsection examines formal operations whose validity is largely determined through explicitly specified symbolic relations. Mathematical calculation, logical transformation, symbolic algebra, formal verification, and some computational procedures can exhibit substantial stability across operators when the rules, inputs, and evaluation criteria are adequately specified.

The relevant property is reproducibility of the operation under substitution of competent executors. A human, software system, or AI-assisted formal tool can perform the operation while the validity conditions remain grounded in the formal structure.

This does not remove the importance of human participation from the wider epistemic process. Selection of axioms, formulation of problems, interpretation of results, choice of representations, and judgment about relevance can remain highly generative activities. The formal operation itself, however, can often be delegated with comparatively limited alteration of its epistemic identity.

Formal and symbolic processes therefore provide clear examples of substantial operator invariance within bounded portions of inquiry.

10.4 Experimental Knowledge

This subsection examines empirical knowledge produced through controlled interaction with physical systems. Experiments combine theoretical assumptions, experimental design, instruments, procedures, measurements, and interpretive judgment. Automation can enter each component to different degrees.

Contemporary self-driving laboratories integrate experimental selection, robotic manipulation, measurement, analysis, and iterative optimization [14]. Agentic control of scientific instruments further demonstrates that machine systems can participate directly in experimental operations [15].

The possibility of robotic experimentation means that physical contact with the investigated object does not establish a general boundary between human and automated inquiry. A robot can manipulate materials, operate instruments, record outcomes, and adapt later actions to earlier measurements.

The more useful distinction concerns which aspects of experimental knowledge depend upon the identity or history of the operator. A calibrated measurement can possess substantial operator invariance. Experimental design and interpretation can display stronger sensitivity to background assumptions and judgment. A complete experimental workflow can therefore contain several different automation classes simultaneously.

10.5 Robotic Empirical Inquiry

This subsection isolates the epistemic significance of robotic engagement with the physical world. Robots, sensors, automated laboratories, and instrument controllers allow empirical operations to be performed without continuous human bodily execution.

Robotic inquiry can substantially enlarge empirical trajectory space. A machine can repeat measurements, operate continuously, explore parameter regions systematically, and enter environments that are costly, dangerous, or inaccessible for human investigators.

This development shifts the philosophical problem of empirical delegation. The relevant issue increasingly concerns the relation between the subject who benefits from an inquiry and the agent that performs the encounter.

A human researcher can formulate the question, interpret unexpected results, challenge the experimental design, and revise the research direction while a robot performs nearly all physical operations. Such a configuration contains extensive executional delegation together with substantial human generative participation.

Robotic execution therefore provides an important case against treating manual performance as the principal measure of epistemic participation.

10.6 Field and Observational Knowledge

This subsection examines observational processes conducted outside tightly controlled experimental environments. Field research can involve environmental monitoring, astronomical observation, ecological surveys, geological measurement, urban observation, participant observation, and other forms of situated evidence collection.

Automation can scale many observational operations through sensors, autonomous platforms, remote instruments, image analysis, and continuous monitoring. Certain measurements can remain comparatively stable across adequately calibrated systems.

Other forms of observation depend more strongly upon selection and interpretation. An observer decides what constitutes a relevant event, which context should be recorded, how an ambiguous interaction should be classified, and when an anomaly deserves further attention.

Field knowledge therefore spans a broad range from highly standardized machine-compatible measurement to strongly situated interpretation. Its automation profile must be determined at the level of particular epistemic operations.

10.7 Survey and Interview-Based Knowledge

This subsection examines processes in which evidence emerges through interaction with human respondents. Survey methodology has long documented interviewer effects across recruitment, measurement, and other stages of data collection [57]. The investigator can therefore enter the causal structure of the evidence being produced.

AI systems can automate questionnaire administration, conversational interviewing, transcription, translation, coding, and follow-up. Such automation can increase scale and standardization while also changing the social relation through which responses emerge.

The relevant epistemic issue extends beyond whether an artificial interviewer can execute the same verbal sequence. Respondents can react differently to perceived identity, social position, authority, empathy, disclosure, language, or expectations associated with the interviewer. Substitution of one operator for another can therefore alter the data-generating process.

Survey and interview research consequently provide clear examples of operator-sensitive epistemic processes. In more relational forms of interviewing, the process can move further toward relation dependence because the interaction itself participates in determining what becomes articulable.

10.8 Embodied and Tacit Knowledge

This subsection examines epistemic capacities that exceed exhaustive explicit articulation. Polanyi's account of tacit knowing emphasizes that human knowledge contains dimensions that cannot be fully captured by what the knower can explicitly state [47]. Practice can involve perceptual discrimination, timing, bodily coordination, practical judgment, and sensitivity acquired through sustained engagement.

Embodied knowledge is relevant to crafts, laboratory practice, clinical work, performance, skilled observation, and many other domains. A practitioner can recognize a meaningful difference before possessing a complete propositional description of the recognition process.

Automation can reproduce or exceed particular performances without necessarily reproducing the same developmental trajectory. A machine can acquire a functional capacity through training data, opti-

mization, simulation, or robotic learning while a human acquires an analogous capacity through embodied practice.

The resulting outputs can be similar while the histories and structures of formation remain different. Functional substitution and formative equivalence therefore require separate analysis.

10.9 Situated Knowledge

This subsection examines epistemic processes whose significance depends upon the circumstances within which the knower is positioned. Situated learning theory describes knowledge and competence through participation in social practices rather than through detached acquisition alone [35]. Phenomenological approaches likewise emphasize the embodied and situated structure through which a world becomes available to a subject [42].

Situatedness can include spatial location, institutional role, bodily condition, cultural background, prior experience, temporal position, and relations with other participants. These conditions shape what becomes visible, salient, intelligible, or actionable.

Automation can represent many features of a situation and can itself operate within physical and social environments. The analytical question concerns whether the relevant epistemic relation can be reconstructed through another agent's situated trajectory or whether the original position contributes materially to what becomes knowable.

Situated knowledge therefore introduces increasing sensitivity to the relation between epistemic content and the history of the knower.

10.10 Relational Knowledge

This subsection examines knowledge that emerges through interaction among agents. In such processes, the epistemic result depends partly upon relations formed during inquiry rather than solely upon information possessed before the interaction.

Dialogue, collaborative interpretation, mentorship, participatory research, and some forms of qualitative inquiry can display this structure. A statement made to one interlocutor can differ from a statement made to another. A question can become intelligible only after trust develops. An interpretation can emerge through disagreement and mutual correction.

Relational knowledge therefore requires analysis of the interaction itself. Substitution of an AI system for a human participant can increase, decrease, or reconfigure generativity depending upon the relation that develops. The outcome cannot be inferred solely from the linguistic competence of the artificial system.

The relevant object of comparison is the complete relational process through which epistemic possibilities emerge.

10.11 Shared-Experience Knowledge

This subsection examines knowledge generated among subjects who have participated in overlapping events, environments, practices, or historical conditions. Shared experience does not imply identical experience. Its epistemic significance can arise precisely through comparison among heterogeneous perspectives on a partially common history.

A community affected by the same disaster can preserve different memories of the event. Participants in a political transformation can interpret the same period differently. Members of a religious or artistic tradition can inherit different experiences of a shared practice. Subsequent dialogue can generate a collective understanding that develops through these differences.

The generative process can be represented descriptively as a sequence of shared event, heterogeneous experience, memory, testimony, disagreement, and provisional collective understanding. The resulting knowledge is temporally and relationally structured.

Artificial intelligence can assist preservation, translation, comparison, retrieval, and synthesis of these materials. Such assistance can substantially increase the future accessibility of the resulting knowledge. The original shared historical relation, however, occupies a distinct position within the process because later representations enter the epistemic field after the event has already occurred.

10.12 Cultural and Community Knowledge

This subsection examines knowledge maintained through communities, practices, languages, customs, rituals, narratives, and repeated forms of participation. Such knowledge can contain explicit texts alongside embodied skills, implicit standards, interpretive conventions, and historically accumulated relations.

Situated-learning theory provides one account of competence developing through participation in communities of practice [35]. Hermeneutic philosophy further emphasizes the historicity of interpretation and the role of inherited horizons in understanding [22].

Digital preservation and AI-mediated synthesis can make cultural representations more accessible. They can also assist translation, comparison, documentation, and educational transmission. These capacities may become important resources for traditions facing demographic or institutional pressure.

The epistemic question concerns which dimensions of a cultural practice can be preserved through representations and which depend upon continuing participation in the relations through which the practice is reproduced.

10.13 Historical Knowledge and Collective Memory

This subsection examines epistemic relations to past events. Historical inquiry can draw upon documents, artifacts, testimony, institutional records, photographs, material environments, and later interpretation. Artificial systems can assist enormously in searching, translating, comparing, and organizing such evidence.

Historical representation nevertheless retains provenance. A testimony recorded by a participant in an event occupies a different relation to that event from an otherwise similar text generated long afterward. The difference concerns historical indexing and provenance rather than textual appearance alone.

Collective memory adds another layer because communities continually interpret, transmit, contest, and revise their relations to past events. Knowledge of the past therefore develops through interactions between preserved traces and later historical subjects.

Automation can expand the processing of historical records while leaving open the status of participation, testimony, inherited memory, and historical location within the resulting epistemic process.

10.14 Operator-Invariant Processes

This subsection formalizes the first class in the differential-automation framework. An epistemic operation is provisionally described as *operator-invariant* when substitution among competent operators leaves the epistemically relevant result approximately stable under specified conditions.

The definition is local and tolerance-dependent. It applies to an operation within a particular inquiry rather than establishing that an entire research domain is independent of its practitioners.

Examples can include routine formal calculation, standardized instrument reading, mechanical sample handling, and other operations for which operator identity has limited relevance once calibration, procedure, and environmental conditions are controlled.

Operator-invariant processes are generally strong candidates for extensive automation. Delegation can reduce cost and increase scale while preserving the relations that determine the validity of the immediate operation.

Their automation can still affect the wider research organization by changing labor requirements, dependence upon infrastructure, learning opportunities, and the distribution of control.

10.15 Operator-Sensitive Processes

This subsection formalizes the second class. An epistemic process is *operator-sensitive* when variation in characteristics or conduct of the operator can systematically alter the evidence, inference, or resulting epistemic artifact.

Interview research provides a clear example because interviewer characteristics and behavior can contribute to variation in survey processes and measurements [57]. Interpretive coding and some observational processes can display analogous sensitivity.

Operator sensitivity does not prevent automation. It changes the object of evaluation. An artificial agent becomes a new operator whose behavioral properties, interaction style, consistency, biases, and effects on other participants require empirical examination.

Automation in this class therefore substitutes one epistemically relevant operator configuration for another.

10.16 Relation-Dependent Processes

This subsection formalizes the third class. A process is *relation-dependent* when the epistemic result depends materially upon the relation generated among participants during the inquiry.

The relevant dependency can involve trust, shared vocabulary, mutual recognition, conflict, responsiveness, mentorship, interpretive negotiation, or the gradual establishment of conditions under which particular experiences can be expressed and understood.

In relation-dependent processes, replacing one participant can alter the epistemic field even when the replacement possesses equivalent propositional knowledge or task competence. The new relation can generate different questions, disclosures, interpretations, and possibilities of correction.

Artificial agents can participate in such relations. The classification therefore establishes no categorical exclusion of AI. It requires analysis of the relation actually generated and of the dimensions of that relation that matter for the epistemic process.

10.17 Participant-Constitutive Processes

This subsection formalizes the fourth class. A process is described as *participant-constitutive* when the participation or historical position of particular subjects contributes to the constitution of the epistemically relevant phenomenon or significance.

Shared historical experience provides one example. Testimony by a survivor, participant, witness, or community member derives part of its epistemic position from a relation to an event that cannot be created retrospectively by producing an informationally similar statement.

Apprenticeship and some forms of tradition can provide another example when knowledge develops through the changing position of a participant within a practice. The epistemic process includes the learner's history of participation rather than merely a sequence of detachable informational exchanges.

Participant-constitutive knowledge therefore creates the strongest boundary against treating automation as simple substitution of execution. An artificial system can represent, preserve, interpret, compare, or extend the resulting knowledge while occupying a different generative history.

This distinction concerns provenance and relational constitution. It does not establish a hierarchy of value between human and machine outputs.

10.18 Mediation and Constitutive Participation

This subsection distinguishes technological mediation from participation that enters the constitution of an epistemic process. The distinction prevents the amount of technological assistance from being used as a proxy for the degree of subject involvement.

A person can rely upon extensive technological mediation for communication, memory, physical manipulation, visual production, calculation, or writing while remaining strongly involved in the questions, judgments, experiences, and relations through which a project develops.

This case is especially important when assistive technologies enable participation that would otherwise be difficult or impossible. Extensive AI execution can coexist with substantial directional, reflective, experiential, and relational participation by the human subject.

The inverse configuration is also possible. A person can perform many operations manually within a routinized workflow while contributing little to problem formation, interpretation, revision, or the wider generative direction.

The degree of machine execution and the degree of subject participation therefore constitute analytically separate variables.

10.19 Representational Preservation and Generative Continuity

This subsection returns to the distinction introduced in Section 4 between preserved representations and preserved generative conditions. AI substantially expands the capacity to archive, translate, summarize, classify, reconstruct, and retrieve representations of knowledge.

These capabilities can improve preservation of endangered texts, oral histories, practices, languages, archival materials, and dispersed historical records. Greater representational preservation can significantly increase future opportunities for inquiry.

Generative continuity concerns a different dimension. A practice can depend upon teachers, communities, places, repeated enactment, shared memories, interpretive traditions, or relations of correction. Preservation of textual or audiovisual residues can support such continuity while remaining distinguishable from continuation of the generative relations themselves.

The distinction prevents archival completeness from being treated as equivalent to survival of a living epistemic practice.

10.20 Relational Provenance and Historical Indexing

This subsection introduces *relational provenance* as a concept for describing the generative history through which an epistemic or cultural artifact entered the world. Conventional provenance can identify origin, authorship, custody, and transformation. Relational provenance additionally directs attention toward the encounters, participants, historical events, and relations that contributed to the artifact's significance.

Two formally indistinguishable representations can possess different relational provenance. A letter written during a historical event and a later synthetic reproduction can contain identical visible text while standing in different relations to the event, writer, recipient, and subsequent historical community.

The distinction is relevant beyond questions of authenticity. A photograph, song, testimony, ritual object, research notebook, or scientific record can derive part of its significance from the trajectory through which it was produced and encountered.

Synthetic abundance therefore increases the analytical importance of provenance. As surface characteristics become easier to reproduce, historical and relational position can remain relevant to the epistemic and cultural meaning assigned to artifacts.

10.21 Boundaries of Epistemic Delegation

This subsection synthesizes the differential-automation framework and defines the boundary conditions for later analysis. Automation can operate across all four classes identified in this section, while the consequences of delegation differ substantially among them.

Operator-invariant processes often permit extensive executational substitution. Operator-sensitive processes require attention to the characteristics of the new operator. Relation-dependent processes require examination of the new relation generated through substitution. Participant-constitutive processes require attention to whether a change of participants changes the historical or relational conditions through which the epistemic phenomenon itself emerges.

These distinctions also clarify the role of physical embodiment. Increasingly capable robots and sensors can participate in physical inquiry, making bodily execution an unstable general boundary for automation. The stronger analytical boundaries arise where the identity, history, relation, or participation of an agent enters the epistemic process itself.

The framework therefore shifts analysis from a binary division between human and machine knowledge toward a relational question concerning the structure of particular knowledge-generating processes. The relevant issue is the degree to which substitution preserves, transforms, or removes epistemically significant relations.

This conclusion has direct political-economic consequences. Capital can purchase additional models, agents, sensors, laboratories, robots, and computational trajectories, thereby scaling many forms of epistemic production. The resulting advantage will vary according to the automation profile of the knowledge being pursued.

Processes that are highly scalable through infrastructure can become especially responsive to capital concentration. Processes whose generativity depends upon situated participation, sustained relations, shared histories, or cultural continuity can exhibit different forms of scarcity and different conditions of reproduction.

Section 11 therefore turns from differences among epistemic processes toward the human positions produced within the emerging relations of epistemic production, with particular attention to control, dependency, productive capacity, and the concept of the epistemic proletariat.

11 Epistemic Labor and the Knowledge Proletariat

This section examines the positions occupied by human actors within increasingly infrastructuralized systems of knowledge production. Its objective is to distinguish epistemic labor from control over the conditions of epistemic production, clarify how productive capability can coexist with infrastructural dependence, and develop the concept of the *epistemic proletariat* as a relational position. The section proceeds from epistemic labor and productive conditions toward access, control, infrastructural dependence, productivity, generative precarity, recursive dependency, concentration, and mobility among epistemic positions. The method is political-economic and relational. Marxian categories provide the structural starting point, while the analysis is adapted to the distinctive properties of knowledge, digital infrastructure, and AI-mediated production [40, 53].

11.1 Epistemic Labor

This subsection defines the productive activity to which the later relational analysis applies. *Epistemic labor* refers to activities through which questions, evidence, interpretations, concepts, methods, models, explanations, arguments, datasets, or other epistemic resources are generated, evaluated, transformed, or transmitted.

Epistemic labor includes activities conventionally recognized as research, such as reading, experimentation, analysis, calculation, interpretation, and writing. It can also include forms of work that maintain the conditions under which inquiry becomes possible, including curation, documentation, software maintenance, instrument operation, data cleaning, translation, archival work, technical support, and organization of collaborative research.

The concept therefore identifies a functional relation to knowledge production rather than an occupational category. A university professor, independent researcher, librarian, laboratory technician, software developer, community archivist, student, or artificial agent can participate in different portions of an epistemic production process.

This functional definition is important because contemporary knowledge production distributes epistemic operations across heterogeneous human and machine participants. The political-economic question concerns how these activities are organized and how control over their productive conditions is distributed.

11.2 Conditions of Epistemic Production

This subsection identifies the resources upon which epistemic labor depends. The means and conditions of epistemic production can include knowledge, education, time, instruments, laboratories, archives, databases, software, models, compute, communication networks, institutional affiliation, funding, publication systems, and access to relevant persons or communities.

These resources differ in their material and institutional properties. Some can be personally possessed. Others exist only through shared institutions or large-scale infrastructures. A researcher can own a textbook or computer while depending upon an external laboratory, proprietary database, cloud platform, model provider, or institutional credential for other parts of the same research process.

The increasing integration of AI intensifies this layered dependence. A single epistemic workflow can rely simultaneously upon public literature, privately operated models, rented compute, software maintained by external communities, subscription databases, remote instruments, and institutional systems for publication or evaluation.

Epistemic productive capacity is therefore relationally distributed across a network of complementary conditions.

11.3 Access and Control

This subsection distinguishes access to an epistemic resource from control over the conditions governing its use. The distinction is necessary because modern digital infrastructures can provide broad practical access while retaining centralized authority over operation, pricing, continuity, modification, or allocation.

A researcher can access a model without controlling its weights, training process, service continuity, usage policy, or future capabilities. A scientist can use a laboratory without determining its investment priorities. A scholar can publish through a platform while possessing little influence over ranking, distribution, or interface design.

Access therefore describes one relation to a productive resource. Control describes another.

The distinction can be expressed conceptually through Equation 16.

$$A_i(R) > 0 \quad \text{while} \quad C_i(R) \approx 0, \quad (16)$$

where $A_i(R)$ denotes actor i 's access to resource R and $C_i(R)$ denotes effective control over the conditions governing that resource. Equation 16 represents a possible configuration in which meaningful access coexists with limited control.

This configuration becomes increasingly important when access to external infrastructure substantially enlarges an actor's productive capacity.

11.4 Capability without Infrastructure

This subsection examines actors who possess substantial intellectual or creative capacity while lacking stable control over the infrastructure required to realize that capacity at comparable scale.

A researcher can formulate important questions while lacking compute to explore them extensively. A scientist can design an experiment while lacking access to the necessary instruments. A scholar can identify relevant public knowledge while lacking the infrastructure required to search, process, translate, and compare it at machine scale.

The resulting limitation concerns realization of generative capacity rather than absence of epistemic ability. An actor can possess strong judgment, curiosity, disciplinary competence, or creative insight while remaining unable to convert those capacities into the number of investigated trajectories available to an infrastructure-rich organization.

This distinction is especially important under AI-mediated knowledge production because the gap between conceiving a question and exploring its possibility space can become increasingly dependent upon external technical resources.

11.5 Productivity under Infrastructural Dependence

This subsection examines a configuration in which an actor becomes more productive while simultaneously becoming more dependent upon externally controlled conditions. The two developments can occur together.

An AI system can allow a researcher to read more literature, test more code, generate more counter-arguments, translate more languages, or explore more hypotheses. The immediate productive capacity of the researcher therefore increases.

If the resulting workflow becomes difficult to reproduce without access to the same models, compute, databases, or platforms, the researcher's dependence upon those infrastructures can also increase.

The resulting trajectory can be summarized conceptually as

$$G_i \uparrow \quad \text{and} \quad D_i \uparrow, \quad (17)$$

where G_i denotes the actor's effective generative capacity and D_i denotes dependence upon externally controlled productive conditions. Equation 17 emphasizes that productivity and autonomy need not move in the same direction.

This configuration prevents technological empowerment from being treated as equivalent to increased control over the conditions of production.

11.6 The Epistemic Proletarian Position

This subsection develops the central relational concept of the section. An *epistemic proletarian position* describes a condition in which an actor possesses meaningful epistemic generative capacity while lacking stable control over principal conditions required to reproduce, scale, or sustain that capacity.

The term is inspired by Marxian analysis of relations between labor and the means of production [40]. Its use here is analogical and restricted. It does not imply that every epistemically dependent actor occupies the same economic class position as an industrial wage worker, and it does not reduce epistemic relations to wage relations.

The defining feature is the relation between productive capacity and control. An epistemic proletarian can know, create, criticize, and formulate questions. The actor can even be highly productive. Dependence arises because continued realization of these capacities relies upon infrastructures whose principal conditions are determined elsewhere.

The concept therefore differs from ignorance, low skill, or lack of education. A world-leading researcher can occupy an epistemically dependent position with respect to a particular infrastructure.

11.7 Relational Position and Occupational Identity

This subsection clarifies that the epistemic-proletarian category applies to relations rather than stable identities. The same person can occupy different positions across different dimensions of production.

A professor can control a research budget while depending upon an external cloud provider. A company researcher can possess privileged model access while depending upon organizational decisions governing employment and research direction. An independent scholar can control personal research questions while lacking access to expensive experimental infrastructure.

The relevant unit of analysis is therefore a relation of productive dependence rather than a social label attached permanently to a person.

This relational approach also permits historical mobility. An actor can acquire infrastructure, lose access, enter a consortium, migrate to open systems, build new tools, or become dependent upon newly indispensable platforms. Epistemic class-like positions can therefore change as productive infrastructures evolve.

11.8 Model and Compute Dependency

This subsection examines dependence upon models and computational infrastructure. Advanced AI-mediated research can require computational resources whose acquisition, maintenance, and scaling exceed the capacity of many individuals and smaller institutions.

Model access can also be conditional. Providers can modify interfaces, prices, rate limits, supported capabilities, geographic availability, or permitted uses. Productive workflows built around such systems can consequently inherit dependencies from the infrastructures on which they rely.

The problem is especially pronounced when model capabilities become difficult to reproduce locally. Access to a highly capable system can dramatically increase an actor's productivity while the actor remains unable to preserve the same productive capacity independently.

Compute and models therefore function as means of epistemic production whose distribution can shape the practical geography of future knowledge generation.

11.9 Platform and Retrieval Dependency

This subsection examines dependency arising through search, indexing, publication, collaboration, and platform infrastructures. Srnicek's analysis of platform capitalism provides a broader account of infrastructural intermediation and data accumulation within contemporary economies [55].

Epistemic production increasingly depends upon intermediaries that determine which resources can be discovered, accessed, cited, circulated, or evaluated. The productive role of these systems grows as the volume of available knowledge exceeds ordinary human navigational capacity.

A researcher can therefore possess formal access to a large public corpus while remaining dependent upon external systems for practical discovery. Changes in ranking, indexing, recommendation, or access conditions can alter the effective epistemic field available to that researcher.

Retrieval infrastructure thus becomes a productive condition rather than a neutral channel located outside the knowledge process.

11.10 Institutional Dependency

This subsection examines dependence upon institutions that organize research, credentialing, funding, publication, and access to specialized resources. Academic capitalism scholarship demonstrates how universities increasingly operate through relations connecting research activity with markets, external funding, intellectual property, and institutional competition [53].

Institutional affiliation can provide laboratories, databases, software, libraries, ethics review, collaborators, legal support, reputation, and access to research communities. Loss of affiliation can therefore produce a decline in productive capacity even when the researcher's knowledge remains unchanged.

Institutional dependence also affects research direction. Funding priorities, evaluation criteria, employment conditions, publication incentives, and organizational strategy can influence which questions become practically pursuable.

The epistemic-proletarian position can consequently arise through institutional relations as well as technical infrastructure.

11.11 Generative Precarity

This subsection introduces *generative precarity* as instability in an actor's capacity to continue producing knowledge because essential generative conditions remain insecure.

Precarity can arise from temporary employment, unstable funding, expiring licenses, revocable platform access, changing model policies, loss of institutional affiliation, inaccessible compute, or discontinuation of specialized technical services.

The central object of concern is future generative capacity. A researcher can possess substantial present productivity while facing uncertainty about the conditions required to reproduce that productivity in the next period.

Generative precarity differs from ordinary resource scarcity because it can occur after a workflow has already become highly capable. The actor's productive capacity may have expanded through external infrastructure while becoming increasingly sensitive to discontinuities in that infrastructure.

This temporal instability becomes politically important when research agendas, skills, and professional trajectories adapt around resources whose persistence the user cannot determine.

11.12 Recursive Dependency

This subsection examines how dependency can deepen through successful use of external infrastructure. Productive dependence can become recursive when each round of successful capitalization increases the value of continuing access to the same infrastructure.

A researcher who builds workflows around a model can accumulate prompts, software, datasets, evaluations, and methodological habits optimized for that system. A laboratory can integrate instruments with a particular platform. An organization can build internal procedures around a proprietary data or computational environment.

The resulting success increases switching costs. Productive gains therefore strengthen the relation to the infrastructure through which those gains were achieved.

Recursive dependency can coexist with recursive epistemic advantage. An actor can become increasingly productive relative to less-equipped researchers while also becoming more tightly dependent upon a provider or institution located higher in the infrastructural hierarchy.

This dual movement complicates simple classifications of winners and losers under technological change.

11.13 Epistemic Subordination

This subsection distinguishes dependency from the stronger condition of *epistemic subordination*. Dependency becomes subordinating when another actor's control over productive conditions substantially constrains the dependent actor's feasible questions, methods, access, continuity, or distribution of outputs.

Subordination can occur through contractual restrictions, platform rules, institutional priorities, resource allocation, model limitations, publication conditions, or control over experimental infrastructure.

The concept concerns practical direction of the epistemic possibility space. An actor can remain formally free to ask a question while lacking realistic access to the means required to pursue it.

Epistemic subordination therefore occupies a stronger position than dependence alone. Dependence can be reciprocal, benign, or voluntarily accepted. Subordination concerns asymmetry sufficient to structure another actor's generative possibilities.

11.14 Concentration and Centralization of Epistemic Infrastructure

This subsection examines the aggregate consequences of unequal control over productive resources. Concentration occurs when successful epistemic actors accumulate increasingly large infrastructures through recursive growth. Centralization occurs when previously separate resources become consolidated within fewer organizational centers.

The distinction parallels the Marxian separation introduced in Section 3 [40]. In epistemic systems, concentration can occur through continued accumulation of compute, models, data, talent, laboratories, and institutional reputation. Centralization can occur through mergers, acquisitions, platform consolidation, exclusive infrastructure agreements, or institutional integration.

Cumulative advantage can reinforce these processes. Recognition can attract resources, resources can expand future productive capacity, and successful production can generate additional recognition [43].

The resulting concentration matters because machine-scaled epistemic production can display substantial returns to complementary infrastructure. Control over multiple layers can permit larger portions of public knowledge to be absorbed, tested, and converted into further capacity.

11.15 Public Knowledge and Unequal Productive Positions

This subsection examines why public access does not remove the distinction between epistemic positions. Knowledge commons can make epistemic inputs broadly available [29]. Actors can nevertheless differ in their control over the means through which those inputs become future productive capacity.

One actor can read a public scientific literature manually. Another can deploy thousands of model calls across the same corpus, connect the results with private datasets, run large simulations, and direct robotic experiments toward promising hypotheses.

Both actors participate in the same public knowledge field. Their practical relations to that field differ because their capitalization capacities differ.

The public character of the input therefore does not eliminate class-like relations around epistemic infrastructure. It can coexist with substantial asymmetry in the ability to transform shared knowledge into future generative power.

11.16 Epistemic Productivity and Appropriation

This subsection distinguishes the generation of epistemic value from the distribution of the benefits associated with that generation. Research can produce knowledge, reputation, institutional prestige, data, technological capability, financial value, or strategic advantage. These outputs can be distributed differently among contributors and controlling organizations.

Bourdieu's analysis of convertible forms of capital is relevant because epistemic success can be transformed into symbolic, social, institutional, and economic resources [8]. An individual contributor can participate strongly in knowledge production while another organization possesses greater capacity to convert the resulting output into durable infrastructural advantage.

The distinction does not imply exploitation in every case. Stronger claims about extraction or exploitation require evidence concerning contribution, control, appropriation, reciprocity, and alternatives.

The present section therefore uses *epistemic dependency*, *subordination*, and *generative precarity* as analytically prior categories. The later justice analysis considers when unequal relations may support stronger normative judgments.

11.17 Mobility across Epistemic Positions

This subsection emphasizes the dynamic character of epistemic productive positions. Individuals and institutions can move across relations of dependence and control as infrastructures change.

Open-source models can reduce dependence upon a proprietary provider. Public laboratories can expand access to instruments. New standards can improve interoperability. A research group can construct local infrastructure. An organization can also lose previously controlled resources or become dependent upon a new technological layer.

Epistemic positions therefore emerge from changing configurations of resources and relations. The concept of the epistemic proletariat should consequently be used as a relational diagnostic rather than a permanent social classification.

This dynamic perspective also preserves the historical openness of the paper's analysis. Current patterns of concentration do not establish an inevitable future structure.

11.18 The Knowledge Proletariat under AI-Mediated Production

This subsection synthesizes the preceding analysis. AI-mediated production can substantially increase the generative capacity of researchers who possess only limited direct control over the infrastructure

producing that increase. This creates the possibility of an epistemic proletariat that is highly capable, highly productive, and deeply infrastructurally dependent at the same time.

The resulting position differs from a simple image of technological displacement. AI can empower epistemic labor while reorganizing the conditions under which that empowerment remains reproducible.

The decisive distinction concerns control over generative conditions. A researcher can possess abundant information, strong ideas, sophisticated skills, and access to powerful tools while remaining dependent upon decisions made by model providers, platform operators, institutions, funders, laboratory owners, or other infrastructural actors.

The political-economic transformation therefore concerns the distribution of the means through which questions can be pursued at scale. Under machine-scaled knowledge production, inequality can increasingly appear as inequality in the number of trajectories that an actor can investigate, the amount of public knowledge that can be absorbed, the empirical encounters that can be financed, and the infrastructures through which successful outputs become recursively productive.

The epistemic proletariat should consequently be understood through a combination of generative capacity, limited control, dependency, and reproductive insecurity. None of these dimensions alone is sufficient.

This framework also prepares the next stage of the analysis. Productive capacity depends not only upon access to knowledge and infrastructure but also upon the allocation of scarce attention. An actor can possess valuable knowledge and substantial generative ability while remaining nearly absent from the epistemic field encountered by other participants.

Section 12 therefore turns from control over productive infrastructure toward attention, visibility, recognition, symbolic authority, and the mechanisms through which machine-scaled epistemic abundance can alter whose knowledge enters future generative relations.

12 Attention, Visibility, and Epistemic Authority

This section examines attention as a scarce condition of epistemic circulation under expanding knowledge production. Its objective is to distinguish public availability from effective epistemic presence, analyze how search, ranking, presentation, and repeated visibility influence the probability that knowledge enters subsequent inquiry, and trace the possible conversion of attention into recognition, symbolic authority, framing power, and definitional power. The section proceeds from attention scarcity and machine-scaled epistemic abundance toward retrieval infrastructure, visibility competition, structural attention capture, epistemic crowding, recursive visibility advantage, and the relation between attention inequality and the epistemic proletariat. The method is political-economic and relational. Attention is treated as a scarce resource through which formally accessible knowledge acquires heterogeneous probabilities of entering future generative relations [52, 28].

12.1 Attention as a Scarce Epistemic Resource

This subsection establishes attention as a limiting condition of knowledge use. Simon identified a fundamental relation between information abundance and the scarcity of the attention required to process it [52]. The relevance of this relation increases as the cost of producing, copying, and circulating informational artifacts declines.

Knowledge can be non-rival in use while attention remains rival in time. Two persons can access the same article simultaneously, yet one person's available reading time cannot be allocated without limit across an expanding literature. The same constraint applies to reviewing, teaching, citation, interpretation, discussion, and institutional evaluation.

Attention therefore enters epistemic production as a selective resource. Available knowledge becomes generatively consequential only when some actor or system encounters, retrieves, evaluates, or incorporates it into a subsequent epistemic process.

The scarcity of attention creates a political-economic problem distinct from scarcity of knowledge itself. Expansion of the public knowledge commons can increase the total quantity of accessible epistemic resources while simultaneously increasing competition for the limited attention through which those resources become socially operative.

12.2 Epistemic Abundance and Attention Scarcity

This subsection examines the divergence between epistemic output capacity and human attentional capacity. Printing, digital publication, networked communication, and computational production have progressively reduced the cost of producing and distributing epistemic artifacts. Artificial intelligence can accelerate this development by reducing the labor required for search, synthesis, drafting, translation, visualization, and repeated production.

The resulting relation can be represented conceptually by Equation 18.

$$\frac{dK_{\text{output}}}{dt} > \frac{dA_{\text{human}}}{dt}, \quad (18)$$

where K_{output} denotes the volume of available epistemic output and A_{human} denotes the aggregate human attention available for direct engagement with that output. Equation 18 represents a possible divergence in growth rates rather than a universal empirical law.

As this divergence increases, selection becomes progressively more important. The epistemic system must determine which resources receive reading time, citations, reviews, classroom inclusion, institutional recognition, media coverage, model retrieval, or further investigation.

Abundance therefore does not remove scarcity. It relocates an important part of scarcity toward attention and mechanisms of selection.

12.3 Machine-Scaled Epistemic Output

This subsection examines the consequences of producing epistemic artifacts at machine scale. AI-assisted and agentic systems can reduce the marginal effort required to generate reports, literature syntheses, candidate theories, software, analyses, reviews, and other textual or computational artifacts [51, 37].

Machine-scaled production can generate substantial epistemic benefits. More hypotheses can be explored, neglected literatures can be synthesized, materials can be translated, and documentation can be produced at lower cost. The same productive expansion increases the number of artifacts competing for finite human attention.

The resulting pressure differs from ordinary information overload in scale and production dynamics. Automated systems can continue producing while human reading, judgment, and institutional evaluation remain temporally constrained.

A central issue therefore concerns the ratio between production and meaningful encounter. Increasing the number of publicly available epistemic artifacts does not guarantee a proportional increase in the number that can enter human deliberation or later inquiry.

12.4 Search and Ranking Infrastructure

This subsection examines search and ranking as infrastructures for allocating attention under epistemic abundance. When direct navigation through a corpus becomes impractical, computational systems mediate which resources are presented in response to a query.

Search therefore performs an epistemic selection function. It transforms a large set of potentially available resources into a much smaller set of practically encountered resources. Contemporary retrieval-augmented systems extend this selection process because retrieved materials become inputs to machine-generated syntheses and answers [4].

The relation can be represented by Equation 19.

$$K_{\text{public}} \xrightarrow{\mathcal{R}} K_{\text{retrieved}} \xrightarrow{\mathcal{A}} K_{\text{encountered}}, \quad (19)$$

where $\mathcal{R}$ denotes retrieval and ranking and $\mathcal{A}$ represents subsequent attentional selection. Equation 19 shows that public knowledge can pass through multiple filters before entering an active epistemic relation.

Search infrastructure therefore participates in knowledge generation indirectly by influencing which prior resources become available for later questions, arguments, models, and decisions.

12.5 Visibility Competition

This subsection examines competition for epistemic visibility. Once search, recommendation, citation, and platform interfaces mediate access to abundant knowledge, producers have incentives to increase the probability that their outputs are selected.

Visibility can depend upon substantive quality, relevance, reputation, timeliness, accessibility, language, titles, keywords, citation networks, formatting, platform compatibility, and optimization for retrieval systems. The resulting competition can therefore involve both epistemic and presentation-oriented characteristics.

Hindman’s analysis of online concentration emphasizes how apparently open digital environments can still produce highly unequal distributions of audience and visibility [30]. The relevance to knowledge production lies in the possibility that formal openness can coexist with strong concentration of effective attention.

Search optimization is therefore epistemically significant even when it contains no deceptive practice. Resources adapted effectively to contemporary discovery infrastructures can acquire substantially greater probabilities of encounter than equally accessible resources that remain poorly indexed or weakly optimized.

12.6 Structural Attention Capture

This subsection introduces *structural attention capture* as the concentration of attention produced by systemic properties of information environments. The concept does not require deliberate attempts to manipulate users.

A resource can accumulate attention because it already ranks highly, receives many citations, appears in widely used databases, is repeatedly summarized, belongs to a prestigious institution, or is frequently retrieved by AI systems. These mechanisms can increase visibility even when every individual participant acts according to ordinary local criteria.

Structural attention capture therefore differs from intentional attention capture. The former can emerge from feedback among ranking systems, user behavior, institutional recognition, citation networks, and machine retrieval.

This distinction matters for governance because harmful concentration can arise without a clearly identifiable actor intending to suppress alternatives. Attention inequality can be an emergent property of the epistemic infrastructure.

12.7 Intentional and Emergent Attention Concentration

This subsection separates strategic efforts to obtain attention from concentration arising through distributed feedback. Intentional mechanisms can include advertising, promotional campaigns, search optimization, repeated publication, platform strategy, or deliberate attempts to dominate a terminological field.

Emergent concentration can arise through cumulative advantage. Merton’s account of cumulative advantage in scientific careers shows how prior recognition can contribute to later advantages in attention and resources [43]. Similar feedback can operate at the level of documents, institutions, theories, datasets, and research programs.

The two processes can interact. An actor possessing greater resources can optimize outputs for visibility, and the resulting visibility can then generate apparently organic recognition through subsequent citations, rankings, and retrieval.

The analytical importance lies in avoiding a reduction of attention inequality to individual intent. The distribution of visibility can be structured by the architecture of the epistemic environment itself.

12.8 Epistemic Crowding

This subsection introduces *epistemic crowding* as a condition in which growth in available epistemic output reduces the practical probability that particular resources receive sufficient attention to enter later generative processes.

Crowding does not require removal or censorship. A work can remain legally public, indexed, downloadable, and formally available while becoming increasingly difficult to encounter within an expanding field.

The basic relation can be represented by Equation 12.8.

$$K_{\text{available}} \uparrow \quad \text{while} \quad P_i(\text{encounter}) \downarrow \quad (20)$$

Equation 12.8 represents a possible decline in the probability that resource i is encountered as the surrounding information field expands.

Epistemic crowding therefore creates a form of effective scarcity within abundance. More knowledge exists, while the practical probability of contact with any particular contribution can decline.

12.9 Surface Quality and Evaluative Compression

This subsection examines how abundant polished output can alter the signals used for epistemic evaluation. Fluency, formatting, citation density, visual presentation, structural coherence, and stylistic professionalism have historically required non-trivial labor. Generative systems can reduce the cost of producing many of these surface characteristics.

The informational value of surface quality as a proxy for underlying research effort or epistemic quality can therefore weaken. A carefully formatted, well-structured document can emerge from either a long investigative trajectory or a short automated workflow.

Attention scarcity simultaneously increases pressure to evaluate quickly. Readers, reviewers, institutions, and search systems can rely more heavily upon cheaply observable signals when the volume of material exceeds available evaluation time.

This combination creates *evaluative compression*: complex judgments about epistemic quality, provenance, originality, depth, and reliability are compressed into smaller sets of observable indicators.

The distinction can be expressed through the separation of substantive quality Q_i , visibility V_i , and perceived quality $\hat{Q}_i$. These variables can be correlated while remaining analytically distinct.

12.10 Slow and High-Cost Knowledge

This subsection examines epistemic work whose production depends upon long durations, difficult access, sustained participation, rare skills, expensive experiments, extensive archival investigation, longitudinal observation, or slow conceptual development.

Such work can compete for attention with outputs generated through much shorter production cycles. Machine-scaled systems can produce large quantities of plausible and polished material within the period required for a single high-cost investigation.

The relevant concern does not imply that slow research is inherently superior. Duration alone does not establish quality. The issue concerns the possibility that systems of attention and ranking become increasingly responsive to production frequency and immediate visibility.

A research trajectory requiring decades can possess high substantive value while producing relatively few opportunities for continuous algorithmic visibility. Output frequency and epistemic significance can consequently follow different temporal structures.

This creates a potential disadvantage for longitudinal, archival, minority, field-based, theoretical, or otherwise slow forms of knowledge when visibility systems strongly reward continual production.

12.11 Recursive Visibility Advantage

This subsection examines feedback through which current visibility can increase future visibility. A resource that receives more attention can accumulate citations, links, discussion, reviews, institutional recognition, and machine retrieval. These traces can become inputs to later ranking and recommendation.

The resulting process can be represented by Equation 21.

$$V_t \rightarrow A_t \rightarrow R_t \rightarrow V_{t+1}, \quad (21)$$

where V_t denotes visibility, A_t received attention, and R_t accumulated recognition signals. Equation 21 represents a positive feedback mechanism through which visibility can become self-reinforcing.

Mertonian cumulative advantage provides an established sociological analogue for this structure in scientific recognition [43]. AI-mediated retrieval can add another recursive layer when highly visible or highly connected works are more likely to enter machine-generated syntheses that subsequently increase their visibility.

Recursive visibility therefore links attention economics with knowledge-capital expansion. Attention received in one period can become an asset affecting future epistemic circulation.

12.12 Attention and Cross-Capital Conversion

This subsection examines the conversion of attention into other resources. Bourdieu's account of multiple convertible forms of capital provides a useful framework for analyzing how recognition can interact with social, cultural, symbolic, and economic resources [8].

Within knowledge production, attention can contribute to citations, invitations, reputation, institutional affiliation, funding, collaboration, media visibility, audience growth, or commercial opportunity. These resources can then increase future productive capacity.

The process can therefore develop into a recursive conversion cycle:

$$A \rightarrow R \rightarrow C \rightarrow G' \rightarrow K' \rightarrow A', \quad (22)$$

where A denotes attention, R recognition, C complementary capital, G' expanded generative capacity, and K' subsequent epistemic output. Equation 22 represents one possible route through which attention becomes productive advantage.

Attention inequality can therefore affect future knowledge production even when attention itself produces no direct epistemic improvement.

12.13 Recognition and Symbolic Authority

This subsection examines the transition from repeated recognition toward epistemic authority. Recognition can function as a useful heuristic under conditions of specialization and limited attention. Researchers routinely rely upon journals, institutions, authors, citation patterns, and other signals when deciding where to allocate scarce evaluative effort.

Repeated visibility can strengthen these signals. A theory, institution, or researcher encountered frequently can become cognitively available and institutionally recognizable across a community.

Symbolic authority can then influence which claims receive initial credibility, which contributions are considered central, and which actors are invited to define the boundaries of a discussion.

The process is compatible with genuine expertise. Recognition can accurately reflect accumulated high-quality contribution. The political-economic issue arises because recognition can also become recursively connected to visibility and infrastructure, allowing epistemic and non-epistemic advantages to reinforce one another.

12.14 Epistemic Authority under Repeated Visibility

This subsection examines repeated visibility as a condition affecting the formation of epistemic authority. In environments of abundant information, familiarity can reduce search costs and uncertainty. Sources repeatedly encountered across platforms, citations, recommendations, and AI-generated answers can therefore acquire a privileged position within the practical epistemic field.

The relevant sequence can be represented conceptually by Equation 23.

$$V \rightarrow F \rightarrow R \rightarrow \mathcal{A}_{\text{ep}}, \quad (23)$$

where V denotes repeated visibility, F familiarity, R recognition, and $\mathcal{A}_{\text{ep}}$ epistemic authority. Equation 23 represents a possible social mechanism rather than a necessary causal law.

The distinction between authority grounded in demonstrated epistemic quality and authority amplified through repeated visibility remains important. Contemporary infrastructures can combine both processes.

AI-mediated interfaces may strengthen this effect when users repeatedly encounter a small set of concepts, sources, or frameworks through synthesized answers rather than through direct exploration of the underlying literature.

12.15 Framing Power

This subsection examines the capacity to influence the conceptual frame within which an object becomes intelligible. Framing power arises when particular categories, questions, distinctions, or narratives become the habitual starting points through which later inquiry approaches a domain.

Attention contributes to framing power because frequently encountered vocabularies become more available for reuse. A concept that dominates search results, textbooks, highly cited literature, public discussion, or machine retrieval can become a default interpretive interface.

Framing power can shape subsequent question formation. A researcher entering a field through a dominant framework can inherit its distinctions and problem definitions before encountering alternatives.

The resulting influence operates upstream from conclusions. It affects which objects become visible, which variables appear relevant, and which questions are easily formulable.

Epistemic concentration can therefore occur through control or dominance of frames even when alternative works remain formally available.

12.16 Definitional Power

This subsection develops the stronger concept of *definitional power*. Definitional power concerns the capacity of a sufficiently established frame to influence how the object of inquiry itself is conventionally described, classified, or recognized.

The transition from framing to definitional power can occur when one interpretation becomes sufficiently dominant that later actors encounter it as the ordinary meaning of the object. Competing conceptualizations can remain available while requiring additional effort to discover or articulate.

A simplified trajectory is shown in Equation 24.

$$V \rightarrow F \rightarrow R \rightarrow \mathcal{A}_{\text{ep}} \rightarrow P_{\text{frame}} \rightarrow P_{\text{def}}, \quad (24)$$

where P_{frame} denotes framing power and P_{def} definitional power. Equation 24 describes a possible accumulation pathway from visibility toward influence over the conceptual organization of a field.

Definitional power is especially significant because it can alter the conditions under which future knowledge is generated. Once a definition becomes the default interface, subsequent questions, datasets, evaluations, and institutional categories can reproduce it recursively.

12.17 Public Availability and Effective Visibility

This subsection distinguishes several stages between public existence and effective epistemic participation. A resource can be publicly available while remaining difficult to retrieve. It can be retrievable while rarely ranked highly. It can be visible while receiving little sustained attention. It can be read while producing limited effect on later inquiry.

The relevant distinctions can be summarized as

$$\text{Availability} \rightarrow \text{Retrievability} \rightarrow \text{Visibility} \rightarrow \text{Attention} \rightarrow \text{Epistemic uptake.} \quad (25)$$

Equation 25 describes stages of possible epistemic circulation. Movement through one stage does not guarantee movement through the next.

This distinction is central to public knowledge. Legal openness remains important because unavailable knowledge cannot participate broadly in future inquiry. Openness alone does not determine effective presence within an attention-constrained epistemic environment.

The concept of *effective visibility* therefore refers to the realistic probability that an epistemic resource becomes encounterable by relevant subjects or systems within the conditions under which they actually search and allocate attention.

12.18 Attention Enclosure

This subsection introduces attention enclosure as a third layer of concentration within public knowledge systems. Earlier analysis distinguished enclosure of epistemic resources from concentration of the infrastructures required to capitalize upon those resources. Attention introduces an additional layer.

The three layers can be distinguished as follows. Resource enclosure concerns restrictions on access to knowledge itself. Capacity enclosure concerns restricted control over the means required to absorb, process, test, or extend knowledge at scale. Attention enclosure concerns concentration of the channels through which knowledge becomes visible and capable of entering future epistemic relations.

Attention enclosure does not require complete exclusion. A large number of alternatives can remain publicly available while a small subset occupies a disproportionate share of search results, recommendation surfaces, citations, institutional attention, or AI retrieval.

The term therefore refers to concentrated control or occupation of effective epistemic visibility rather than legal ownership of attention.

This third layer is particularly important under conditions where public knowledge remains formally open. Concentration can migrate from possession of the resource toward control over the conditions of its encounter.

12.19 AI Retrieval and Recursive Visibility

This subsection examines the role of AI-mediated retrieval in recursive visibility dynamics. Retrieval-augmented systems select sources from large corpora and present their contents through synthesized outputs [4]. As such systems become common interfaces to knowledge, inclusion in machine retrieval can become an increasingly important form of epistemic visibility.

A source frequently retrieved by AI can receive additional human attention, citations, references, links, or derivative discussion. These signals can then increase its visibility within future retrieval systems.

The resulting loop can be represented by Equation 26.

$$V_t \rightarrow R_t^{\text{AI}} \rightarrow A_t \rightarrow S_t \rightarrow V_{t+1}, \quad (26)$$

where R_t^{AI} denotes machine retrieval and S_t denotes the new social and epistemic signals produced by subsequent use. Equation 26 represents one possible feedback mechanism between machine selection and later visibility.

The same process can operate in the opposite direction. Resources rarely retrieved by machine systems can receive fewer opportunities to generate the signals that would increase later retrieval.

This creates a possibility of functional disappearance in which knowledge remains technically preserved while its probability of entering active epistemic relations becomes very small.

12.20 Epistemic Diversity under Machine-Scaled Production

This subsection examines the relation between output expansion and epistemic diversity. Artificial intelligence can increase diversity by lowering barriers to publication, translation, interdisciplinary exploration, and access to specialized knowledge. It can allow previously isolated perspectives to become more legible across linguistic and disciplinary boundaries.

Machine-scaled production can also create homogenizing pressures when large numbers of outputs draw upon overlapping models, retrieval systems, source corpora, evaluative criteria, and optimization conventions. Messeri and Crockett identify a broader concern that AI-assisted science can increase individual productivity while narrowing collective scientific focus [44]. Hao and colleagues similarly report evidence of expanded individual scientific impact alongside contraction in the collective range of topics pursued [26].

The present analysis adds an attention mechanism to this problem. Diversity in production does not guarantee diversity in effective visibility. A large number of heterogeneous contributions can coexist with a strongly concentrated attention distribution.

Epistemic diversity therefore requires analysis at several stages: production, preservation, retrieval, visibility, attention, and subsequent incorporation into new knowledge production.

12.21 Attention Inequality and the Knowledge Proletariat

This subsection connects attention inequality with the relational positions developed in Section 11. An epistemic actor can possess substantial knowledge, curiosity, and generative capacity while lacking the institutional, computational, symbolic, or platform resources required to secure visibility for resulting work.

The epistemic proletarian position can therefore involve dependence on two distinct sets of means of production. The first concerns resources required to produce knowledge. The second concerns infrastructures required for produced knowledge to enter wider epistemic circulation.

A researcher can produce valuable work and make it publicly available while remaining dependent upon indexing systems, journals, recommendation systems, platforms, citation networks, institutional affiliation, or model retrieval for effective visibility.

Attention inequality consequently affects future productive capacity. Work that receives little attention generates fewer opportunities for criticism, collaboration, citation, funding, recombination, and recursive epistemic development.

The distinction between the capacity to produce and the capacity to become epistemically encountered therefore becomes central to the political economy of public knowledge.

12.22 Collective Attention and the Public Knowledge Commons

This subsection synthesizes attention as a condition of commons generativity. A public knowledge commons can contain a very large number of accessible resources while only a small subset enters the active attention field of researchers, institutions, and machine systems.

The generativity of the commons therefore depends partly upon how collective attention is distributed. Search, ranking, recommendation, citation, education, libraries, archives, scholarly review, and AI re-

trieval all participate in maintaining or restructuring the pathways through which public knowledge becomes encounterable.

Attention differs from many informational resources because allocation to one object necessarily reduces the time available for others. Machine-scaled production can therefore impose an attention cost upon the wider epistemic environment even when the generated outputs themselves are freely available.

This creates the possibility of an attention externality. The producer obtains the benefit associated with additional output while some of the cost of selection, evaluation, and displacement is distributed across readers, reviewers, institutions, retrieval systems, and competing knowledge producers.

The concept does not establish an immediate governance prescription. Output restrictions, ranking interventions, quotas, licensing systems, or other regulatory mechanisms can themselves generate substantial epistemic costs. The present analysis identifies the structural problem that later justice and governance work must address.

The resulting question concerns how an open knowledge commons can preserve the benefits of large-scale epistemic production while maintaining realistic possibilities of encounter for slow, minority, historically accumulated, or less infrastructurally advantaged forms of knowledge.

12.23 Attention-Mediated Generative Displacement

This subsection introduces *attention-mediated generative displacement* as a process through which changes in visibility reduce the probability that particular epistemic resources contribute to future knowledge generation.

The mechanism does not require the displaced resource to disappear physically or legally. A work can remain stored permanently while losing practical opportunities to be read, cited, taught, retrieved, challenged, recombined, or extended.

The relevant sequence can be represented by Equation 27.

$$V_i \downarrow \rightarrow A_i \downarrow \rightarrow P_i(\text{uptake}) \downarrow \rightarrow G_i^{\text{future}} \downarrow, \quad (27)$$

where G_i^{future} represents the future generative contribution made possible through epistemic uptake of resource i . Equation 27 describes a pathway through which visibility conditions can affect future generativity.

A sufficiently strong form of this process can produce *functional disappearance*. The knowledge survives materially while becoming weakly connected to active epistemic networks.

This distinction is especially relevant to historical and minority knowledge. Preservation can succeed at the archival level while generative continuity declines because later subjects rarely encounter the preserved material.

12.24 Attention within Epistemic Capitalization

This subsection integrates attention into the wider theory of knowledge-capital expansion. Public knowledge provides potential epistemic resources. Capitalization capacity determines which portions can be productively absorbed and extended. Attention and retrieval determine which resources enter the practical field from which capitalization begins.

The process can therefore be represented through Equation 28.

$$K_{\text{public}} \rightarrow V_i \rightarrow A_i \rightarrow C_i \rightarrow G'_i \rightarrow K'_i, \quad (28)$$

where V_i denotes effective visibility, A_i received attention, C_i capitalization activity, G'_i expanded generative capacity, and K'_i subsequent epistemic output. Equation 28 places attention upstream from recursive epistemic accumulation.

Attention can also emerge downstream as a product of successful capitalization. Greater generative capacity can produce more outputs, stronger presentation, wider distribution, and greater institutional recognition. The result is a feedback relation between epistemic capital and attention capital.

AI can intensify both directions. It can increase output, improve discoverability, enable rapid repackaging of knowledge, and place machine retrieval between the public corpus and many human users. At the same time, AI can help recover obscure literature, translate marginalized work, and broaden the range of resources that become practically searchable.

The historical direction therefore remains open. The same infrastructure can support concentration or discovery depending upon system design, institutional relations, user practices, and the distribution of productive capacity.

The central analytical conclusion is that public availability, effective visibility, attention, recognition, and epistemic authority are distinct. Expansion of the knowledge commons therefore does not by itself determine the distribution of future epistemic influence.

Section 13 turns from this social distribution of epistemic visibility toward the relation between human subjects and increasingly automated productive processes. The next analysis examines alienation from epistemic products, inquiry, empirical encounter, and subject-formative processes under conditions in which knowledge production can continue at increasing scale while human participation becomes differently organized.

13 Alienation under Automated Knowledge Production

This section examines alienation within increasingly automated systems of knowledge production. Its objective is to distinguish several forms of separation that can emerge among epistemic products, productive activity, empirical encounter, human knowing, judgment, and subject formation. The analysis develops from Marx's treatment of alienated labor toward a relational account appropriate to AI-mediated inquiry. The method is diagnostic rather than technologically deterministic. Automation, delegation, and reduced manual execution are treated as analytically distinct from alienation. The stronger condition arises when the subject's relation to the generative processes of inquiry becomes progressively attenuated, externally organized, or difficult to reconstitute [39, 40].

13.1 Epistemic Labor and Epistemic Products

This subsection establishes the relation between epistemic labor and its products. Research activity can generate articles, datasets, models, interpretations, proofs, experimental records, software, classifications, methods, and other epistemic artifacts. These outputs can subsequently circulate independently of the particular activities through which they were produced.

Marx's analysis of alienated labor identifies separation between the worker and the product of labor as one dimension of alienation [39]. Within epistemic production, the relevant translation concerns the relation between contributors and the epistemic artifacts emerging from their activity.

A researcher can participate extensively in the production of knowledge while possessing limited control over its later circulation, interpretation, commercialization, visibility, or institutional appropriation. Large collaborative and automated systems can increase this separation because the completed artifact may incorporate operations distributed across many human and machine contributors.

Epistemic products therefore acquire trajectories that can become increasingly independent of the individual subjects involved in their production.

13.2 Separation of Inquiry and Execution

This subsection examines the separation between the organization of inquiry and the execution of its component operations. AI systems can perform literature retrieval, coding, calculation, simulation, experimental control, drafting, and evaluation while a human participant remains responsible for broader objectives or decisions.

Executorial delegation can substantially increase productive capacity. It can also enable participation by subjects who would otherwise face physical, technical, linguistic, or temporal barriers. The amount of delegated execution therefore provides no sufficient measure of alienation.

The relevant distinction concerns whether the subject remains engaged with the generative structure of the inquiry. A person can delegate nearly all execution while continuing to formulate problems, evaluate alternatives, reject outputs, reinterpret evidence, and redirect the process.

Conversely, a person can perform many operations manually while following a highly routinized workflow whose objectives, evaluative criteria, and conceptual structure are determined externally.

Executorial participation and generative participation must therefore remain analytically separate.

13.3 Separation of Questions and Investigative Labor

This subsection examines the relation between question formation and the labor through which questions are pursued. Traditional research often distributes these activities across different persons. AI can increase the degree and speed of that distribution.

A human subject can formulate a question and delegate literature search, hypothesis generation, experimentation, analysis, and drafting to external systems. The original question can therefore remain human while most of the investigative trajectory unfolds elsewhere.

This configuration can be highly productive. It can allow an individual to pursue questions that would otherwise exceed available time, expertise, or physical capacity. The resulting epistemic relation depends upon what happens after delegation.

If the investigator repeatedly encounters intermediate results, develops new questions, challenges assumptions, and redirects inquiry, the delegated process can remain strongly integrated with human epistemic development.

A different configuration emerges when the initial question functions primarily as an instruction passed to an external productive system whose subsequent trajectory receives little human interrogation. Question authorship alone does not guarantee sustained participation in inquiry.

13.4 Separation of Epistemic Encounter and Human Participation

This subsection examines the distribution of direct epistemic encounters. Robots, sensors, instruments, autonomous laboratories, and artificial agents can increasingly perform empirical operations through which evidence is generated [14, 15].

The resulting development weakens a simple association between human knowing and direct human contact with the investigated object. A machine can encounter the relevant physical state, register a measurement, perform an intervention, and use the result to determine subsequent operations.

A human subject can remain epistemically involved through interpretation, problem formulation, experimental design, criticism, or conceptual revision. The empirical encounter itself can nevertheless occur primarily within an external technical system.

The resulting separation is analytically important because the subject benefiting from the inquiry and the agent undergoing the immediate encounter can become different participants.

This condition is neither inherently alienating nor inherently emancipatory. Its significance depends upon how the resulting evidence re-enters the human subject's epistemic trajectory.

13.5 Separation of Knowledge Production and Human Knowing

This subsection distinguishes the production of epistemically valuable outputs from the state of knowing achieved by a particular human subject. A system can produce a valid result, useful synthesis, successful prediction, or novel experimental finding even when the human recipient cannot reconstruct the process through which it was obtained.

Knowledge production and human knowing therefore operate at different levels of analysis.

The distinction can be represented conceptually by Equation 29.

$$\Delta K_{\text{system}} > 0 \quad \text{while} \quad \Delta K_{\text{human}} \approx 0. \quad (29)$$

Equation 29 represents a possible configuration in which the epistemic state of the wider productive system changes substantially while the epistemic state of a particular human participant changes only slightly.

This distinction becomes increasingly important when autonomous systems can conduct extended research cycles. Society can acquire additional epistemic outputs without a corresponding increase in understanding among the humans who commission, fund, supervise, or consume them.

13.6 Separation of Epistemic Output and Subject Formation

This subsection examines the deeper distinction between obtaining an answer and being transformed through inquiry. Section 4 showed that learning and inquiry can alter concepts, judgment, habits, perceptual sensitivities, interpretive horizons, and future capacities. Section 5 further distinguished formative and existential values of knowing.

Automated production allows these effects to diverge from epistemic output. A human recipient can obtain a sophisticated answer while undergoing little of the questioning, failure, resistance, conceptual revision, or practical engagement through which similar knowledge might otherwise have become formative.

This does not imply that every epistemic result must be personally reconstructed. Modern knowledge depends upon testimony, specialization, and distributed expertise. The issue concerns cumulative patterns in which external epistemic production grows while opportunities for subject-formative participation become systematically reduced.

The resulting concern can therefore be expressed as a possible decoupling between output generativity and subject-formative generativity.

13.7 Alienation from Epistemic Products

This subsection returns to the product dimension under contemporary epistemic conditions. Alienation from epistemic products can involve reduced control, recognition, access, interpretive authority, or capacity to determine how one's contributions are subsequently used.

AI-mediated workflows complicate authorship and contribution because outputs can emerge through distributed relations among prompts, models, retrieval systems, software, datasets, human judgments, and institutional infrastructures.

The relevant issue therefore extends beyond identifying a single author. Questions of contribution, control, provenance, appropriation, and recognition can become distributed across the productive network.

A researcher can contribute important questions, evaluations, or empirical insights while another organization controls the system through which the final artifact is generated and circulated. Conversely, an institution can possess formal ownership of an artifact while depending upon extensive external public knowledge and distributed labor.

Alienation from the product is therefore best analyzed relationally rather than through authorship status alone.

13.8 Alienation from Epistemic Activity

This subsection examines the subject's relation to the activity of inquiry. Marx's early analysis emphasizes the significance of productive activity becoming externally organized [39]. Within knowledge production, epistemic activity can be shaped by publication requirements, funding priorities, institutional metrics, platform incentives, market demand, or automated optimization objectives.

A researcher can consequently spend substantial effort producing epistemic outputs while experiencing limited relation between that activity and the questions that originally generated intellectual interest.

Automation can intensify or relieve this condition. AI can remove repetitive operations and return time to conceptual work, reflection, or other relations. The same systems can also increase output expectations and accelerate institutional production cycles.

The effect therefore depends upon the productive relation within which automation is introduced. A technology that reduces labor per output can either reduce burdens or become the basis for demanding more output within the same period.

13.9 Relational Epistemic Alienation

This subsection introduces *relational epistemic alienation* as the central concept of the present analysis. The term describes a condition in which epistemic production continues while the subject becomes increasingly detached from the generative relations through which the object is investigated, interpreted, questioned, and incorporated into a developing epistemic trajectory.

The concept concerns relational thinning rather than technological mediation. A heavily mediated inquiry can remain non-alienated when the subject's questions, judgments, experiences, and revisions continue to reorganize the process.

A more alienated configuration emerges when the subject's relation to inquiry contracts toward a small set of supervisory actions while the substantive generative trajectory develops outside the subject's active epistemic life.

A limiting case can be represented by Equation 30.

$$\mathcal{R}_{S,\text{inquiry}} \rightarrow \{\text{initiate, authorize, receive}\}, \quad (30)$$

where $\mathcal{R}_{S,\text{inquiry}}$ denotes the relation between subject S and the inquiry. Equation 30 represents an illustrative limiting configuration rather than a threshold definition of alienation.

The central concern is the progressive disappearance of curiosity, counterargument, interpretation, failure, revision, empirical encounter, and other generative relations from the subject's own trajectory.

13.10 Thin Participation in Autonomous Epistemic Production

This subsection examines configurations in which human participation remains formally present while becoming substantively thin. A human can initiate a research objective, approve continuation, and receive outputs from increasingly autonomous systems.

Such a person remains causally relevant to the process. The human may determine the broad subject, allocate resources, or decide whether results are published. These functions can be socially and institutionally important.

Thin participation refers to the limited degree to which the human subject enters the intervening generative process. The participant encounters few of the failed hypotheses, conflicting interpretations, surprising observations, or intermediate decisions through which the final output emerges.

The degree of thinness is therefore multidimensional. Directional control, reflective participation, empirical participation, conceptual transformation, and existential integration can vary independently.

This framework avoids treating a repeated "continue" instruction as a literal definition. The example functions only as a limiting case in which formal authorization survives while richer epistemic participation approaches a minimum.

13.11 Executorial Participation and Generative Participation

This subsection explicitly separates two dimensions whose conflation would produce misleading judgments about AI-mediated inquiry.

Executorial participation concerns the extent to which a subject personally performs the operations required for an epistemic or creative process.

Generative participation concerns the extent to which the subject's questions, judgments, experiences, interpretations, revisions, commitments, and historical trajectory enter the process through which the epistemic result emerges.

The two dimensions can vary independently. A person using assistive technologies can delegate almost all physical or textual execution while remaining deeply involved in problem formation, selection, interpretation, and revision.

The converse is equally possible. A person can manually execute many operations within an externally prescribed workflow while contributing little to the generative organization of the inquiry.

The degree of AI involvement therefore cannot serve as a proxy for the degree of subject participation.

13.12 Alienation and Assistive Delegation

This subsection examines assistive delegation as an important boundary case for the concept of alienation. Technologies can make participation possible for subjects whose physical, sensory, linguistic, or other conditions would otherwise restrict access to particular productive activities.

A creator or researcher can rely upon AI for typing, drawing, transcription, translation, coding, manipulation of instruments, or organization of complex materials while the generative trajectory remains strongly grounded in that subject's experience and judgment.

Such cases demonstrate that preservation of human manual execution cannot serve as the normative objective of epistemic analysis.

The relevant concern is preservation or expansion of meaningful participation. Automation can increase such participation by removing barriers between a subject and the realization of questions, interpretations, or creative intentions.

Delegation therefore has emancipatory as well as alienating possibilities within the same technological class.

13.13 Inquiry, Resistance, and Revision

This subsection examines resistance and revision as indicators of continued subject participation. Inquiry rarely develops as a sequence of accepted outputs. Unexpected evidence, conceptual tension, disagreement, failed hypotheses, and counterexamples can redirect the process.

A human subject remains strongly integrated into AI-mediated inquiry when machine-generated outputs become objects of judgment rather than terminal answers. The subject can reject a synthesis, identify a missing distinction, question an assumption, request a counterexample, or reformulate the original problem.

The resulting process can be represented by Equation 31.

$$Q_t \rightarrow I_t \rightarrow K'_t \rightarrow J_t \rightarrow Q_{t+1}, \quad (31)$$

where I_t denotes delegated or hybrid inquiry and J_t denotes subjective judgment, including acceptance, resistance, interpretation, or revision. Equation 31 represents a recursive trajectory in which machine-mediated production continues to feed back into human question formation.

Alienation becomes more plausible as this feedback relation weakens systematically.

13.14 Institutional and Productive Imperatives

This subsection examines the social conditions through which automated production can acquire objectives partially independent of individual curiosity. Academic institutions already connect publication, grants, promotion, prestige, rankings, and organizational survival to continuing epistemic output [53].

AI can reduce the cost of producing additional outputs within these structures. A reduction in production cost can create opportunities for slower reflection, greater accessibility, and wider experimentation. It can also increase the expected rate of output when competitive institutions adapt to the new productive frontier.

The latter process can deepen alienation when researchers use automation primarily to satisfy externally escalating production requirements. The technology then participates in a cycle through which increased productivity becomes the basis for increased demands.

The problem therefore lies partly in institutional organization. The same technical capability can generate different relations to inquiry under different incentive structures.

13.15 Self-Continuation of Epistemic Production

This subsection examines the possibility that knowledge production becomes increasingly capable of generating its own subsequent tasks. Agentic systems can identify literature gaps, propose hypotheses, execute analyses, evaluate results, and generate new questions [37, 23].

The resulting process can become partially self-continuing at the level of epistemic operations. One output generates candidate problems for the next round, and automated evaluation selects which trajectories continue.

The political-economic significance lies in the separation between the continuation of production and the purposes of particular human subjects. Epistemic infrastructure can possess increasingly strong internal mechanisms for reproducing further activity.

This does not imply independent machine desire. The relevant property is organizational: the productive system can continue generating and selecting subsequent epistemic operations with decreasing requirements for direct human intervention.

The distinction permits analysis of self-expanding epistemic production without making claims about artificial consciousness, intentionality, or intrinsic motivation.

13.16 Alienation and Epistemic Productivity

This subsection emphasizes that alienation and productivity can increase simultaneously. A highly automated system can generate more knowledge while human participants become less involved in the processes through which that knowledge emerges.

The relation can be expressed conceptually by Equation 32.

$$G_{\text{system}} \uparrow \quad \text{while} \quad R_{S,\text{inquiry}} \downarrow, \quad (32)$$

where G_{system} denotes the generative capacity of the epistemic system and $R_{S,\text{inquiry}}$ denotes the richness of the subject's participation in inquiry. Equation 32 represents a possible divergence rather than a necessary effect of automation.

The inverse trajectory is also possible. Automation can increase system productivity while deepening human participation by removing routine execution and enlarging the range of questions a subject can explore.

Productivity therefore provides insufficient evidence for evaluating the quality of the human epistemic relation.

13.17 Alienation and Relational Redistribution

This subsection introduces an important limit to the diagnosis of epistemic alienation. Human formation occurs through many relations beyond formal knowledge production. Love, care, friendship, art, religion, political participation, craft, bodily activity, nature, place, community, and contingent everyday experience can all contribute to the continuing formation of a subject.

Delegation of epistemic labor can therefore redistribute rather than simply reduce subject-formative activity. A person who spends less time on repetitive research operations can redirect time and attention toward other generative relations.

The normative evaluation of automation must consequently consider the wider relational field of human life. A decline in one form of epistemic participation does not establish an overall decline in subject formation.

This possibility will later be developed through the concept of relational redistribution of subject formation within the Generative Relational account.

13.18 Historical Openness of Epistemic Alienation

This subsection situates the preceding analysis within an historically open framework. Artificial intelligence can support several trajectories simultaneously. It can automate repetitive work, expand access, assist disabled participants, increase intellectual experimentation, and create new forms of collaboration. It can also enable intensified productivity demands, deeper infrastructural dependence, thinner participation, and stronger separation between epistemic outputs and human formation.

These possibilities need not resolve into a single technological tendency. Their relative significance depends upon educational practices, labor relations, institutional incentives, ownership structures, model design, research norms, and the ways in which subjects integrate AI into their own epistemic lives.

The concept of alienation is therefore used diagnostically. It identifies specific relations of separation and attenuation that can emerge under automated production without treating technological mediation itself as the problem.

The central conclusion of this section is that epistemic alienation concerns the quality of the relation between subject and generative process. Extensive delegation can coexist with deep participation, while extensive human execution can coexist with externally organized and weakly formative activity.

Section 14 therefore turns from alienation within productive relations toward education and epistemic formation. The next section examines how AI-mediated access to answers, explanations, and completed procedures can alter learning when the educational objective includes the development of judgment, inquiry capacity, practical competence, and future generativity.

14 Epistemic Formation and Education under Automated Production

This section examines education under conditions in which increasingly capable artificial systems can retrieve information, explain concepts, generate solutions, perform calculations, write code, construct arguments, and complete extended investigative tasks. Its objective is to distinguish the production of correct epistemic outputs from the formation of persons capable of future judgment and inquiry. The section proceeds from educational output and epistemic formation toward understanding, reconstruction, judgment, practical competence, inquiry capacity, scaffolded learning, delegated problem solving, dependence, and the institutional organization of education. The method is comparative and developmental. AI is evaluated according to the epistemic capacities that particular educational practices cultivate, preserve, weaken, or reorganize rather than according to the amount of machine assistance alone [17, 10, 56, 34, 35].

14.1 Educational Output and Epistemic Formation

This subsection distinguishes completion of an educational task from transformation of the learner. A correct answer, successful proof, functioning program, polished essay, or accurate laboratory report can serve as evidence of learning under some conditions. The artifact itself does not determine how the learner arrived at it or which capacities were developed during its production.

Section 4 established that learning can modify concepts, perceptual sensitivities, practical skills, judgment, and the capacity to formulate later questions. Educational activity therefore has a developmental object in addition to an output object.

The distinction can be expressed conceptually by Equation 33.

$$O_{\text{task}} \neq \Delta G_{\text{learner}}, \quad (33)$$

where O_{task} denotes the quality of a completed educational output and $\Delta G_{\text{learner}}$ denotes the change in the learner's future epistemic capacity. Equation 33 indicates analytical independence rather than absence of correlation.

Artificial intelligence makes the distinction more visible because high-quality outputs can increasingly be produced with limited reconstruction of the underlying epistemic process by the learner.

14.2 Information Acquisition and Understanding

This subsection distinguishes access to information from development of understanding. AI can substantially reduce the cost of obtaining definitions, summaries, translations, examples, comparisons, and explanations. These functions can remove unnecessary barriers to learning and increase access to materials that would otherwise remain difficult to interpret.

Understanding requires additional relations among concepts. Bruner emphasizes the importance of disciplinary structure and of grasping relations that support transfer beyond isolated factual recall [10]. A learner therefore benefits from being able to connect a new proposition with prior knowledge, identify its conditions of application, reconstruct its implications, and recognize circumstances in which it fails.

AI can support this process through adaptive explanation, alternative examples, dialogue, and immediate clarification. The same system can also allow a learner to obtain answers without constructing the conceptual relations required for independent use.

The educational significance of AI therefore depends partly upon whether interaction increases the learner's capacity to regenerate and extend an understanding after external assistance is removed.

14.3 Reconstruction and Epistemic Development

This subsection examines the educational value of reconstructing results that are already known at the level of society. Discovery-oriented education does not require that a learner produce globally novel knowledge. A familiar theorem, experimental result, historical interpretation, or programming technique can still be epistemically new for the learner.

Bruner's account of discovery and disciplinary structure provides a useful basis for this distinction [10]. The educational value of reconstruction lies partly in developing the relations through which the learner becomes able to derive, evaluate, or apply the result independently.

Automation creates an opportunity to separate social novelty from personal formation more sharply. AI can produce the established result immediately, while the learner's developmental trajectory can require substantially more time.

The relevant educational question is therefore how much of the reconstructive process contributes to capacities that remain useful after the particular task has ended.

14.4 Judgment and Epistemic Evaluation

This subsection examines judgment as a capacity that becomes increasingly important when external systems can generate large quantities of plausible epistemic material. Learners need to evaluate assumptions, evidence, uncertainty, relevance, competing explanations, and conditions under which a claim should be revised.

The need for judgment does not disappear when AI performance improves. Increased system capability can make evaluation more difficult because weak outputs can be expressed with high linguistic and formal quality. The learner must therefore distinguish surface coherence from evidential or conceptual adequacy.

Educational use of AI can support judgment when students are required to compare outputs, locate unsupported assumptions, construct counterexamples, check evidence, or explain why one solution should be preferred.

A different pattern emerges when evaluation is delegated together with generation. If the same external infrastructure generates a solution, criticizes it, selects among alternatives, and presents the final answer, the learner can receive a highly refined output while exercising little direct judgment.

Judgment therefore represents a distinct educational target whose development cannot be inferred from the quality of the system assisting the learner.

14.5 Error, Revision, and Learning

This subsection examines the formative role of error and revision. Experiential and inquiry-oriented approaches treat learning as a process in which action, feedback, reflection, and subsequent action modify the learner's capacities [17, 34].

An incorrect hypothesis, failed derivation, unsuccessful experiment, or misinterpretation can reveal a discrepancy between the learner's present model and the structure of the problem. Revision of that discrepancy can contribute to later judgment.

Educational design therefore needs to distinguish unproductive repetition from formative error. AI can remove routine mistakes whose correction contributes little additional understanding. It can also eliminate encounters with difficulty that would otherwise expose important conceptual weaknesses.

The value of error depends upon what the learner becomes capable of recognizing and revising through the process. Preservation of every difficulty is therefore neither necessary nor desirable.

14.6 Practical Competence and Repeated Participation

This subsection examines educational processes in which competence develops through repeated practice. Experiential and situated-learning theories emphasize that participation in activity can develop capacities that exceed explicit knowledge of rules [34, 35].

Laboratory technique, clinical practice, field observation, craft, interpretation, programming, and many other activities involve sensitivities that develop through interaction with particular tasks and environments.

AI can assist practical formation by providing feedback, simulation, adaptive instruction, translation, accessibility, or rapid comparison with alternative methods. It can also perform portions of practice on behalf of the learner.

The relevant educational boundary depends upon which operations are themselves constitutive of the competence being developed. Delegation of repetitive calculation can preserve the target skill when the educational objective is higher-level modeling. Delegation of all model construction can undermine the same course if model construction is itself the competence under formation.

Automation must therefore be evaluated relative to the pedagogical object.

14.7 Situated Learning and Participation

This subsection examines education through participation in social practices. Lave and Wenger describe learning through changing participation within communities of practice [35]. Vygotsky likewise emphasizes the role of socially mediated activity in cognitive development [56].

Education within this perspective includes learning how a community identifies problems, evaluates evidence, communicates uncertainty, resolves disagreement, and recognizes competent participation.

AI can mediate entry into such practices by explaining terminology, simulating dialogue, supporting communication, and lowering barriers to participation. Artificial tutors can also provide forms of individualized interaction that are difficult to supply institutionally at comparable scale.

These functions do not make human communities educationally irrelevant. Participation in a living practice can involve responsibility, trust, recognition, shared standards, and exposure to heterogeneous persons whose responses cannot be reduced to informational instruction.

AI therefore changes the composition of educational relations while leaving open how different combinations of human and artificial participation affect formation.

14.8 Apprenticeship and Delegated Expertise

This subsection examines apprenticeship under conditions where expert-like assistance can be generated computationally. Traditional apprenticeship places learners in sustained relation with practitioners whose actions, corrections, standards, and judgments become progressively intelligible through participation [35].

AI can provide immediate explanations, examples, criticism, rehearsal, and technical support. Such capabilities can make forms of guided practice available to learners who lack continuous access to human experts.

The epistemic structure differs when expertise is encountered primarily through an artificial interface. A human mentor can possess a biography within the practice, institutional responsibilities, tacit standards, memories of prior cases, and participation in the consequences of advice. An artificial system can reproduce parts of the functional guidance while possessing a different relation to the practice.

The educational consequences depend upon which dimensions of apprenticeship are relevant to the competence being developed. Technical correction, interpretive formation, professional judgment, ethical responsibility, and community membership can exhibit different degrees of delegability.

14.9 Inquiry Capacity

This subsection identifies the capacity to conduct future inquiry as a central educational outcome. A learner who knows how to formulate problems, identify evidence, generate alternatives, test assumptions, evaluate failure, and revise questions possesses a form of generative capacity that extends beyond mastery of any particular answer.

Inquiry capacity is closely related to the cumulative structure described in Section 4. Successful learning changes which questions and methods become available to the learner in later periods.

AI can increase inquiry capacity by exposing learners to unfamiliar domains, rapidly generating examples and counterexamples, supporting exploratory coding, and making difficult source materials accessible.

A risk appears when AI substitutes for the organization of inquiry itself. Learners can become proficient at specifying broad objectives to external systems while developing less capacity to decompose a problem, determine what evidence is required, or recognize when the resulting workflow is inappropriate.

The educational objective therefore concerns future generativity rather than the preservation of any fixed distribution of manual tasks.

14.10 Scaffolding through Artificial Intelligence

This subsection examines AI as a potential scaffold for epistemic development. Vygotskian educational theory provides a general framework for understanding assistance that enables learners to perform beyond their current independent capacity while participating in processes through which new capacities develop [56].

AI can provide dynamically adjusted explanations, hints, examples, questions, translation, feedback, and decomposition of difficult tasks. These functions can lower entry barriers and allow learners to engage with material that would otherwise remain inaccessible.

The developmental value of scaffolding depends upon whether assistance changes as learner capacity changes. Permanent substitution of the learner's target activity can create dependency, while calibrated assistance can permit increasingly independent performance.

The relevant distinction is therefore between assistance that expands the learner's future capacity and assistance whose usefulness remains conditional upon continuing external substitution.

14.11 Delegated Problem Solving

This subsection examines educational situations in which the solution process is largely delegated to AI. Delegated problem solving can be valuable when the learner's objective lies outside the delegated

operation. A physics student investigating a complex system may reasonably delegate routine algebra. A researcher may use software to solve numerical systems whose manual solution is irrelevant to the research objective.

The same delegation has different consequences when the delegated operation is the object of learning. A learner studying algebra develops little algebraic capacity by consistently delegating the complete manipulation of expressions.

The educational significance of automation therefore cannot be determined by the operation alone. It depends upon the relation between the operation and the capacity under formation.

This principle can be summarized as a pedagogical alignment condition: automation is educationally supportive when delegated execution remains compatible with development of the target generative capacity.

14.12 Answer Availability and Learning Trajectories

This subsection examines how immediate access to high-quality answers changes the temporal structure of learning. Historically, some educational activities required learners to remain with uncertainty long enough to formulate hypotheses, attempt solutions, encounter failure, and revise their approach.

AI can compress this sequence by making explanations and completed solutions available almost immediately. Such compression can reduce frustration and make learning more efficient when the difficulty adds little developmental value.

Rapid resolution can also remove opportunities for the learner to identify what is unclear, generate an initial model, or experience the discrepancy between an expectation and the structure of a problem.

The educational issue therefore concerns the timing and form of assistance. Efficiency in obtaining an answer and efficiency in developing a capacity need not be identical.

This point should not be interpreted as a general preference for difficulty. The relevant question is which portions of an investigative trajectory contribute to later generativity and which can be delegated without significant developmental loss.

14.13 Epistemic Dependence in Learning

This subsection examines dependence that can develop when external systems become persistent components of ordinary cognitive activity. Modern education has always relied upon external resources including books, teachers, calculators, libraries, software, and institutional expertise. Dependence upon external resources is therefore not intrinsically problematic.

The relevant distinction concerns what capacities remain available when a particular infrastructure is unavailable, inappropriate, erroneous, or contested.

A learner can rely extensively upon AI while retaining the capacity to recognize uncertain outputs, formulate alternative approaches, seek independent evidence, and continue reasoning under reduced assistance. Another learner can possess similar access while becoming unable to initiate or evaluate work without the system.

The educational concern is consequently *fragile dependence*: productive performance can remain high while the learner's independent capacity to reorganize inquiry under changing conditions remains weak.

This structure parallels the generative precarity identified in Section 11, although the relevant unit here is the developing learner rather than the research worker.

14.14 Epistemic Autonomy and Assisted Learning

This subsection examines autonomy as a developmental objective compatible with extensive technological assistance. Epistemic autonomy does not require solitary cognition or independence from testimony. Modern subjects necessarily rely upon distributed knowledge and institutional specialization.

Autonomy concerns the capacity to orient within those dependencies. A learner develops autonomy by acquiring sufficient judgment to determine when assistance is appropriate, what kind of source is required, how conflicting outputs should be compared, and when a conclusion remains uncertain.

AI can strengthen this capacity when it broadens access to competing arguments, provides alternative explanations, or allows rapid testing of provisional ideas. It can weaken the same capacity when interaction becomes a habitual substitute for judgment.

The educational challenge is therefore relational. Dependence and autonomy can coexist when external resources enlarge agency while the learner retains the capacity to interrogate and reorganize the relation.

14.15 Educational Inequality and Capitalization Capacity

This subsection connects education with the political economy of epistemic capitalization. AI can reduce some inequalities by providing low-cost access to explanation, translation, tutoring, writing support, and computational assistance. Learners excluded from elite institutions can gain access to resources previously available only through expensive educational structures.

The same technology can generate new inequalities when productive use depends upon premium models, compute, institutional data, specialized tools, expert supervision, or prior educational capital.

The effect of AI on educational equality therefore depends upon differences in capitalization capacity. Two learners can access similar models while differing substantially in prior knowledge, available time, linguistic resources, institutional support, and capacity to evaluate outputs.

AI can consequently reduce information-access inequality while leaving or increasing inequalities in the ability to transform information into durable epistemic capacity.

14.16 Educational Institutions and Changing Productive Conditions

This subsection examines the institutional consequences of AI-mediated epistemic production. Schools and universities historically organize both knowledge transmission and development of capacities for participation in future epistemic and professional practices.

When external systems can perform tasks previously used as indicators of learning, educational institutions must distinguish the artifact being assessed from the capacity the artifact was intended to reveal.

A polished essay can no longer be assumed to index the same underlying activities of reading, synthesis, argumentation, and revision. A correct program can be produced without the learner possessing equivalent programming capacity. A mathematical derivation can be generated without the student being able to reconstruct its logic.

Assessment therefore becomes increasingly dependent upon explicit specification of the capability being evaluated. Oral explanation, interactive problem solving, iterative critique, process documentation, practical demonstration, and other forms of evidence can acquire greater importance where the objective is to assess formation rather than artifact production.

The appropriate educational response need not consist of excluding AI. Assessment can instead examine how learners formulate, interrogate, revise, and integrate machine-mediated outputs within their own reasoning.

14.17 Differential Automation of Educational Processes

This subsection applies the differential-automation framework developed in Section 10 to education. Educational processes vary in the degree to which execution, interaction, relation, and participant history contribute to the capacity being formed.

Routine retrieval and some formal operations can often be automated with limited loss when they are supporting activities. Experimental training, interview practice, clinical judgment, apprenticeship, collaborative inquiry, and culturally situated learning can depend more strongly upon forms of participation whose educational effects require separate evaluation.

A single course can contain several such processes. AI can appropriately automate one component while direct participation remains important in another.

Educational policy therefore benefits from analysis at the level of learning processes rather than broad judgments about whether a discipline should “use AI.”

The relevant decision concerns which relation is pedagogically generative for the capacity under development.

14.18 Epistemic Formation under Abundant Assistance

This subsection synthesizes the consequences of increasingly abundant epistemic assistance. Artificial intelligence can make explanation, correction, translation, computation, simulation, and expert-like interaction available at unprecedented scale. These capacities can substantially increase access to learning and permit individuals to explore domains previously constrained by time, language, disability, or institutional position.

The same abundance changes the structure of educational scarcity. Answers can become inexpensive while attention, judgment, sustained participation, and the formation of durable epistemic capacities remain temporally constrained.

The educational objective therefore cannot be identified simply with reducing the cost of answer production. It concerns the organization of relations through which learners become capable of later inquiry.

A generative educational trajectory can involve substantial AI delegation when the technology expands the learner’s ability to encounter problems, compare possibilities, test ideas, receive feedback, and revise understanding. A different trajectory can produce excellent artifacts while leaving the learner increasingly dependent upon external execution.

The distinction is developmental rather than technological.

14.19 Education within Knowledge-Capital Expansion

This subsection integrates education into the wider theory of knowledge-capital expansion. Education is itself a process of capitalization because existing public and institutional knowledge is transformed into capacities that alter what a learner can subsequently understand, question, produce, and evaluate.

The process can be represented by Equation 34.

$$K_{\text{available}} \rightarrow \mathcal{L}_i \rightarrow G'_i \rightarrow Q'_i \rightarrow K'_i, \quad (34)$$

where $\mathcal{L}_i$ denotes the learning process of subject i , G'_i the resulting generative capacity, Q'_i newly available questions, and K'_i possible later epistemic production. Equation 34 treats education as a transformation of available knowledge into future epistemic possibility.

AI can alter every transition in this process. It can increase the amount of knowledge that becomes accessible, mediate the learning process, expand the range of questions a learner can explore, and assist subsequent production.

The central educational problem is therefore the distribution of generativity across the system and the learner. A highly productive external infrastructure can increase a learner’s future capacity, substitute for it, or produce some combination of both.

This distinction preserves an open evaluation of educational automation. Extensive AI use can support autonomy, accessibility, creativity, and deeper inquiry. It can also create fragile dependence or separate task completion from formation. The resulting trajectory depends upon the relation among learner, technology, teacher, institution, task, and the capacities being cultivated.

Section 15 turns from the educational formation of epistemic capacities toward the motives and ends that orient their use. The next section examines curiosity, question generation, inquiry, and the purposes for which increasingly powerful systems of knowledge production continue to operate.

15 Curiosity and the Ends of Knowledge Production

This section examines curiosity, question formation, and the purposes that orient knowledge production under increasingly automated conditions. Its objective is to distinguish the generation of epistemic outputs from the motives through which particular subjects enter inquiry, and to analyze how artificial systems capable of generating and pursuing questions alter this relation. The section proceeds from curiosity and epistemic motivation toward uncertainty, question formation, counterargument, failure, machine-generated questions, production-oriented research systems, and partially self-continuing epistemic production. The method is conceptual and comparative. Curiosity is treated as one important source of inquiry rather than a universal explanation of knowledge production, while the ends of inquiry are examined across human, institutional, and automated levels [36, 33].

15.1 Curiosity and Epistemic Motivation

This subsection establishes curiosity as a motive capable of directing attention and inquiry toward epistemic uncertainty. Aristotle's account of the human desire to know provides an early philosophical formulation of the intrinsic significance of knowing [1]. Contemporary psychological research has examined curiosity as a motivational state connected with information seeking, uncertainty, and the acquisition of knowledge [36, 33].

Curiosity matters for the present analysis because it links an epistemic gap with the activity of a situated subject. A person notices something unexplained, surprising, incomplete, inconsistent, or otherwise salient and allocates attention toward reducing or exploring that uncertainty.

The resulting inquiry can have instrumental consequences while originating from a motive whose immediate object is understanding. A child can ask why a phenomenon occurs without possessing a professional, economic, or institutional reason for obtaining the answer.

Curiosity therefore represents one pathway through which knowledge production becomes integrated into the life and development of a subject.

15.2 Uncertainty and the Generation of Inquiry

This subsection examines uncertainty as a condition from which inquiry can emerge. Loewenstein's information-gap account relates curiosity to perceived gaps between what an individual knows and what the individual seeks to know [36]. Kidd and Hayden review broader psychological and neuroscientific research in which uncertainty and information seeking play central roles in curiosity [33].

A perceived gap is relational. The same informational state can be trivial to one subject, invisible to another, and deeply puzzling to a third because each enters the encounter with a different epistemic history.

Curiosity therefore depends partly upon what the subject is already capable of recognizing as unresolved. Accumulated knowledge can reduce some uncertainties while creating others by making previously invisible distinctions available.

This recursive property gives curiosity a generative role. Learning can produce additional ignorance in the epistemically productive sense that new knowledge reveals further questions.

15.3 Encounter and Question Formation

This subsection connects curiosity with the encounter structures developed in Sections 4 and 5. Questions often emerge when an encountered phenomenon exceeds, frustrates, or destabilizes an existing expectation.

Dewey's theory of inquiry begins from indeterminate or problematic situations whose transformation motivates investigative activity [18]. The relevant epistemic movement therefore begins before a fully articulated question exists.

A subject can first experience confusion, discrepancy, surprise, practical failure, or uncertainty. Conceptual articulation subsequently transforms this disturbance into a question capable of organizing inquiry.

The process can be represented schematically in Equation 35.

$$(S_t, E_t) \rightarrow \Delta_t \rightarrow Q_t, \quad (35)$$

where S_t denotes the situated subject, E_t an encounter, Δ_t an experienced epistemic discrepancy, and Q_t an emerging question. Equation 35 represents one possible path of question formation and does not imply that every question requires an affectively salient encounter.

The important property is historical dependence. A question can carry a trajectory through which it became meaningful to a particular subject.

15.4 Question Formation as Epistemic Capacity

This subsection examines the ability to formulate productive questions as an epistemic capacity in its own right. Section 9 treated questions as resources capable of opening new investigative possibilities. The present subsection focuses on the subject capable of producing them.

Question formation requires sensitivity to incompleteness, contradiction, anomaly, relevance, and unexplored relations. Development of expertise can therefore change the space of questions visible to a subject.

A learner who initially asks for definitions can later ask about assumptions, boundary conditions, competing models, unresolved mechanisms, or consequences across domains. Growth in knowledge consequently modifies the topology of the subject's practical question space.

Question-forming capacity is therefore a component of future epistemic generativity. Its value persists even when external systems can answer particular questions more efficiently than the human investigator.

15.5 Curiosity and Situated Salience

This subsection briefly recognizes the role of situated experience in making some questions matter to particular subjects. Curiosity can arise from wonder, care, practical inadequacy, perceived injustice, bodily vulnerability, aesthetic experience, surprise, or other encounters that acquire significance within a life.

The resulting question carries more than informational incompleteness. It can reflect a relation between the subject and a world whose present configuration has become practically, ethically, intellectually, or existentially salient.

Such situated origins are important because identical questions can occupy different positions within different epistemic trajectories. The present paper does not develop a full phenomenology of curiosity. The broader relation among experience, affect, wonder, suffering, and inquiry is reserved for separate philosophical analysis.

15.6 Counterargument and Epistemic Resistance

This subsection examines resistance to provisional answers as a component of continued inquiry. Curiosity does not disappear when an initial answer becomes available. An answer can generate further questioning when it conflicts with evidence, prior experience, conceptual commitments, or alternative interpretations.

Counterargument therefore functions as a generative operation. A subject can ask what assumptions support an answer, which cases challenge it, whether an alternative explanation fits the evidence, and how the conclusion changes under different conditions.

AI can increase access to such resistance by rapidly generating counterexamples, objections, alternative models, or adversarial interpretations. Section 9.9 described this capacity at the level of automated research infrastructure.

For human epistemic formation, the central issue concerns whether machine criticism becomes another object of judgment. AI can widen the adversarial field through which a subject tests a position while the subject remains responsible for interpreting the significance of the resulting conflict.

15.7 Failure and Revision

This subsection examines failure as a possible transition within inquiry. Experimental failure, rejected hypotheses, inconsistent interpretations, and unsuccessful attempts can reveal structure that was unavailable before the failure occurred.

Deweyan and experiential accounts of learning emphasize iterative relations among action, consequences, reflection, and subsequent reconstruction [17, 34]. The epistemic value of failure therefore lies in the revision it makes possible.

The process can be summarized by Equation 36.

$$H_t \rightarrow E_t \rightarrow F_t \rightarrow J_t \rightarrow H_{t+1}, \quad (36)$$

where H_t denotes a provisional hypothesis, E_t an investigative encounter, F_t a recognized failure or mismatch, and J_t subsequent judgment. Equation 36 represents a formative trajectory through which failure contributes to revision.

Automation can compress large numbers of failed trials into an external computational process. This can be highly efficient. The epistemic consequence for a human subject depends upon which failures remain visible and which patterns of revision the subject is able to understand.

The educational or formative value of failure therefore does not require preservation of every unsuccessful operation. It concerns access to the discrepancies through which relevant judgment develops.

15.8 Answers and Subsequent Questions

This subsection examines the recursive relation between knowing and further questioning. An answer can close one uncertainty while creating new distinctions that expose previously unavailable questions.

The process can be represented by Equation 37.

$$S_t \rightarrow Q_t \rightarrow K_{t+1} \rightarrow S_{t+1} \rightarrow Q_{t+1}. \quad (37)$$

Equation 37 represents a trajectory in which knowledge changes both the epistemic state of the subject and the question space subsequently available to that subject.

This formulation connects curiosity with subject-formative generativity. Knowledge contributes to future inquiry partly because the knower becomes capable of perceiving additional unknowns.

AI can participate at every point in this sequence. The system can supply answers, generate further questions, expose contradictions, or suggest unexpected relations. The degree to which the human subject undergoes the intermediate transformation remains a separate variable.

15.9 Machine-Generated Questions

This subsection examines artificial generation of research questions and hypotheses. Contemporary agentic scientific systems can generate candidate ideas, identify possible gaps, formulate hypotheses, and use previous results to initiate subsequent investigative steps [37, 23].

Machine-generated questions can possess genuine scientific utility. Their value does not depend upon prior human authorship of each individual question. Automated question generation can enlarge the practical possibility space of research and expose human investigators to directions they had not considered.

The distinction required for the present analysis concerns the relation between *question production* and *question emergence within a subject*. A computational system can generate a productive question without that question having originated in the human participant's own curiosity or situated encounter.

The distinction does not establish a hierarchy between the resulting questions. It identifies different generative histories.

A machine-generated question can subsequently become deeply integrated into a human trajectory when the subject encounters it, becomes puzzled by its implications, develops objections, modifies it, or reorganizes further inquiry around it.

15.10 Human Curiosity and Machine Exploration

This subsection examines complementarity between human curiosity and machine-scaled exploration. A human subject can formulate a question emerging from a particular intellectual, practical, or existential trajectory while AI systems explore a much larger set of candidate paths than the subject could personally execute.

The resulting configuration can preserve strong human generative participation despite extensive delegation. The human supplies, modifies, or adopts the direction of inquiry, while machine systems expand search, generate counterarguments, conduct experiments, or compare alternatives.

The important relation is recursive. Machine exploration returns results to the human participant, whose judgment can alter subsequent questions and redirect the external system.

This configuration illustrates how automation can amplify curiosity rather than replace it. A small number of human questions can open substantially larger spaces of practical investigation when coupled to machine-scaled generative capacity.

15.11 Institutional Motives of Knowledge Production

This subsection distinguishes curiosity from other motives organizing modern knowledge production. Scientific and scholarly activity can be oriented by public problems, institutional missions, professional advancement, grant priorities, commercial objectives, strategic interests, publication requirements, or organizational competition.

Academic capitalism scholarship documents the increasing importance of market-like and externally oriented relations within university knowledge production [53]. Such institutional motives can coexist with substantial personal curiosity among individual researchers.

The distinction becomes important when knowledge production is analyzed at different scales. A person can pursue an inquiry because a problem is intellectually compelling while the institution finances the same inquiry because it expects economic or reputational returns.

The ends of knowledge production are therefore distributed across actors. Research systems need not possess a single unified motive.

15.12 Production-Oriented Epistemic Systems

This subsection examines systems in which continuation of epistemic production becomes an important organizational objective. Universities, research laboratories, firms, publishers, and platforms can depend upon recurrent production for funding, evaluation, market position, reputation, or institutional continuity.

Under such conditions, questions can acquire value partly because they sustain further productive activity. Research programs generate additional projects, publications create future citation opportunities, successful infrastructures attract further funding, and accumulated resources support subsequent production.

AI increases the capacity of such systems to generate and pursue new epistemic tasks. Question production, hypothesis generation, experimentation, evaluation, and documentation can all become partially automated.

The result is an increasing possibility that the operational continuation of knowledge production becomes less dependent upon the continuing curiosity of any particular human participant.

15.13 Self-Continuing Epistemic Production

This subsection develops the organizational concept of self-continuing epistemic production introduced in Section 13.15. Agentic systems can use one result to generate a subsequent hypothesis, evaluate that hypothesis, conduct additional analysis, and initiate another cycle [37, 23].

The process can be represented by Equation 38.

$$K_t \rightarrow Q_{t+1} \rightarrow I_{t+1} \rightarrow K_{t+1} \rightarrow Q_{t+2}, \quad (38)$$

where I_{t+1} denotes the investigative process associated with the new question. Equation 38 represents organizational continuity of epistemic operations and does not attribute consciousness, desire, or intrinsic motivation to the artificial system.

This distinction is important. An epistemic infrastructure can generate successive tasks according to optimization criteria or learned procedures without the present paper resolving whether the system experiences curiosity.

The political-economic issue concerns the increasing independence of productive continuity from individual human motivation.

15.14 Epistemic Production and Human Purposes

This subsection examines the relation between scalable knowledge production and the purposes for which humans seek knowledge. Section 5 distinguished instrumental, autonomy, generative, formative, and existential values of knowing. These values need not remain aligned under automated production.

A system can increase instrumental knowledge dramatically while contributing little to the formation of a particular human subject. Automated research can expand collective epistemic capacity while individual participants devote less time to inquiry. Machine-generated questions can advance science while having little existential significance for the humans who receive their answers.

The resulting divergence does not establish a failure of the epistemic system. Different social purposes can justify different arrangements. Medical research can be valuable because it reduces suffering even when few people personally experience the discovery process. Astronomical research can carry cultural and existential significance alongside its scientific value.

The analytical requirement is therefore to specify which end of knowledge production is under evaluation.

15.15 Curiosity under Epistemic Abundance

This subsection examines curiosity in an environment where answers become increasingly inexpensive. The cost of obtaining information has historically limited which questions individuals could practically pursue. AI can reduce that constraint and allow a subject to follow many small curiosities that would previously have remained unexplored.

This expansion can be strongly generative. Rapid access to explanations, translations, calculations, and counterarguments can allow one question to lead quickly into several unfamiliar domains.

Abundant answers can also change the temporal relation between uncertainty and resolution. Some questions can be answered before the subject has substantially developed an initial interpretation, hypothesis, or sense of why the problem is difficult.

The educational significance of this temporal compression was examined in Section 14.12. At the broader epistemic level, it indicates that reduction of answer scarcity can increase the importance of capacities for selecting, sustaining, and developing questions.

Curiosity under abundance may therefore depend increasingly upon the quality of engagement with uncertainty rather than the mere availability of missing information.

15.16 Curiosity and Epistemic Capitalization

This subsection connects curiosity with the wider framework of knowledge-capital expansion. Curiosity can generate questions, and questions can direct available epistemic resources toward new productive trajectories. Question-forming capacity therefore contributes to capitalization capacity.

The relation can be represented through Equation 39.

$$S_t \rightarrow Q_t \rightarrow C_t \rightarrow K_{t+1} \rightarrow G_{t+1}, \quad (39)$$

where S_t denotes the situated epistemic subject, Q_t a question, C_t the capitalization of available epistemic resources, K_{t+1} the resulting knowledge, and G_{t+1} subsequent generative capacity. Equation 39 places curiosity upstream from one possible cycle of knowledge-capital expansion.

AI can intervene between every stage. It can suggest questions, expand capitalization capacity, conduct investigation, and generate subsequent knowledge. The resulting system can therefore contain both human-generated and machine-generated sources of epistemic direction.

The central distinction concerns whose generative trajectory changes through the process. Expansion of the system's question space and expansion of a human subject's capacity to question can occur together or separately.

15.17 Ends of Knowledge Production under Artificial Intelligence

This subsection synthesizes the problem of epistemic ends under artificial intelligence. Knowledge production can serve practical intervention, prediction, institutional objectives, public welfare, economic accumulation, intellectual autonomy, education, curiosity, self-cultivation, and the continuing development of human subjects. These ends can overlap while remaining analytically distinct.

Artificial intelligence changes their relation because epistemic production can increasingly proceed without requiring equivalent human participation at every stage. The system can generate useful answers, questions, experiments, and artifacts while the human role moves toward direction, judgment, adoption, supervision, or consumption.

The resulting historical development creates several possible trajectories. AI can release human attention from routine execution and permit greater engagement with questions that carry intellectual or existential significance. It can expand the number of curiosities that individuals are practically able to pursue. It can also support institutional systems in which production continues at increasing scale while the relation between inquiry and particular human purposes becomes progressively indirect.

The relevant philosophical problem therefore concerns the relation among the ends of the epistemic system, the ends of institutions controlling its infrastructure, and the ends of the subjects whose lives are affected by its outputs.

The present paper does not prescribe a requirement that humans personally perform all knowledge-generating activities. Such a requirement would conflict with the distributed character of modern knowledge and with the emancipatory possibilities of delegation. The stronger analytical concern is whether social arrangements preserve sufficiently rich possibilities for subjects to develop questions, exercise judgment, revise their understanding, and enter generative relations with the worlds they inhabit.

Section 16 develops this problem through the Generative Relational framework. It distinguishes several forms of participation and generativity in order to analyze how epistemic delegation can produce expanded capacity, relational alienation, subject formation, and redistribution of generative experience within the same technological environment.

16 A Generative Relational Account of Epistemic Delegation

This section develops a Generative Relational account of epistemic delegation. Its objective is to describe how knowledge production, epistemic capacity, subject formation, and relational transformation can follow partially independent trajectories when inquiry is distributed across human subjects, artificial

agents, institutions, and technical infrastructures. The analysis proceeds from epistemic relations and delegated inquiry toward differentiated forms of participation, four dimensions of generativity, relational epistemic alienation, spatiotemporal integration, shared experience, transmission, relational provenance, and the redistribution of subject-formative activity. The method is relational and process-oriented. The analysis evaluates the generative trajectory through which an epistemic result emerges and the changes produced among participating subjects, objects, relations, and future possibilities. The amount of human manual execution and the amount of machine execution are therefore treated as variables within a wider relational system.

16.1 Knowledge through Generative Relations

This subsection establishes the relational starting point of the analysis. Within the present framework, knowledge production occurs through configurations of subjects, objects, representations, instruments, institutions, histories, questions, and practices. Epistemic resources acquire generative significance through the relations in which they become capable of producing subsequent questions, judgments, experiments, interpretations, or transformations.

A proposition stored within an archive possesses one form of epistemic existence. The same proposition encountered by a subject attempting to resolve a specific problem can acquire a different generative role. A method becomes epistemically consequential when it enters a trajectory of use. A historical record becomes generative when it enters interpretation, contestation, or reconstruction.

The relevant unit of analysis is therefore the generative relation through which epistemic resources become operative. This perspective extends the concept of knowledge capital developed earlier in the paper by examining the relations through which accumulated epistemic resources modify future possibilities.

16.2 Epistemic Encounter and Relational Transformation

This subsection examines epistemic encounter as an event capable of changing both knowledge and the configuration of the participating subject. An encounter can introduce evidence, contradiction, novelty, uncertainty, resistance, or a previously unavailable distinction. Its generative consequence depends upon how that encounter enters subsequent interpretation and action.

The process can alter what the subject knows while also altering what the subject becomes capable of noticing, questioning, evaluating, and pursuing. The epistemic trajectory therefore contains a transformation of relations rather than a transfer of informational content alone.

A simplified representation appears in Equation 40.

$$(S_t, K_t, \mathcal{R}_t) \rightarrow E_t \rightarrow (S_{t+1}, K_{t+1}, \mathcal{R}_{t+1}), \quad (40)$$

where S_t denotes the subject, K_t the available epistemic configuration, $\mathcal{R}_t$ the relevant relational configuration, and E_t an epistemic encounter. Equation 40 represents the possibility that inquiry modifies knowledge, subject, and relations within the same trajectory.

Artificial intelligence can participate in the encounter, mediate it, or perform portions of it on behalf of another subject. The subsequent distribution of transformation becomes the central analytical concern.

16.3 Delegation of Knowledge-Generating Relations

This subsection defines epistemic delegation through the transfer of particular operations or relations within an inquiry to another agent or infrastructure. Delegation can include retrieval, calculation, observation, experimentation, translation, criticism, interpretation, drafting, or coordination.

Delegation has long characterized knowledge production. Scientists rely upon instruments, laboratories, collaborators, technicians, prior literature, and specialized expertise. Artificial intelligence expands the range, continuity, and autonomy of activities that can be delegated.

The GR perspective therefore treats delegation as a reconfiguration of a generative system. The relevant questions concern which relations move to another agent, which remain with the human subject, which new relations emerge, and how the redistribution changes subsequent generativity.

Delegation can reduce unnecessary burdens, increase accessibility, expand empirical reach, and create new opportunities for reflection. It can also separate subjects from processes through which epistemic capacities and orientations would otherwise develop. These possibilities can coexist within the same technological arrangement.

16.4 Executorial Participation

This subsection defines *executorial participation* as the degree to which a subject directly performs the operations required for an epistemic process. Such operations can include calculation, transcription, coding, manipulation of instruments, data collection, drafting, or physical execution of an experiment.

Executorial participation is easily observable and consequently risks becoming an overly dominant measure of authorship or involvement. The preceding analysis shows that its theoretical significance is limited when considered in isolation.

A researcher can delegate extensive calculation and remain responsible for the problem, interpretation, criticism, and conceptual transformation. A disabled researcher or creator can delegate almost all physical execution to assistive systems while the resulting process remains deeply organized by that person's experience, questions, judgments, and history.

Executorial participation therefore constitutes one dimension of participation rather than a general measure of generative involvement.

16.5 Directional Participation

This subsection defines *directional participation* as involvement in determining the object, problem, priorities, and changing direction of an epistemic process.

Directional participation includes formulation of research problems, selection among possible trajectories, identification of relevant goals, and decisions concerning when an inquiry should be redirected or terminated.

A human participant can possess high directional participation while performing little execution. A principal investigator can formulate a question and coordinate a large team. A person using AI can determine the conceptual direction of a project while automated systems perform the majority of technical operations.

Directional participation can also become thin. A broad request such as producing an "important" result can provide initial direction while leaving the substantive organization of inquiry to external systems.

The degree of directional involvement therefore needs to be distinguished from the fact that a person initiated the process.

16.6 Reflective Participation

This subsection defines *reflective participation* as the degree to which a subject evaluates, questions, resists, interprets, revises, and reorganizes an ongoing generative process.

Reflective participation becomes especially important under AI mediation because generated outputs can be accepted, rejected, interrogated, compared, or transformed. The same technical system can therefore support substantially different epistemic trajectories depending upon the relation established by the human participant.

A highly reflective process can involve repeated counterargument, testing of assumptions, generation of alternative explanations, examination of failures, and modification of the original problem.

A weakly reflective process can preserve formal human approval while allowing the substantive sequence of judgments to remain primarily external.

Reflective participation therefore captures the recursive relation between machine-mediated output and subsequent human inquiry.

16.7 Existential-Generative Participation

This subsection defines *existential-generative participation* as the degree to which a subject's accumulated experiences, concerns, relationships, historical position, sensitivities, and transformations enter the generative trajectory of an epistemic or creative process.

This dimension concerns the historical subject from whom a question becomes salient. A research problem can emerge from a long encounter with a practical difficulty, an experience of injustice, a bodily condition, sustained observation, aesthetic wonder, or a conceptual tension developed over many years.

The resulting trajectory can remain strongly subject-integrated even when technical execution is extensively automated. The artificial system operates within a process whose direction and significance continue to be reorganized by a particular subject's history.

Existential-generative participation therefore supplies a deeper measure of involvement than manual production. It also provides a bridge between epistemology and the analysis of artistic or cultural creation developed later in the discussion.

16.8 Participation Configuration

This subsection combines the preceding dimensions into a provisional participation configuration. For a subject S , participation can be represented through Equation 41.

$$\mathbf{P}_S = \left(P_S^{\text{exec}}, P_S^{\text{dir}}, P_S^{\text{refl}}, P_S^{\text{exist}} \right), \quad (41)$$

where the components represent executorial, directional, reflective, and existential-generative participation. Equation 41 is a conceptual representation and does not presume a common quantitative scale among the four components.

This formulation allows substantially different processes to be distinguished. Two projects can involve comparable levels of AI use while possessing very different participation configurations. Likewise, two projects with similar human execution can differ sharply in reflection or existential integration.

The relevant analytical object is therefore the configuration of participation across a trajectory.

16.9 Subject-Integrated Generation

This subsection introduces *subject-integrated generation* as a process in which the subject's history, encounters, questions, judgment, and revision remain materially connected to the emergence of the resulting epistemic or creative artifact.

A schematic trajectory appears in Equation 42.

$$H_S \rightarrow E_S \rightarrow Q_S \rightarrow J_S \rightarrow \mathcal{M} \rightarrow O, \quad (42)$$

where H_S denotes the subject's accumulated history, E_S relevant encounters, Q_S questions, J_S continuing judgment, $\mathcal{M}$ the mediated generative process, and O the resulting output. Equation 42 permits $\mathcal{M}$ to include extensive artificial intelligence, robotics, collaboration, or other external execution.

Subject integration therefore concerns historical and generative connection. A highly automated artifact can remain deeply integrated into the trajectory of a subject when the mediated process repeatedly returns to the subject's experience and judgment.

A process can also exhibit weak subject integration when the human role becomes primarily initiation and reception. These configurations form a continuum rather than discrete categories.

16.10 Epistemic-Output Generativity

This subsection introduces the first of four dimensions of generativity. *Epistemic-output generativity* concerns the capacity of a process to produce additional epistemic resources.

An inquiry possesses high output generativity when it generates useful propositions, evidence, datasets, models, interpretations, methods, or other resources capable of entering subsequent epistemic activity.

AI can substantially increase output generativity through faster retrieval, parallel exploration, automated experimentation, and scalable production.

Output generativity is therefore an important social and scientific value. Its increase can improve medicine, engineering, public policy, science, and many other domains even when the corresponding human formative effects remain limited.

The GR account preserves this value while distinguishing it from the other forms of generativity developed below.

16.11 Epistemic-Capacity Generativity

This subsection defines *epistemic-capacity generativity* as the degree to which a process increases the future capacity of an actor or system to conduct additional inquiry.

A new instrument, method, model, dataset, research skill, or conceptual framework can increase subsequent productive possibilities even when its immediate epistemic output is modest.

Epistemic-capacity generativity corresponds closely to the capitalization process developed throughout the paper. Successful inquiry can alter the conditions under which later questions become practically pursuable.

AI infrastructure can generate substantial capacity gains by preserving workflows, models, experimental systems, or reusable agents whose productive effects continue across many subsequent tasks.

The relevant beneficiary can be an individual, institution, community, or technical system. Capacity generativity therefore requires specification of where the increase occurs.

16.12 Subject-Formative Generativity

This subsection defines *subject-formative generativity* as the degree to which participation in a process changes a subject's future capacities, judgment, orientation, sensitivities, or question space.

Learning, experimentation, interpretation, failure, dialogue, and sustained practice can all produce subject-formative effects. The subject emerges from the process capable of perceiving or pursuing possibilities that were previously unavailable.

This dimension is central to education and self-cultivation. It also gives epistemic activity significance beyond production of socially novel outputs.

Subject-formative generativity can remain high under intensive AI use when the system supports exploration, confrontation with alternatives, criticism, revision, or access to experiences otherwise unavailable.

It can remain low even in predominantly human activity when participation is highly routinized and generates little change in future capacity.

16.13 Relational Generativity

This subsection introduces *relational generativity* as the degree to which a process creates, transforms, or preserves relations capable of supporting further generative activity.

These relations can connect subjects with objects of inquiry, other persons, communities, practices, traditions, places, institutions, or future possibilities. Their value lies in opening or sustaining subsequent paths of formation and interaction.

An educational process can generate a durable relation between a student and a field. A collaborative project can create relations through which later research becomes possible. A cultural practice can preserve intergenerational relations that sustain future interpretation.

Relational generativity is particularly important for forms of knowledge whose continuity depends upon communities, mentorship, shared experience, or historically situated practices.

16.14 Generativity Configuration

This subsection combines the four dimensions into a provisional generativity configuration. Equation 43 represents the configuration associated with a process Π .

$$\mathbf{G}_{\Pi} = (G_{\Pi}^O, G_{\Pi}^C, G_{\Pi}^S, G_{\Pi}^R), \quad (43)$$

where G^O denotes epistemic-output generativity, G^C epistemic-capacity generativity, G^S subject-formative generativity, and G^R relational generativity. Equation 43 is an analytical decomposition rather than a proposal for immediate numerical measurement.

The four dimensions can move together or diverge. A traditional apprenticeship can generate moderate external output while producing substantial subject and relational generativity. A fully automated research pipeline can produce substantial output and infrastructural capacity while producing limited subject-formative effects for a particular human observer.

AI-mediated inquiry can also produce simultaneous increases across all four dimensions when external execution enlarges human exploration, learning, collaboration, and relational possibilities.

16.15 Decoupling of Generative Trajectories

This subsection examines the increasing possibility that the dimensions identified above follow different trajectories. Historically, many forms of human inquiry coupled production, learning, and transformation because the same subjects who investigated a problem also experienced much of the process through which its answer emerged.

Automation allows portions of this coupling to loosen. A research system can produce new knowledge and improve its own productive infrastructure while a human beneficiary experiences limited epistemic formation.

A representative configuration can be expressed by Equation 44.

$$\Delta G^O > 0, \quad \Delta G^C > 0, \quad \Delta G_{\text{human}}^S \approx 0. \quad (44)$$

Equation 44 represents one possible decoupling pattern in which output and capacity increase while subject-formative change for a particular human participant remains limited.

The equation does not evaluate the configuration by itself. A highly automated medical discovery can possess enormous social value even when few human participants undergo deep epistemic transformation.

The analytical purpose is to prevent increases in one dimension of generativity from being treated as evidence of increases in the others.

16.16 Relational Epistemic Alienation

This subsection develops the concept of relational epistemic alienation introduced in Section 13. Within the GR framework, alienation concerns attenuation of the generative relations through which a subject encounters, questions, interprets, and is transformed by an object of inquiry.

The concept therefore differs from technological delegation alone. A subject can remain strongly integrated into an inquiry through direction, reflection, interpretation, and historical significance even while execution occurs elsewhere.

Relational epistemic alienation becomes more pronounced when epistemic output continues to accumulate while the subject's generative participation becomes increasingly thin.

The relevant concern is a changing topology of relations. The subject remains connected to the output while losing substantial connection to the sequence of encounters, uncertainties, judgments, and revisions through which the output was generated.

This definition permits alienation to vary by degree and by dimension.

16.17 Spatiotemporal Integration of Epistemic Significance

This subsection examines how epistemic significance becomes integrated into the spatiotemporal trajectory of a subject. The same proposition or artifact can acquire substantially different significance depending upon the subject's history, relationships, location, and prior encounters.

A medical fact can be encountered as abstract information in one context and become existentially significant after illness enters a person's life. A legal principle can acquire different meaning after direct exposure to institutional injustice. Astronomical knowledge can become integrated into a subject's orientation through experiences of wonder or sustained observation.

The epistemic object therefore enters a relational history rather than an empty recipient.

AI can greatly expand access to representations and explanations. The spatiotemporal integration of their significance remains dependent upon the relations through which those resources enter particular lives.

This distinction provides one reason that informational equivalence does not guarantee experiential equivalence.

16.18 Subjective History in Generative Relations

This subsection develops subjective history as a generative variable. A subject's prior trajectory contributes to which differences become perceptible, which questions become compelling, and which outputs acquire significance.

The same AI-generated suggestion can therefore enter different generative processes for different users. One subject can treat it as a routine answer. Another can recognize a relation to a problem developed over many years and transform the suggestion into a new research program.

Subjective history also affects resistance. A person can challenge an apparently authoritative answer because prior experience reveals a discrepancy that the external system failed to represent.

The GR account therefore treats subjective history as part of the generative configuration rather than as background noise surrounding a supposedly pure epistemic process.

16.19 Shared Experience and Collective Epistemic Emergence

This subsection integrates the shared-experience model developed in Sections 4 and 10. Collective understanding can emerge when subjects with partially overlapping histories compare memories, interpretations, disagreements, and responses.

A shared event can generate heterogeneous experiences. Subsequent testimony, negotiation, comparison, and revision can produce a provisional collective understanding whose structure depends upon relations among those experiences.

AI can support preservation, translation, comparison, retrieval, and synthesis within this process. It can increase the number of testimonies that become available and reveal patterns difficult for individual participants to identify.

The machine-mediated synthesis nevertheless occupies a different historical position from the original event. The later system processes residues and representations of a relation that has already occurred.

The distinction concerns generative history rather than a permanent exclusion of artificial participants from collective knowledge.

16.20 Transmission and Relational Continuity

This subsection examines transmission across generations and participants. Knowledge can persist through texts and archives while practices, judgments, skills, or interpretive relations weaken.

Relational continuity concerns preservation of enough of the generative field for future subjects to enter a meaningful process of reconstruction, participation, correction, and development.

AI can strengthen relational continuity by preserving endangered materials, providing translation, reconstructing context, supporting instruction, and making dispersed resources discoverable.

The same technology can produce an appearance of complete preservation when only representational residues remain available. A tradition can be richly documented while communities, practices, places, and teacher–student relations through which its significance was reproduced continue to disappear.

Generative preservation therefore requires analysis beyond storage capacity.

16.21 Creative Mediation and Subject Participation

This subsection extends the GR framework from epistemic production to creative activity because the distinction clarifies the structure of AI mediation. Creative generation can involve extensive technical delegation while remaining deeply integrated into a subject's historical trajectory.

A person can use AI to generate images, music, prose, or other material while repeatedly selecting, rejecting, modifying, and redirecting outputs according to experiences and concerns formed elsewhere in life.

The degree of machine execution therefore provides limited information about the degree of subjective participation.

The same distinction applies directly to research. AI can perform coding, derivation, retrieval, experimentation, or drafting while the inquiry remains generated through a human subject's sustained questions, judgments, and revisions.

Creative mediation therefore supplies an illustrative case for the more general GR distinction between executional and generative participation.

16.22 Meaning Generation and Result Acquisition

This subsection distinguishes participation in the generation of significance from acquisition of an artifact carrying the appearance or social markers of significance.

A subject can request a “meaningful” work and accept successive outputs with minimal evaluation. The resulting artifact can still become meaningful to another observer, and it can possess substantial aesthetic quality. The originating subject's participation in the generation of that significance can nevertheless remain limited.

A similar structure can occur in knowledge production. A person can seek a novel theory, an influential article, or an intellectually prestigious result while delegating most of the questioning, counterargument, revision, and interpretive trajectory through which such a result emerges.

The distinction concerns the relation between desired outcome and generative history. Social recognition, epistemic validity, personal transformation, and historical participation can therefore diverge.

16.23 Relational Provenance

This subsection develops *relational provenance* as the history of generative relations through which an artifact, testimony, or epistemic object entered the world.

Conventional provenance records origin, authorship, custody, and alteration. Relational provenance additionally concerns relevant encounters, historical events, practices, relations, and subjective trajectories contributing to the artifact's significance.

A historical letter and an exact later reproduction can display identical symbols while possessing different relations to the event, writer, recipient, and historical field. A scientific notebook generated

during an experiment and a later synthetic reconstruction can convey similar information while possessing different evidential histories.

Relational provenance therefore becomes increasingly important when surface characteristics are inexpensive to reproduce.

The concept does not imply that historically original artifacts possess universally greater value. It specifies a dimension of difference that can matter epistemically, culturally, legally, or existentially.

16.24 Existential Formation through Contingent Encounter

This subsection examines contingent encounter as a source of subject formation. Some of the questions that organize a life emerge through events that were not selected in advance: illness, injustice, migration, love, loss, artistic experience, an unexpected observation, or an encounter with unfamiliar ideas.

Such events can reorganize the subject's question space and create new relations to knowledge.

Artificial systems can subsequently support extensive inquiry into these questions. The initial encounter and the later technical exploration therefore belong to the same generative trajectory even when their agents differ.

This structure provides another reason to avoid evaluating epistemic participation through direct execution alone. The generative source of an inquiry can lie within a history extending far beyond the operations performed during formal research.

16.25 Epistemic Relations and Subjective Continuity

This subsection examines epistemic relations as one family of relations through which a subject maintains and develops continuity across time. Long-term questions, intellectual practices, disciplinary commitments, and repeated encounters with particular objects can become part of how a person organizes a life.

Delegation can modify these relations. Automation can reduce time spent on routine operations and allow deeper engagement with enduring questions. It can also reduce direct participation in activities through which the relation was previously sustained.

The significance depends upon what replaces the delegated activity and how the subject reorganizes the resulting time, attention, and relations.

Epistemic activity therefore contributes to subjective continuity without exhausting the possible sources of such continuity.

16.26 Existential Witnessing beyond Epistemic Production

This subsection broadens the analysis beyond knowledge production. Human subjects participate in generative relations through care, friendship, love, art, ritual, political life, craft, bodily practice, place, nature, and ordinary shared experience.

These activities can form subjects even when they produce little formally recognized knowledge. Reduction in direct epistemic labor therefore does not determine the overall generativity of a human life.

Automation can release time from activities whose execution previously consumed substantial attention. That time can enter other forms of relational participation.

The concept of *existential witnessing* is used here provisionally for forms of attentive presence through which subjects encounter and participate in the world without requiring the encounter to become an epistemic product.

This broader field prevents the GR framework from reducing human flourishing to maximization of intellectual production.

16.27 Relational Redistribution of Subject Formation

This subsection introduces *relational redistribution of subject formation*. The concept describes a change in the distribution of relations through which a subject develops when some epistemic activities are delegated and time or attention becomes available for other forms of participation.

An automated workflow can reduce subject-formative activity within one epistemic domain while increasing opportunities for interpersonal, aesthetic, civic, contemplative, embodied, or other generative relations.

A different trajectory can occur when automation reduces epistemic participation and the released time becomes absorbed by additional production requirements, passive consumption, or other relations with weak formative effects.

The normative consequence therefore depends upon redistribution rather than the quantity of delegated labor alone.

This concept also preserves historical openness. Future human lives can become less centered on direct epistemic execution without becoming generatively poorer if alternative relations become sufficiently rich.

16.28 Alternative Generative Relations

This subsection identifies the plurality of relations capable of contributing to subject formation. Epistemic inquiry represents one important family. Interpersonal, artistic, religious, political, ecological, spatial, bodily, and practical relations provide additional pathways of transformation.

The GR perspective therefore avoids treating the preservation of human knowledge production as an absolute end. A society in which machines perform more scientific operations could still support rich human formation through other relational configurations.

The reverse possibility also remains open. High levels of knowledge production can coexist with impoverished relational conditions when human subjects are organized primarily around accelerated output, evaluation, and consumption.

The relevant analytical object is the total configuration of generative conditions surrounding subjects and communities.

16.29 Coexisting Emancipatory and Alienating Tendencies

This subsection examines the simultaneous presence of emancipatory and alienating tendencies within AI-mediated epistemic systems.

Automation can reduce barriers created by disability, language, geography, institutional exclusion, limited technical skill, or repetitive labor. It can allow a single subject to investigate questions previously requiring large organizations. It can expose individuals to counterarguments, distant disciplines, and unfamiliar cultural materials.

The same systems can deepen dependency upon external infrastructures, accelerate output expectations, thin participation, concentrate generative capacity, and separate human subjects from processes through which epistemic formation previously occurred.

These tendencies can coexist within one institution or even one individual's practice.

The GR analysis therefore evaluates changing relations and generative conditions rather than assigning a fixed emancipatory or alienating essence to the technology.

16.30 Historical Openness and Relational Revisability

This subsection places epistemic delegation within an historically open framework. The social organization of artificial intelligence remains revisable. Educational practices, ownership structures, research norms, interfaces, institutions, governance arrangements, and cultural expectations can change as the consequences of existing systems become more visible.

The future relation between humans and epistemic production is therefore not determined by current technical capabilities.

A configuration producing dependency or alienation in one historical context can be reorganized through new infrastructures, public institutions, cooperative arrangements, open systems, pedagogical practices, or alternative relations to work.

Relational revisability becomes a central criterion because generative systems require the capacity to respond to consequences that were difficult to predict in advance.

16.31 Generative Conditions for Continuing Becoming

This subsection synthesizes the normative orientation of the Generative Relational account. The objective is not to maximize the amount of knowledge personally produced by human beings. The relevant concern is whether social and technical arrangements preserve sufficiently rich conditions through which subjects and communities can continue to encounter difference, formulate questions, exercise judgment, undergo revision, participate in meaningful relations, and develop new possibilities.

AI can contribute substantially to these conditions. It can enlarge access, increase epistemic capacity, support disabled participants, expand empirical reach, facilitate dialogue across languages, and release attention from repetitive execution.

AI can also reorganize these conditions in ways that make generative relations increasingly dependent upon infrastructures controlled elsewhere or reduce the range of encounters through which subject formation occurs.

The central GR distinction therefore concerns the distribution of generativity. Output, capacity, subject formation, and relational transformation can be generated in different parts of the system and can follow different trajectories.

The degree of AI involvement is analytically distinct from the degree of subject participation in a generative process. A heavily mediated process can remain deeply subject-integrated, while a largely human-executed process can remain weakly generative for the participating subject.

The normative analysis consequently concerns the configuration and future revisability of generative relations. Preservation of human agency requires more than preservation of manual tasks. It concerns continued possibilities for subjects to form questions, contest outputs, integrate encounters into their histories, and participate in relations through which further becoming remains possible.

Section 17 turns from this relational account toward the distributional and normative consequences of AI-mediated knowledge-capital expansion. The next section examines access justice, capitalization justice, attention justice, generative extraction, infrastructural enclosure, and the conditions under which public epistemic resources contribute to asymmetrically controlled future generative capacity.

17 Justice under AI-Mediated Epistemic Capitalization

This section develops the justice implications of AI-mediated knowledge-capital expansion. Its objective is to distinguish several distributional dimensions that can diverge even within formally open knowledge systems: access to epistemic resources, capacity to capitalize upon those resources, effective visibility within attention-constrained environments, control over productive infrastructure, participation in epistemic labor, and the circulation of benefits generated from shared knowledge. The section proceeds from generative capacity and public knowledge toward access justice, capitalization justice, attention justice, infrastructural concentration, generative extraction, provenance, commons regeneration, and intergenerational considerations. The method is diagnostic and relational. Justice is examined through the distribution of conditions affecting future generativity rather than through equality of epistemic outputs alone [21, 29, 19].

17.1 Distribution of Generative Capacity

This subsection establishes generative capacity as the principal distributive object of the present analysis. Earlier sections showed that public knowledge can increase collective epistemic resources while actors remain highly unequal in their capacity to absorb, recombine, test, extend, and circulate those resources.

Justice therefore concerns more than the distribution of existing knowledge. It also concerns the distribution of conditions from which future knowledge can be generated.

These conditions include education, time, models, compute, laboratories, robots, datasets, institutional affiliation, language, networks, retrieval systems, visibility, and opportunities to participate in relevant communities or empirical environments.

A distributive analysis focused exclusively on current outputs can overlook large inequalities in future possibility. Two actors can possess access to the same article while facing radically different spaces of practically executable research.

Generative justice therefore requires attention to the structure of future epistemic possibility as well as the present distribution of informational resources.

17.2 Access Justice

This subsection defines *access justice* as the distribution of realistic opportunities to obtain epistemic resources required for participation in knowledge production, learning, judgment, or public life.

Access can concern publications, datasets, archives, educational materials, software, models, laboratories, institutions, communities, and other resources. Knowledge commons scholarship provides an important foundation for analyzing shared informational resources and the institutional arrangements supporting their use [29].

Access justice remains important under artificial intelligence because inaccessible resources cannot enter broad generative circulation. Paywalls, language barriers, inaccessible formats, institutional restrictions, and technical incompatibilities can all limit the usable epistemic field.

AI can improve access by translating, summarizing, explaining, searching, and adapting materials for users with different linguistic, cognitive, physical, or educational conditions.

The expansion of access, however, addresses one layer of epistemic justice. The ability to convert accessible knowledge into future generative capacity requires additional conditions examined below.

17.3 Capitalization Justice

This subsection defines *capitalization justice* as the distribution of realistic capacities to transform accessible epistemic resources into further questions, methods, experiments, interpretations, technologies, and durable productive capabilities.

Capitalization justice follows from the distinction between equal access and unequal practical capitalizability developed in Section 7. Actors possessing similar access can differ substantially in compute, training, time, institutional support, experimental infrastructure, and complementary capital.

The resulting inequality can be represented conceptually by Equation 45.

$$A_A(K) \approx A_B(K) \quad \text{while} \quad \Delta G_A(K) \gg \Delta G_B(K), \quad (45)$$

where $A_i(K)$ denotes access to epistemic resource K and $\Delta G_i(K)$ the resulting increase in generative capacity for actor i . Equation 45 represents a condition in which similar access produces highly unequal future productive effects.

AI can reduce capitalization inequalities by supplying low-cost translation, coding, explanation, simulation, and research assistance. The same technologies can enlarge inequality when the highest levels of productive capacity depend upon expensive models, compute, proprietary data, robotic systems, or specialized organizational infrastructure.

Capitalization justice therefore concerns the distribution of the means through which openness becomes practically generative.

17.4 Attention Justice

This subsection defines *attention justice* as the distribution of realistic opportunities for epistemic contributions to enter the attention fields through which future inquiry, evaluation, recognition, and public understanding are organized.

Section 12 showed that public availability does not guarantee effective visibility. Search, ranking, recommendation, citation, language, institutional prestige, and machine retrieval influence the probability that a resource becomes encountered.

Attention justice therefore concerns a distinct stage of epistemic circulation. A contribution can be accessible and technically retrievable while receiving very few opportunities to affect later inquiry.

This dimension becomes increasingly important under machine-scaled production. As epistemic output expands faster than human attention, the mechanisms that select which resources become visible acquire greater distributive significance [52, 28].

Attention justice does not require equal attention for every contribution. Relevance, quality, reliability, and context provide legitimate grounds for differential attention. The justice problem concerns structural conditions that systematically reduce realistic visibility for particular forms of knowledge independently of their epistemic significance.

17.5 Public Availability and Effective Visibility

This subsection examines the justice implications of the distinction between formal openness and effective epistemic presence. A public knowledge commons can expand substantially while attention remains concentrated around a small subset of contributions.

The relevant sequence is:

public availability → retrievability → visibility → attention → epistemic uptake.

Because this expression describes a conceptual sequence rather than a formal quantitative relation, it is retained in prose-level notation rather than treated as a separate model.

Justice can be affected at every transition. Poor metadata can reduce retrievability. Ranking systems can reduce visibility. Attention scarcity can reduce sustained engagement. Institutional conventions can reduce uptake even after a work is encountered.

The resulting problem is especially important for knowledge that depends upon slow production, minority languages, small communities, historical archives, or weakly connected institutions.

17.6 Machine-Scaled Production and Epistemic Crowding

This subsection examines epistemic crowding as a justice problem. AI can reduce the cost of producing polished epistemic artifacts, allowing individuals and organizations to generate substantially larger volumes of material.

This expansion can increase collective knowledge and widen opportunities for participation. It can also occupy shared attention environments at scales that are difficult for slower producers to match.

The distributive concern arises when the cost of producing additional output is borne primarily by the producer while part of the cost of evaluating, filtering, and navigating that output is distributed across the wider epistemic community.

Machine-scaled production can therefore create attention externalities. The consequences can include reduced discoverability of other work, increased review burdens, greater reliance upon automated filters, and intensified competition for ranking positions.

The justice issue concerns the distribution of these externalized costs and their effects on the future generativity of the commons.

17.7 Structural Attention Capture

This subsection examines structural attention capture as a distributive process. Attention can concentrate through ranking feedback, citation accumulation, institutional reputation, search optimization, recommendation systems, and machine retrieval without requiring deliberate suppression of alternatives.

Merton's analysis of cumulative advantage provides an established model for recursive inequalities in scientific recognition [43]. Digital infrastructures can extend such feedback through increasingly automated mechanisms of selection.

Structural attention capture matters for justice because resources that receive more visibility also receive more opportunities to generate citations, criticism, collaboration, funding, and further epistemic development.

Visibility therefore affects future generativity.

The distributive problem becomes especially significant when visibility is strongly influenced by prior capital, institutional prestige, output volume, or technical optimization rather than by epistemic significance alone.

17.8 Visibility Concentration and Recursive Advantage

This subsection examines the coupling between visibility and recursive epistemic advantage. A highly visible contribution can generate recognition, and recognition can increase subsequent visibility. Visibility can then contribute to funding, collaboration, authority, or inclusion in AI retrieval systems.

The resulting cycle can reinforce both epistemic and infrastructural inequalities.

A smaller or less established actor can therefore face a dual disadvantage: limited resources for producing knowledge at scale and limited opportunities for produced knowledge to enter high-attention channels.

This process links attention justice with capitalization justice. Reduced visibility can restrict the external recognition and complementary capital required for future expansion, while stronger capitalization capacity can finance greater visibility.

Justice analysis must therefore consider feedback among production, attention, recognition, and future productive capacity.

17.9 Epistemic Crowding-Out of Slow Knowledge

This subsection examines the vulnerability of slow and high-cost forms of knowledge under conditions of accelerated production. Longitudinal research, archival scholarship, fieldwork, cultural documentation, theoretical development, and research requiring sustained trust or participation can operate on temporal scales poorly aligned with rapid publication cycles.

The concern does not establish a general preference for slow production. High-speed research can be rigorous and socially valuable. The justice issue concerns whether shared attention infrastructures systematically privilege frequency, recency, or surface optimization in ways that reduce realistic encounter with knowledge whose generative process requires longer durations.

A decades-long research trajectory may produce relatively few artifacts while a machine-scaled system produces thousands within the same period. If visibility is strongly coupled to continuous output, the slower work can become functionally marginal despite remaining publicly available.

This condition can be described as attention-mediated crowding-out.

17.10 Recognition and Symbolic Authority

This subsection examines recognition as both an epistemic resource and a possible source of inequality. Recognition can appropriately follow sustained high-quality contribution. It can also become a recursively productive asset.

Bourdieu’s analysis of symbolic capital is useful for understanding how recognition can be converted into authority and other forms of capital [8]. Within epistemic systems, recognized actors receive more invitations, citations, collaboration opportunities, institutional access, and presumptive credibility.

Symbolic authority therefore affects the conditions under which later claims are heard and evaluated.

Justice concerns arise when authority becomes strongly disconnected from the generative history or epistemic quality of particular contributions, or when initial infrastructural advantages become amplified through recognition loops.

17.11 Framing and Definitional Power

This subsection examines the distributive consequences of framing and definitional power. A sufficiently visible framework can become the default language through which an object is described, measured, taught, and retrieved.

Such power influences future inquiry upstream from particular conclusions. It helps determine which distinctions become ordinary, which variables are measured, which questions appear legitimate, and which alternatives require additional effort to articulate.

AI-mediated synthesis can increase the importance of this process because many users increasingly encounter a field through compressed representations rather than through direct engagement with a wide underlying literature.

If highly visible framings become disproportionately represented in retrieval and synthesis, their conceptual position can reproduce itself across subsequent epistemic cycles.

Justice therefore concerns plurality within the conditions of question formation as well as distribution of completed answers.

17.12 Public Epistemic Inputs and Private Generative Gains

This subsection examines the distributional implications of commons-to-private capitalization. Publicly funded research, open publications, public datasets, open-source software, and other shared epistemic resources can enter privately controlled infrastructures that generate additional productive capacity.

The original public resource can remain available while the downstream capacity becomes substantially concentrated.

The political-economic sequence can be represented through Equation 46.

$$K_{\text{public}} \rightarrow I_A \rightarrow G'_A \rightarrow I'_A, \quad (46)$$

where I_A denotes infrastructure controlled by actor A , G'_A the resulting generative gain, and I'_A the strengthened infrastructure available for subsequent capitalization. Equation 46 highlights concentration of future capacity rather than privatization of the original input.

This process can generate substantial public benefits through innovation, products, services, or further research. Justice analysis therefore requires attention to circulation and return rather than a presumption that private capitalization is intrinsically wrongful.

The central issue concerns how public epistemic contribution relates to the distribution of downstream generative capacity and benefit.

17.13 Generative Extraction

This subsection develops *generative extraction* as a stronger relational category. The term applies when an actor derives substantial generative benefit from persons, communities, or commons while the productive relation weakens the conditions through which those sources can continue to generate value for themselves.

Generative extraction therefore concerns more than asymmetric benefit. Asymmetry can arise legitimately through specialization, investment, skill, or risk. The stronger concept requires attention to the effects of the relation on the future generativity of contributing sources.

Examples could include extensive appropriation of community knowledge without meaningful return to the conditions sustaining that knowledge, extraction of research labor while contributors remain unable to access the resulting infrastructure, or machine-scaled use of public knowledge that contributes to attention displacement of the communities from which the knowledge originated.

The concept remains diagnostic in the present paper. Establishing extraction in specific cases requires empirical analysis of contribution, control, effects, reciprocity, and alternative arrangements.

17.14 Enclosure of Epistemic Resources

This subsection distinguishes the first of several forms of epistemic enclosure. Resource enclosure concerns restricted access to knowledge, data, archives, software, or other epistemic materials.

Such enclosure can arise through property rights, contracts, institutional restrictions, technical barriers, paywalls, secrecy, or other access conditions.

Resource enclosure can sometimes support legitimate objectives including privacy, security, sustainability of production, or protection of sensitive communities. Justice therefore requires contextual evaluation.

The present framework treats resource enclosure as one dimension among several. Even a fully open resource environment can exhibit concentration at later stages of capitalization and attention.

17.15 Enclosure of Generative Capacity

This subsection defines *capacity enclosure* as concentration of control over infrastructures through which available knowledge becomes future productive power.

Models, compute, laboratories, robots, specialized datasets, agent orchestration, and large-scale experimental systems can all function as means of epistemic production.

Public access to upstream knowledge does not provide equivalent access to these downstream capacities.

Capacity enclosure therefore shifts the locus of concentration from knowledge itself toward the means through which knowledge is operationalized, recombined, tested, and extended.

This form of enclosure becomes increasingly important under AI because large differences in machine-scaled exploration can emerge even where the underlying scientific literature remains public.

17.16 Enclosure of Scalable Epistemic Encounter

This subsection examines control over the infrastructure required to generate large numbers of empirical encounters. Robotic laboratories, sensors, satellites, field platforms, instruments, autonomous vehicles, and experimental networks can convert capital into access to additional regions of empirical possibility.

An actor with greater control over these systems can test more hypotheses, sample more environments, conduct longer experiments, and generate larger streams of proprietary or strategically valuable evidence.

The resulting inequality concerns contact with reality at scale.

This form of enclosure therefore extends capacity enclosure into the empirical domain. Public theories can coexist with highly unequal capacities to expose those theories to systematic experimental challenge.

Justice analysis must consequently consider the distribution of empirical infrastructure alongside access to codified knowledge.

17.17 Enclosure of Epistemic Attention

This subsection develops attention enclosure as concentration within the infrastructures through which knowledge becomes effectively visible.

Search engines, recommendation systems, publication platforms, ranking systems, institutional evaluation mechanisms, and AI retrieval interfaces can all shape the probability that particular resources enter later epistemic relations.

Attention enclosure can occur without removal of alternatives. Its characteristic form is disproportionate occupation or control of pathways of encounter.

The resulting structure completes a three-layer distinction central to this paper:

1. enclosure of epistemic resources;
2. enclosure of generative capacity and scalable epistemic encounter;
3. enclosure of effective epistemic attention.

The three layers can coexist or develop independently. A knowledge system can be open at the first layer while highly concentrated at the second and third.

17.18 Infrastructural Justice

This subsection integrates the preceding forms of concentration through the concept of infrastructural justice. Epistemic infrastructures mediate the relations through which subjects access knowledge, transform it into further capacity, conduct empirical inquiry, and circulate resulting outputs.

Justice therefore concerns the architecture of these relations.

A public model, shared compute facility, community laboratory, open retrieval system, public archive, or interoperable research infrastructure can redistribute generative conditions even when the underlying epistemic resources have not changed.

Conversely, concentration of critical infrastructure can create dependence among actors who remain formally free to produce knowledge.

Infrastructural justice consequently directs analysis toward control, continuity, interoperability, accessibility, governance, and the distribution of future productive possibility.

17.19 Labor Justice and Epistemic Production

This subsection examines the relation between epistemic labor and the benefits generated through AI-mediated capitalization. Researchers, annotators, technicians, software maintainers, archivists, community participants, reviewers, and other contributors can participate in the generation of resources from which later infrastructures derive value.

The distribution of recognition, compensation, access, control, and future opportunity can differ substantially across these contributors.

Labor justice therefore requires attention to contribution and productive relations rather than authorship alone.

Automation also changes the organization of labor. Some repetitive tasks can be reduced, while new tasks emerge around supervision, evaluation, data curation, model interaction, system maintenance, and verification.

The justice implications depend upon how productivity gains and new dependencies are distributed across participants.

17.20 Justice and the Epistemic Proletariat

This subsection connects the justice analysis with the epistemic-proletarian position developed in Section 11. A researcher can possess high generative capacity while lacking stable control over models, compute, laboratories, platforms, or attention infrastructure.

The resulting position can combine empowerment with dependency.

Justice therefore concerns the conditions under which productive actors can maintain, reproduce, revise, and redirect their own generative capacities.

A system can provide extraordinary access to powerful tools while exposing users to abrupt changes in price, availability, governance, or permitted use. Productivity gains can therefore coexist with generative precarity.

The epistemic-proletarian concept directs attention toward this combination of capacity and dependence.

17.21 Recognition, Attribution, and Relational Provenance

This subsection examines recognition and attribution under increasingly distributed and synthetic production. Section 16.23 introduced relational provenance as the generative history through which an artifact or epistemic object entered the world.

Justice can depend upon preserving relevant portions of this history. A final artifact can incorporate public knowledge, community experience, human questions, machine-generated material, institutional resources, and technical labor.

Simple attribution to a single visible producer can therefore conceal the relational field from which the artifact emerged.

Recognition practices can support justice by making significant contributions and historical relations legible. The appropriate level of granularity depends upon the domain and practical context.

Provenance also matters for evaluation. Under synthetic abundance, knowledge of how an artifact was generated can become increasingly important for interpreting its evidential, cultural, or historical significance.

17.22 Generative Return

This subsection introduces *generative return* as the circulation of resources or capacities back toward the persons, communities, institutions, or commons contributing to a generative process.

Generative justice emphasizes the circulation of value toward the communities from which it arises [19]. Within epistemic systems, return can take many forms: open publication, infrastructure, funding, training, attribution, data access, technical capacity, preservation, community support, or participation in governance.

Generative return therefore differs from simple redistribution of completed outputs. Its stronger form improves the future capacity of contributing participants to continue generating value on their own terms.

The appropriate form of return will vary across domains. A universal formula would overlook differences among scientific research, cultural knowledge, public data, indigenous knowledge, open-source communities, and commercial innovation.

The concept is therefore used here as a normative direction for later analysis rather than a complete distributive rule.

17.23 Commons Regeneration

This subsection examines the capacity of epistemic systems to reproduce and expand the commons from which they draw. Public knowledge becomes more durable when successful capitalization contributes additional knowledge, tools, institutions, preservation, education, or infrastructure to shared generative conditions.

A regenerative cycle can therefore involve both individual accumulation and commons expansion.

The concern arises when capitalization repeatedly draws from public resources while downstream generative capacity and attention become concentrated in ways that weaken future participation by other actors.

Commons regeneration consequently requires analysis of feedback. The relevant question concerns whether present uses enlarge, maintain, or degrade the conditions from which future participants can generate knowledge.

This perspective extends commons analysis from preservation of shared resources toward preservation of shared generative capacity [29].

17.24 Intergenerational Epistemic Justice

This subsection examines justice across temporal generations of knowers. Current epistemic systems inherit accumulated knowledge, institutions, languages, archives, methods, and infrastructures produced by earlier generations.

Present actors also shape the epistemic field available to future participants.

Intergenerational justice therefore concerns preservation of more than data. Future subjects require realistic opportunities to retrieve, interpret, question, contest, and extend inherited knowledge.

Machine-scaled production can improve preservation by increasing indexing, translation, reconstruction, and redundancy. It can also produce overwhelming volumes of material whose future navigation becomes increasingly dependent upon proprietary retrieval systems.

The intergenerational problem therefore concerns the legibility and generativity of inherited epistemic fields.

Slow, minority, culturally situated, and historically accumulated knowledge can require particular attention because loss of communities, languages, practices, or provenance can become difficult to reverse even when documentary residues survive.

17.25 Publicly Derived Generative Capacity

This subsection identifies publicly derived generative capacity as an important object for future governance analysis. AI infrastructures can be constructed through combinations of public knowledge, private investment, collective labor, open software, public research funding, user interaction, and proprietary engineering.

The resulting capacity therefore has a relational provenance that can cross conventional public-private boundaries.

Normative analysis must consequently consider several questions together: which resources contributed to the capacity, which actors bore costs, who controls the resulting infrastructure, which benefits return to contributors, and how the arrangement affects the future generativity of the wider commons.

These questions cannot be resolved solely by identifying legal ownership.

The relevant object is the complete generative relation through which productive capacity emerged and continues to reproduce itself.

17.26 Governance as an Open Problem

This subsection defines the boundary between the diagnostic contribution of the present paper and the institutional questions reserved for later work. Knowledge-capital expansion creates tensions among openness, innovation, productive scale, attention scarcity, infrastructural concentration, and the preservation of heterogeneous generative conditions.

Several governance problems follow.

A public knowledge commons must accommodate large-scale epistemic production while maintaining realistic possibilities of encounter for slower, minority, historically accumulated, and less infrastructurally advantaged knowledge. Collective attention must be allocated under conditions in which output can expand far more rapidly than human evaluative capacity. Public epistemic resources can contribute to privately controlled infrastructures whose social benefits and generative returns vary across cases.

Possible institutional responses could involve publication systems, retrieval design, public infrastructure, interoperability, attribution practices, funding, commons governance, competition policy, licensing, education, or other arrangements.

The present paper does not select among these instruments. Their consequences can include tradeoffs among innovation, openness, pluralism, administrative burden, freedom of inquiry, sustainability, and accessibility.

The appropriate governance architecture therefore constitutes a separate research problem requiring empirical, jurisprudential, ethical, and institutional analysis.

17.27 Justice within Knowledge-Capital Expansion

This subsection synthesizes the justice framework developed throughout the section. AI-mediated knowledge-capital expansion can increase collective epistemic resources while distributing access, capitalization capacity, attention, infrastructure, recognition, and subject-formative opportunities unequally.

These dimensions should remain analytically distinct.

Access justice concerns who can obtain epistemic resources. Capitalization justice concerns who can convert those resources into future generative capacity. Attention justice concerns whose contributions possess realistic opportunities to enter subsequent epistemic relations. Infrastructural justice concerns control over the systems through which knowledge is produced, encountered, tested, and circulated.

Generative extraction concerns relations in which the accumulation of one actor weakens the continuing generative conditions of contributing sources. Generative return and commons regeneration concern circulation that strengthens those conditions.

The resulting framework avoids identifying openness with complete epistemic justice. A corpus can remain public while capacity and attention become highly concentrated. It also avoids treating concentration as intrinsically unjust. Large-scale infrastructure can create substantial collective benefits, and specialization can generate legitimate asymmetries.

The normative issue concerns how asymmetries affect participation, dependency, future possibility, recognition, revisability, and the regenerative conditions of the wider epistemic field.

From a Generative Relational perspective, justice therefore concerns the distribution and reproduction of conditions through which heterogeneous subjects and communities can continue to participate in knowledge generation, enter future epistemic relations, and revise the structures shaping those relations.

The analysis remains intentionally incomplete at the level of institutional prescription. The present paper identifies the justice dimensions generated by AI-mediated epistemic capitalization and establishes the conceptual vocabulary required for later work in generative ethics, jurisprudence, governance, and commons design.

Section 18 next integrates the political-economic, epistemological, educational, relational, and justice analyses. It considers the broader transformation produced when public knowledge, machine-scaled productive capacity, scarce attention, delegated inquiry, and human subject formation become increasingly differentiated components of the same epistemic system.

18 Discussion

This section integrates the political-economic, historical, epistemological, educational, relational, and justice analyses developed throughout the paper. Its objective is to identify the broader transformation represented by AI-mediated knowledge-capital expansion and to clarify the tensions that remain open after the preceding conceptual analysis. The discussion proceeds through historical continuity, industrialization of epistemic production, public knowledge and private generative capacity, epistemic labor, attention, subject formation, shared experience, relational provenance, creative production, slow knowledge, and the coexistence of emancipatory and alienating tendencies. The method is synthetic. The section does not introduce a new normative system; it examines how the concepts developed in earlier sections interact when applied to the emerging organization of knowledge production.

18.1 Historical Continuity and Contemporary Transformation

The analysis developed in Section 6 places artificial intelligence within a much longer history of epistemic externalization. Writing, archives, printing, libraries, universities, scientific journals, databases, search systems, and computational infrastructure progressively expanded the extent to which epistemic resources could persist beyond the immediate subjects and situations through which they emerged.

Artificial intelligence continues this historical development while changing its productive structure. Earlier infrastructures primarily increased preservation, reproduction, organization, retrieval, or bounded forms of calculation. Contemporary systems increasingly participate in extended sequences of epistemic operations, including question generation, literature search, hypothesis formation, experimentation, analysis, criticism, and writing [37, 23, 14].

The resulting transformation is therefore neither a complete historical rupture nor a simple continuation. Its significance lies in the degree to which external epistemic infrastructure can participate recursively in producing its own subsequent inputs.

Knowledge externalization increasingly includes the externalization of knowledge-generating operations.

18.2 Industrialization of Epistemic Production

Sections 8 and 9 described the technical conditions under which knowledge production can become increasingly scalable, repeatable, parallelizable, and partially autonomous.

The resulting development resembles industrialization at the level of epistemic production. Models preserve reusable computational capacities. Agents coordinate specialized operations. Compute supports parallel trajectories. Automated evaluators filter intermediate results. Robotic systems extend machine execution into empirical environments. Successful outputs can re-enter later cycles as data, methods, models, or infrastructure.

The resulting productive unit increasingly exceeds the individual researcher. It can consist of an integrated system of humans, models, software, databases, retrieval systems, instruments, laboratories, and institutional resources.

This transformation changes the scale at which epistemic capitalization becomes possible. A single question can be expanded into large populations of candidate hypotheses, simulations, counterarguments, or physical experiments. Differences in infrastructure therefore become differences in the number and diversity of epistemic trajectories that can be practically explored.

The political-economic importance of this transformation lies in the conversion of capital into epistemic search space.

18.3 Public Knowledge and Machine-Scaled Capitalization

The public knowledge commons acquires new significance under this industrialized structure. Public knowledge supplies a historically accumulated field of theories, methods, data, code, observations, and questions that can be processed at increasing computational scale [29].

The resulting change concerns practical capitalizability. A corpus that previously required years of specialized reading can increasingly be searched, translated, summarized, compared, and operationalized through machine-mediated infrastructure.

This development can democratize knowledge. Individuals and small groups can gain access to forms of interdisciplinary assistance, translation, coding, and analysis previously available only through larger organizations.

The same development can increase the value of complementary infrastructure. Actors controlling more capable models, compute, laboratories, data pipelines, robotics, or agent systems can capitalize upon the same public corpus at substantially greater scale.

The resulting tension can therefore be summarized as an expansion of public epistemic inputs accompanied by potential concentration of machine-scaled generative capacity.

This is the openness–concentration dynamic developed throughout the paper.

18.4 Knowledge Capitalists and the Epistemic Proletariat

The Marxian analysis provides a vocabulary for distinguishing the dynamic of knowledge-capital expansion from the relational positions through which that expansion is organized.

A knowledge-capitalist position concerns substantial control over important conditions of epistemic production. An epistemic-proletarian position concerns meaningful generative capacity combined with limited control over the principal conditions required to reproduce or scale that capacity.

These positions should not be reduced to occupational categories. A highly productive researcher can occupy a dependent position with respect to model, compute, laboratory, platform, or institutional infrastructure. Conversely, an actor with limited direct epistemic expertise can control extensive means of knowledge production.

The most important contemporary possibility is therefore not simply technological displacement of researchers.

A researcher can become substantially more productive while simultaneously becoming more infra-structurally dependent.

This combination distinguishes the emerging epistemic proletariat from an image of technological exclusion. The subject can possess abundant knowledge, strong judgment, and powerful tools while remaining unable to reproduce the same generative capacity independently of infrastructures controlled elsewhere.

18.5 Attention as a Second Scarcity

Knowledge-capital expansion transforms scarcity rather than eliminating it. Digital reproduction reduces the scarcity of many informational resources, while machine-generated production can reduce the scarcity of polished epistemic output.

Human attention remains limited [52, 28].

The resulting problem is increasingly one of selection. Public knowledge must pass through search, ranking, recommendation, citation, machine retrieval, and human attention before it becomes actively incorporated into later inquiry.

This condition changes the political economy of openness. A resource can remain public while becoming functionally absent from the active epistemic field. Formal accessibility therefore provides weaker evidence of effective participation as the surrounding volume of output increases.

The resulting distinction among availability, retrievability, visibility, attention, and uptake is central to the contemporary public knowledge commons.

The same transformation also changes the value of visibility. Attention can generate recognition, recognition can generate symbolic authority, and symbolic authority can influence the frames through which future questions are formulated.

Epistemic power can therefore operate through occupation of attention as well as control of information.

18.6 Visibility, Authority, and Definitional Power

Section 12 showed that repeated visibility can become recursively connected with recognition and authority. Such authority can be epistemically justified when it reflects reliable expertise. It can also be reinforced by infrastructures that repeatedly expose users to already visible sources.

The strongest consequence arises when a highly visible framework becomes the default conceptual interface through which an object is encountered.

At that point, attention can contribute to framing power and eventually to definitional power.

The relevance to AI-mediated knowledge systems is substantial. A user receiving a synthesized response can encounter the representation selected by a retrieval and generation pipeline without seeing the diversity of alternative frameworks present in the underlying literature.

The problem therefore extends beyond misinformation. A synthesis can be accurate within a dominant framework while still narrowing the conceptual space through which the object becomes intelligible.

Plurality in future knowledge systems consequently concerns diversity of questions and frames as well as diversity of completed answers.

18.7 Production of Knowledge and Formation of Knowers

One of the central distinctions developed in this paper concerns the separation between knowledge production and epistemic formation.

A research system can produce a valid result while a particular human subject undergoes little transformation. Conversely, a learner can reconstruct a centuries-old result and undergo substantial epistemic development while adding almost nothing to the global stock of knowledge.

AI makes this distinction increasingly visible.

The quality of an externally produced answer therefore cannot be used as a measure of the formative process experienced by the human recipient.

This point has direct educational implications. The reduction of answer cost can be highly beneficial while leaving unresolved how learners develop judgment, problem formation, practical competence, resistance to error, and the capacity to pursue future inquiry independently.

The educational object must therefore be specified explicitly.

When the objective is practical access to an answer, extensive delegation can be appropriate. When the objective is formation of a particular capacity, the same delegation can bypass the relation through which that capacity would have developed.

18.8 Curiosity and Human Epistemic Participation

Curiosity provides one important connection between epistemic production and the situated life of a subject. Questions can emerge from uncertainty, practical difficulty, surprise, care, wonder, perceived injustice, bodily vulnerability, or other encounters that become significant within a particular history.

The present paper has treated this point narrowly because a fuller analysis of the existential origins of curiosity lies beyond its primary scope.

Its relevance here is structural. Human epistemic participation can involve a recursive trajectory in which encounters generate questions, answers generate further questions, and inquiry changes the subject capable of asking them.

Machine systems can also generate productive questions. The important distinction therefore concerns question production and question emergence within a situated subject.

The two can interact productively. An artificially generated question can enter a human trajectory and become deeply generative when it produces surprise, resistance, interpretation, or further inquiry.

The continued significance of human curiosity therefore does not depend upon maintaining a monopoly over question generation. It depends upon preserving relations through which questions continue to matter and transform the subjects who pursue them.

18.9 Execution and Generative Participation

The distinction between executional participation and generative participation is one of the most important implications of the GR analysis.

The amount of work physically or textually executed by a human does not determine the degree to which that human participates in the generative history of an epistemic or creative process.

This distinction becomes particularly clear in assistive uses of artificial intelligence. A subject can delegate typing, drawing, coding, calculation, instrument control, or other executable operations while remaining deeply present through experience, intention, judgment, resistance, selection, and revision.

The inverse configuration is equally possible. A person can perform many operations manually while participating weakly in the formulation, evaluation, or transformation of the process.

The binary category of human-made versus AI-made therefore obscures the more important relational question.

The relevant issue concerns how the subject enters the generative trajectory.

This conclusion applies both to knowledge production and to creative activity.

18.10 Creative Production and Subjective Historical Participation

Creative production provides a useful parallel because questions of authorship and significance become especially visible when artificial systems perform substantial execution.

An artwork can emerge through extensive AI mediation while remaining deeply connected to a subject's memories, bodily condition, relationships, experiences, aesthetic judgment, and continuing revisions.

The resulting artifact can therefore be highly subject-integrated despite low manual execution.

A different process can begin with a request for a conventionally "meaningful" artifact and proceed through repeated acceptance of externally generated outputs. The resulting work can still become meaningful to an audience. Its significance for the originating subject can nevertheless have a different generative history.

The relevant distinction concerns participation in meaning generation and acquisition of an output carrying the appearance or social recognition of meaning.

An analogous separation can occur in research when a subject seeks the status of producing an important theory while delegating most of the questioning, counterargument, failure, and revision through which the theoretical object emerges.

The distinction concerns generative history rather than technological purity.

18.11 Artifact Appearance and Generative History

Synthetic production makes the relation between surface appearance and generative history increasingly important.

A polished article, image, argument, or musical work can be generated through substantially different trajectories while displaying similar formal characteristics.

This reduces the amount of information that surface sophistication provides about the process underlying an artifact.

Generative history can nevertheless matter independently of appearance. A historical document produced during an event and an exact later simulation of that document occupy different relations to the event. A testimony generated from a survivor's experience and a formally similar synthetic narrative possess different historical indexing.

The same principle applies more subtly to creative and epistemic artifacts. Their significance can partly depend upon the trajectory through which they entered the world.

This is the role assigned to relational provenance in the GR framework.

Under conditions of synthetic abundance, provenance can become increasingly important precisely because formal resemblance becomes cheaper to produce.

18.12 Shared Experience and Future Knowledge Systems

The analysis of differential automation showed that some forms of knowledge depend materially upon shared experience, participant history, or relational continuity.

A shared historical event can produce heterogeneous experiences whose later comparison contributes to collective understanding. A community can maintain knowledge through repeated practice, correction, narration, and intergenerational transmission.

Artificial intelligence can assist these processes substantially. It can preserve records, translate testimony, connect dispersed archives, compare large collections, and make endangered materials more discoverable.

These capacities should not be underestimated.

The limitation concerns the distinction between representation of a historical trajectory and participation in that trajectory. A later system can reconstruct and interpret records of an event while occupying a different historical position from the participants whose experiences generated the records.

This distinction does not establish human exclusivity over relational knowledge. Future artificial agents can themselves participate in events and develop histories within particular systems.

The analytical point is that trajectories belong to particular participants and cannot be transferred merely through informational reproduction.

18.13 Transmission and Relational Continuity

Cultural, professional, and religious transmission further illustrates the limits of equating public documentation with preserved knowledge.

A tradition can possess publicly accessible canonical texts while the practices, languages, interpretive relations, teacher–student structures, communities, or places through which those texts were historically understood become weakened.

Archival preservation can therefore succeed while generative continuity declines.

AI can improve both sides of this relation by preserving materials and by providing new forms of instruction, reconstruction, and connection. The technology can become part of the relational infrastructure through which a practice survives.

The relevant question is therefore how transmission is reorganized.

A synthetic explanation of a tradition and participation in an evolving community can provide different epistemic relations, even when both contribute to learning.

Future systems of cultural preservation will need to distinguish preservation of artifacts from preservation of the relations through which future subjects can continue to generate meaning from them.

18.14 Slow Knowledge under Machine-Scaled Production

Machine-scaled epistemic production creates a temporal mismatch with forms of knowledge that develop slowly.

Longitudinal research, extended fieldwork, historical scholarship, trust-based community research, difficult experiments, and long-term theoretical development can require years or decades before producing mature outputs.

The resulting work enters an attention environment increasingly populated by artifacts generated at much shorter intervals.

The danger is not that rapid production is intrinsically superficial. AI-assisted research can be both fast and rigorous.

The concern is that visibility systems can become increasingly coupled to frequency, recency, formatting, and machine-readable signals of relevance. Slow research can therefore experience attention disadvantage even when its substantive quality remains high.

This possibility reinforces the need to distinguish quality, perceived quality, visibility, and generative history.

A public knowledge commons can preserve slow research materially while allowing its practical probability of encounter to decline.

18.15 AI Abundance and Situated Experience

The increasing abundance of generated information can alter the relative scarcity of other epistemic resources.

When sophisticated prose, summaries, diagrams, explanations, and candidate theories become inexpensive, situated experience, longitudinal observation, relational trust, historical participation, rare empirical access, and provenance can become comparatively more important.

This does not imply a universal shift toward experiential knowledge. Many scientific problems remain primarily constrained by computation, formal analysis, or instrumentation.

The broader point is that automation changes the scarcity structure of epistemic production.

Resources that were previously expensive can become abundant, while others remain resistant to rapid reproduction.

The political economy of future knowledge will therefore depend upon the interaction between machine-abundant symbolic production and forms of epistemic participation whose relevant histories cannot be generated instantaneously.

18.16 Alienation and Relational Redistribution

The concept of relational epistemic alienation identifies one possible consequence of extensive delegation: epistemic production continues while the human subject becomes increasingly detached from the generative relations through which inquiry unfolds.

This possibility should not be interpreted as a general argument against automation.

Delegation can remove repetitive labor, increase accessibility, expand empirical reach, and allow subjects to redirect time toward deeper reflection or other generative relations.

The wider question therefore concerns relational redistribution.

A decline in direct epistemic execution can be accompanied by greater participation in art, care, community, political life, embodied practice, nature, or other forms of human relation.

A different institutional structure can transform productivity gains into higher output expectations, leaving little time for either epistemic formation or alternative forms of participation.

The same technological capability can therefore support substantially different existential trajectories.

The evaluation of automation requires attention to what forms of relation replace the activities being delegated.

18.17 Emancipatory and Alienating Tendencies

The analysis throughout this paper reveals no single directional effect of artificial intelligence upon epistemic life.

AI can reduce language barriers, assist disabled subjects, democratize access to technical expertise, allow independent researchers to explore larger problem spaces, support cultural preservation, accelerate scientific discovery, and release time from repetitive execution.

It can also deepen dependency upon concentrated infrastructure, increase output pressures, amplify attention inequality, accelerate recursive advantage, and separate human subjects from the processes through which knowledge and judgment are formed.

These tendencies can coexist.

The important distinction is therefore between technological capability and the relations through which capability becomes socially organized.

Historical outcomes depend upon institutional design, ownership, education, norms, funding structures, commons governance, platform architecture, and the practices through which human subjects integrate artificial systems into their own epistemic trajectories.

18.18 Public Knowledge and Generative Justice

The justice analysis developed in Section 17 can now be placed within the complete structure of knowledge-capital expansion.

Public knowledge can increase collective generativity while supporting unequal private capitalization. Machine-scaled production can increase the quantity of shared knowledge while crowding the attention environment. Infrastructure can expand access while creating new dependencies.

Justice therefore cannot be reduced to a single distributive variable.

Access justice concerns whether resources can be obtained. Capitalization justice concerns whether subjects possess realistic capacities to transform those resources into future generativity. Attention justice concerns whether their contributions possess realistic opportunities to enter future epistemic relations. Infrastructural justice concerns control over the systems through which these processes occur.

Generative return adds a temporal dimension. The relevant issue is whether successful capitalization strengthens or weakens the generative conditions of the commons and communities from which it draws [19].

The resulting perspective is compatible with unequal outcomes and specialized institutions. Its normative concern is the reproduction of conditions through which heterogeneous actors can continue to generate, contest, and revise knowledge.

18.19 Historical Openness of the Emerging Epistemic System

The contemporary epistemic system remains historically open.

The technical capacities described in this paper do not determine a fixed social arrangement. Models can be proprietary or open. Compute can be privately controlled or publicly provided. AI can substitute for educational processes or serve as a scaffold within them. Retrieval systems can reinforce dominant visibility patterns or deliberately broaden discovery. Automation can increase output demands or create additional time for other forms of inquiry and life.

The GR perspective therefore resists both technological optimism and technological pessimism.

The relevant question concerns the changing generative conditions produced by particular arrangements.

A system should be examined through the relations it creates, the capacities it concentrates or distributes, the questions it makes possible, the forms of participation it enables, the dependencies it produces, and its capacity for later revision.

This historical openness also limits the conclusions that can responsibly be drawn from the present analysis. Many institutional consequences of machine-scaled epistemic production remain empirical questions.

18.20 Synthesis of the Present Inquiry

The analysis developed throughout the paper supports several connected conclusions.

Modern knowledge systems have progressively externalized epistemic resources and productive capacities. Artificial intelligence accelerates this process by making increasingly extended sequences of epistemic operations computationally executable.

Public knowledge thereby acquires greater practical capitalizability, while the capacity to capitalize upon it remains distributed unevenly across models, compute, institutions, laboratories, robotics, attention, and other complementary resources.

Knowledge-capital expansion can therefore increase collective epistemic capacity while simultaneously generating recursive concentration.

The human consequences are equally differentiated. AI-mediated production can increase output without producing equivalent human understanding. Extensive delegation can coexist with deep subject participation, while extensive human execution can coexist with weak generative involvement. Differ-

ent forms of knowledge also possess different automation profiles because operator identity, relation, participant history, and shared experience can enter the epistemic process to different degrees.

The GR framework consequently distinguishes epistemic-output, epistemic-capacity, subject-formative, and relational generativity. Their trajectories can diverge.

Justice under these conditions concerns access to knowledge, capacity to capitalize upon knowledge, visibility within scarce attention environments, control over productive infrastructure, recognition of generative provenance, and regeneration of the commons.

The resulting transformation is therefore larger than an increase in the speed of knowledge production. It reorganizes the relations among public knowledge, capital, infrastructure, attention, epistemic labor, empirical encounter, human formation, and future possibility.

Section 19 identifies the principal empirical, theoretical, methodological, and governance questions that remain unresolved by the present foundational analysis.

19 Open Problems and Research Directions

This section identifies the principal theoretical, empirical, methodological, and institutional questions left unresolved by the present analysis. Its objective is to convert the conceptual distinctions developed throughout the paper into a research agenda without prematurely specifying normative or governance solutions. The section proceeds from measurement of epistemic capitalization and generativity toward differential automation, subject formation, attention, visibility, provenance, infrastructural concentration, labor relations, commons regeneration, and institutional design. The method is programmatic. Each problem is formulated as a domain requiring further conceptual clarification, empirical investigation, or interdisciplinary analysis.

19.1 Measurement of Epistemic Capitalization

The first research problem concerns measurement of epistemic capitalization. The present paper defines capitalization as a transformation through which epistemic resources increase future generative capacity. Operationalizing this concept requires identification of observable indicators that distinguish short-term output gains from durable changes in productive possibility.

Possible dimensions include expansion of accessible question space, reduction in the cost of investigating a problem, increase in cross-domain reach, improvement in evaluative capacity, access to additional empirical environments, and persistence of reusable infrastructure.

Measurement must also remain sensitive to the beneficiary of capitalization. A process can increase the generative capacity of an individual, laboratory, firm, public institution, model ecosystem, or wider epistemic commons by different amounts.

Future empirical work should therefore distinguish the location, duration, and transferability of capitalization gains.

19.2 Measurement of Capitalization Asymmetry

A second problem concerns the empirical measurement of capitalization asymmetry. Equal access to a public resource can generate highly unequal future productive effects, yet those effects can be difficult to observe directly.

Relevant variables can include prior knowledge, compute, time, language, institutional affiliation, funding, model access, laboratory infrastructure, network position, and visibility.

Longitudinal research is especially important because small initial differences can become amplified across recursive cycles. Cross-sectional comparisons can therefore underestimate the historical effects of unequal capitalization capacity.

Future work could examine how identical or comparable public epistemic inputs produce different trajectories across independent researchers, universities, firms, countries, or communities.

19.3 Measurement of Generativity Dimensions

The four-part distinction among epistemic-output, epistemic-capacity, subject-formative, and relational generativity requires further conceptual and empirical development.

Output generativity is comparatively observable through produced knowledge, methods, data, or other epistemic artifacts. Capacity generativity requires measurement of changes in future productive capability. Subject-formative generativity concerns changes in judgment, sensitivity, question formation, and future inquiry. Relational generativity concerns creation or preservation of relations capable of supporting subsequent generative activity.

These dimensions can interact while remaining non-equivalent.

Future work should examine whether reliable qualitative or quantitative indicators can be developed without collapsing heterogeneous forms of generativity into a single metric.

19.4 Participation under Epistemic Delegation

The distinction among executional, directional, reflective, and existential-generative participation requires further refinement.

A major methodological problem concerns how participation can be inferred from observable traces. Amount of manual labor, prompt count, interaction time, or number of revisions provides only partial evidence of the subject's generative involvement.

A short intervention can radically redirect an inquiry, while a long sequence of mechanical operations can contribute little to its conceptual structure.

Future research should therefore examine process histories, decision points, revision trajectories, provenance records, and participant accounts to develop more adequate descriptions of generative participation.

This problem is relevant to scientific authorship, education, artistic creation, intellectual property, evaluation, and research ethics.

19.5 Differential Automation across Epistemic Processes

The classification developed in Section 10 requires systematic testing across empirical domains.

Operator-invariant, operator-sensitive, relation-dependent, and participant-constitutive processes were introduced as analytical classes. Their boundaries can vary according to research purpose, methodology, and historical context.

Future studies should examine particular epistemic operations rather than assigning entire disciplines to fixed automation categories.

Experimental measurement, clinical interviewing, ethnography, archival interpretation, mathematical proof, field observation, cultural transmission, and collaborative inquiry provide useful comparative domains.

The relevant research task is to determine which relations remain stable under substitution, which relations change, and which changes alter the epistemic significance of the resulting process.

19.6 Operator Dependence and Relational Effects

A related problem concerns the empirical effects of replacing human operators with artificial agents in operator-sensitive and relation-dependent settings.

Future studies can compare how participants respond to human, artificial, and hybrid interviewers; how trust develops across different interaction configurations; how disclosure changes; and how the identity of the interlocutor affects the form of evidence produced.

The same issue applies to mentorship, collaborative reasoning, negotiation, public consultation, and participatory research.

Such work would clarify whether artificial agents merely execute comparable operations or generate systematically different epistemic relations.

19.7 Participant-Constitutive Knowledge

Participant-constitutive knowledge remains one of the least developed parts of the present framework.

Further conceptual work is required to determine the conditions under which a participant's historical position becomes constitutive of the epistemic object or significance.

Shared experience, testimony, collective memory, apprenticeship, religious transmission, artistic practice, and community knowledge provide possible cases.

Future research should distinguish several possibilities: participation can supply evidence, alter interpretation, generate trust, constitute historical indexing, or contribute to the identity of the practice itself.

The resulting distinctions will be important for preservation, automation, provenance, and epistemic justice.

19.8 Subject-Formative Effects of AI-Mediated Inquiry

The subject-formative consequences of AI-mediated inquiry require direct empirical investigation.

Two individuals can use the same system and obtain similar outputs while undergoing very different changes in judgment, understanding, curiosity, or future inquiry capacity.

Research should therefore examine interaction patterns associated with durable development. Possible variables include frequency of counterargument, independent hypothesis generation, explanation seeking, revision, retrieval of primary sources, delayed assistance, and post-interaction performance without the system.

Longitudinal studies will be especially important because subject formation concerns future capability rather than immediate task completion.

19.9 Relational Epistemic Alienation

Relational epistemic alienation requires clearer empirical indicators and boundary conditions.

The concept presently describes progressive attenuation of the subject's relations to questioning, encounter, interpretation, revision, and other generative processes while epistemic production continues.

Future work should distinguish alienation from efficient delegation, specialization, ordinary reliance on testimony, and assistive use of technology.

Potential indicators could include declining capacity to reconstruct the logic of an inquiry, increasing dependence upon externally selected questions, reduced ability to challenge outputs, limited awareness of evidential provenance, and weakening continuity between received results and subsequent human question formation.

Any measurement scheme should preserve the possibility that extensive delegation can coexist with deep generative participation.

19.10 Relational Redistribution of Subject Formation

The wider consequences of delegated epistemic labor depend upon how released time and attention are redistributed.

A reduction in direct research execution can produce more time for conceptual reflection, care, interpersonal relations, art, political participation, embodied activity, or other forms of subject formation. The same reduction can also support intensified output requirements or passive consumption.

Future research should therefore examine the relational destinations of time released through automation.

This problem cannot be evaluated solely through productivity metrics. It requires broader investigation of work organization, education, daily life, institutional expectations, and the plurality of relations through which human subjects develop.

19.11 Curiosity under Abundant Answers

The relation between answer abundance and curiosity remains theoretically and empirically open.

AI can allow individuals to pursue more questions by reducing search and explanation costs. Immediate answers can also alter the temporal space within which uncertainty, hypothesis formation, and independent exploration occur.

Future research should examine how different patterns of assistance affect question generation, persistence of inquiry, tolerance of uncertainty, and the development of further curiosity.

The relevant variable may be the organization of the interval between encounter and externally supplied resolution.

This paper leaves the phenomenology and existential significance of curiosity for separate philosophical treatment.

19.12 Measurement of Effective Visibility

Attention justice requires better measurement of effective visibility.

Downloads, impressions, citations, search position, recommendation frequency, AI retrieval frequency, classroom use, and social discussion capture different dimensions of epistemic presence.

A resource can perform strongly on one measure and remain weak on another. Visibility also varies across communities, languages, disciplines, and time.

Future work should therefore develop multidimensional approaches to the probability that a resource enters relevant future epistemic relations.

Such measures will be necessary for distinguishing archival preservation from active generative presence.

19.13 Measurement of Epistemic Crowding

Epistemic crowding requires empirical indicators capable of distinguishing healthy growth in knowledge from displacement produced by attention scarcity.

Possible measures include changes in the probability of discovery as output volume increases, concentration of citations or retrieval, shortening of attention half-lives, increased dependence upon ranking systems, and declining encounter rates for older or less frequently produced work.

Research should also distinguish crowding by quantity from crowding generated by concentrated institutional or machine-scaled production.

The goal is to identify when additional output expands the generative field and when it reduces the practical visibility of other valuable epistemic resources.

19.14 Recursive Visibility under AI Retrieval

AI-mediated retrieval creates a new research problem concerning feedback between machine selection and future visibility.

If frequently retrieved sources receive more citations, links, summaries, and institutional attention, those signals can increase the probability of later retrieval.

Future empirical work should examine whether such feedback produces increasing concentration, diversification, or context-dependent mixtures of both.

The unit of analysis can include individual publications, authors, institutions, conceptual frameworks, languages, or entire research traditions.

Particular attention should be given to resources that are public and machine-readable yet rarely selected by dominant retrieval systems.

19.15 Framing and Definitional Concentration

The transition from visibility to framing and definitional power requires further theoretical and empirical analysis.

Research should examine how repeated exposure to particular conceptual vocabularies affects later question formation, classification, and retrieval. AI-generated synthesis provides a particularly important context because users can encounter a domain through a compressed interface whose underlying selection process remains partially hidden.

Future work could compare conceptual diversity in direct literature search, conventional search engines, retrieval-augmented systems, and autonomous research agents.

The relevant outcome concerns the range of frames through which future inquiry remains practically accessible.

19.16 Preservation of Slow Knowledge

The position of slow and high-cost knowledge under machine-scaled production requires sustained investigation.

Longitudinal research, archival scholarship, community-based work, difficult field studies, rare-language research, and long-term theoretical development can possess temporal structures that differ substantially from automated production.

Future studies should examine whether contemporary ranking, publication, funding, and retrieval systems systematically disadvantage these forms of knowledge.

Preservation should be evaluated at several levels: material survival, retrievability, effective visibility, and generative continuity.

The relevant challenge is to preserve realistic future encounter without assuming that slower production is intrinsically superior.

19.17 Relational Provenance under Synthetic Abundance

The concept of relational provenance requires formal development and domain specific application.

Future work should determine which aspects of generative history matter for scientific evidence, historical testimony, artistic creation, cultural heritage, legal attribution, and educational evaluation.

Provenance systems can potentially record source materials, model operations, human interventions, revisions, empirical encounters, and institutional contexts. Excessively detailed provenance can become unusable, while insufficient provenance can conceal epistemically relevant relations.

The research problem therefore concerns selection of the aspects of generative history that remain important for later interpretation and trust.

19.18 Cultural Transmission and Generative Continuity

Cultural preservation under AI requires investigation beyond digital archiving.

Future research should examine which elements of a practice can be sustained through textual, audiovisual, or synthetic representation and which depend upon communities, places, rituals, embodied practice, mentorship, shared history, or continued use of a language.

Artificial systems can become important components of preservation and instruction. Their role should be evaluated according to whether they expand opportunities for future participation and reinterpretation.

The relevant object is generative continuity: the persistence of conditions through which future subjects can continue to create meaning within or from the tradition.

19.19 Infrastructure Concentration

The concentration and centralization of epistemic infrastructure require systematic empirical study.

Relevant resources include foundation models, compute, cloud infrastructure, scientific databases, laboratory automation, sensors, research platforms, publication systems, and retrieval interfaces.

Future work should distinguish concentration of ownership, control, technical capacity, access, and dependency.

The consequences also need domain-specific analysis. Concentration can generate economies of scale, reliability, shared standards, and substantial public benefits. It can also create bottlenecks, fragility, dependency, and asymmetrical control over epistemic possibility.

The normative significance therefore cannot be inferred from concentration alone.

19.20 Scalable Epistemic Encounter

The capitalization of empirical encounter creates a new research agenda around the distribution of machine-mediated contact with reality.

Future work should examine how access to robotic laboratories, automated field platforms, remote instruments, satellites, sensor networks, and autonomous experimental systems changes scientific inequality.

The relevant unit is the number and diversity of empirical trajectories that different actors can practically execute.

A public theoretical literature can coexist with substantial inequality in the capacity to expose theories to empirical challenge.

This distinction may become increasingly important as experimental automation develops.

19.21 Epistemic Labor and Changing Occupational Relations

The transformation of epistemic labor under AI requires detailed labor-process research.

Automation can reduce repetitive reading, coding, transcription, drafting, and technical execution while increasing demand for evaluation, orchestration, verification, provenance management, data curation, and infrastructure maintenance.

Future studies should examine how these changes affect autonomy, workload, skills, employment security, attribution, bargaining power, and access to the means of epistemic production.

Particular attention should be given to the possibility that productivity gains lead either to reduced burdens or to intensified output expectations.

The epistemic-proletarian concept developed in this paper should be tested against such empirical variation.

19.22 Generative Precarity

Generative precarity requires longitudinal analysis of dependence upon revocable or unstable infrastructure.

Researchers can build productive practices around models, platforms, databases, cloud services, institutional affiliations, or experimental resources whose availability they do not control.

Future work should examine switching costs, portability of workflows, interoperability, local fallback capacity, and the effects of sudden changes in pricing or access conditions.

The important outcome is continuity of future generative capacity rather than immediate productivity alone.

19.23 Public Inputs and Private Generative Gains

The transformation of public epistemic resources into privately controlled generative capacity raises empirical and normative questions concerning contribution and return.

Future research should trace how public research, open-source software, public datasets, shared standards, community knowledge, and public investment enter the construction of private AI and research infrastructures.

The relevant analysis should also examine benefits returned through new products, public knowledge, infrastructure, employment, taxation, open tools, training, or other channels.

Such studies are necessary before stronger claims concerning generative extraction can be evaluated responsibly.

19.24 Generative Extraction

The concept of generative extraction requires criteria capable of distinguishing unequal but regenerative relations from relations that weaken the future generativity of contributing sources.

Future work should identify observable effects on communities, public institutions, research ecosystems, open-source projects, and other contributors.

Potential dimensions include depletion of labor, loss of control, erosion of visibility, deterioration of shared infrastructure, inability to reproduce local capacity, and weak return of benefits.

The concept should remain sensitive to reciprocal and mixed cases in which the same process generates both extraction and substantial public value.

19.25 Generative Return and Commons Regeneration

Generative return requires further normative and institutional specification. Possible forms include open knowledge, shared infrastructure, funding, education, attribution, technical assistance, community capacity, and participation in governance.

Future research should examine which forms of return strengthen the future generativity of different epistemic communities.

The appropriate arrangement is likely to vary substantially across domains. Scientific commons, cultural knowledge, community data, open-source software, and publicly funded research possess different relational histories and institutional conditions.

Commons regeneration therefore requires contextual analysis rather than a single distributive formula.

19.26 Attention Justice

Attention justice remains one of the least institutionalized dimensions of the framework.

Future work must clarify what constitutes a fair opportunity for epistemic encounter under unavoidable attention scarcity.

Equal visibility is neither feasible nor necessarily desirable. Relevance, quality, reliability, diversity, historical significance, and context can all justify differentiated attention.

The difficult problem concerns designing selection environments that preserve epistemic quality while preventing recursive visibility dynamics from systematically suppressing valuable alternatives.

This research will require interaction among information science, political economy, epistemology, platform governance, library science, and institutional design.

19.27 Governance of Machine-Scaled Epistemic Output

Machine-scaled output raises governance questions concerning publication, ranking, review, filtering, provenance, and allocation of collective attention.

The present paper does not endorse output quotas, mandatory ranking rules, licensing restrictions, or other specific interventions.

Future research should compare possible governance architectures according to their effects on openness, innovation, pluralism, administrative cost, accessibility, freedom of inquiry, and the generativity of the public knowledge commons.

Institutional experiments may be more informative than universal rules because different epistemic environments possess different scales, risks, and purposes.

19.28 Institutional Design for Generative Visibility

A related research direction concerns infrastructures that improve the probability of encounter with valuable but weakly visible knowledge.

Possible domains for investigation include libraries, repositories, scholarly search, recommendation systems, citation networks, AI retrieval, educational curricula, and public research platforms.

The goal would be to understand how discovery systems can preserve serendipity, historical depth, minority perspectives, and conceptual diversity while remaining useful under severe attention constraints.

The present paper leaves the appropriate institutional mechanisms open.

19.29 Public Infrastructure for Epistemic Capitalization

The possibility of public or commons-based epistemic infrastructure constitutes another important research direction.

Shared compute, public models, open scientific agents, community laboratories, interoperable data systems, and publicly governed retrieval infrastructure could alter the distribution of capitalization capacity.

Such arrangements also create challenges involving cost, maintenance, governance, abuse prevention, reliability, technical expertise, and long-term sustainability.

Future work should compare public, private, cooperative, university-based, and hybrid infrastructures according to both productive performance and distribution of generative capacity.

19.30 Educational Design under Epistemic Automation

Educational institutions require new methods for distinguishing task completion from epistemic formation.

Future research should identify when AI assistance supports understanding, judgment, inquiry capacity, and autonomy, and when it creates fragile dependence or bypasses the target learning process.

Assessment practices also require reconsideration because polished artifacts provide weaker evidence about the generative trajectory through which they were produced.

Research should therefore compare process-oriented, dialogical, practice-based, and reconstruction-based assessment under different levels of AI mediation.

The central outcome is durable future generativity rather than prohibition or maximization of AI use.

19.31 Verification and Epistemic Dependence

Increasingly autonomous research systems create unresolved questions concerning verification.

Machine-scaled production can generate more outputs than human experts can inspect individually. Automated evaluation can increase throughput while introducing dependence upon additional machine systems.

Future work should examine layered verification architectures combining independent models, formal methods, empirical replication, provenance, specialist review, and selective human auditing.

The relevant problem concerns how trust can remain revisable when the complete generative trajectory exceeds the direct comprehension of any single participant.

19.32 Comparative Political Economy of Epistemic Systems

The framework developed in this paper should be tested comparatively across institutional environments.

Universities, private laboratories, public research agencies, open-source communities, independent researchers, international organizations, and community knowledge institutions possess different relations among ownership, control, labor, access, and commons contribution.

AI-mediated capitalization can therefore generate different outcomes across these settings.

Comparative analysis would clarify which tendencies arise from the technology itself and which arise from particular institutional arrangements.

19.33 Historical and Cross-Cultural Epistemic Models

The present analysis draws from several philosophical and educational traditions while remaining incomplete from a global historical perspective.

Future work should examine how different intellectual traditions conceptualize inquiry, transmission, learning, self-cultivation, testimony, practice, and the relation between knowledge and subject formation.

Such work is especially important for participant-constitutive and relation-dependent knowledge because assumptions about the knower and the purpose of learning vary across cultural and historical contexts.

Comparative analysis can therefore expand the conceptual vocabulary available for evaluating epistemic automation.

19.34 Long-Term Transformation of Human Epistemic Life

The broadest open problem concerns the historical transformation of the human relation to knowing.

If artificial systems increasingly perform search, derivation, experimentation, evaluation, and synthesis, human epistemic activity can become reorganized around different combinations of curiosity, direction, judgment, interpretation, experience, and social participation.

The resulting change can alter education, occupations, institutions, self-understanding, and the place of inquiry within ordinary life.

The long-term trajectory remains indeterminate.

Future research should therefore avoid assuming either the disappearance of human inquiry or the preservation of its current forms. The relevant object is the changing distribution of generative relations across human subjects, artificial agents, institutions, communities, and technical infrastructures.

19.35 Research Agenda across the Paper Series

The present paper establishes a foundational research agenda whose components require treatment across several subsequent studies.

A jurisprudential project is needed to examine licensing, rights, obligations, commons governance, and institutional control over publicly derived generative capacity. An ethical project is needed to develop criteria for generative extraction, generative return, dependency, reciprocity, and the preservation of heterogeneous generative conditions.

A practical project is needed to examine strategies available to low-capital researchers and communities operating within increasingly infrastructuralized knowledge systems. A separate epistemological project is needed to examine more deeply the relation among investigation, knowing, subject formation, and delegated inquiry, including the problem represented by the traditional idea of investigation of things.

Additional work is required on attention governance, relational provenance, epistemic praxis, and the philosophical significance of curiosity and subjective participation under AI-mediated production.

The present article therefore functions as a diagnostic and conceptual bridge among these later investigations.

19.36 Boundary of the Present Contribution

This subsection defines the boundary of the present paper. The analysis has developed a conceptual account of knowledge-capital expansion under modern and AI-mediated conditions. It has identified mechanisms of accumulation, infrastructural dependence, differential automation, attention concentration, subject-formative decoupling, relational epistemic alienation, and several dimensions of justice.

The paper has deliberately left several tasks unresolved.

It does not provide a complete empirical measurement system for epistemic capital. It does not determine the optimal distribution of public and private research infrastructure. It does not establish a universal threshold for alienation, extraction, or attention injustice. It does not prescribe a final governance architecture for AI-mediated knowledge production.

These boundaries are methodological rather than deficiencies to be concealed. The phenomena examined are historically developing and involve interacting technical, economic, epistemological, educational, cultural, and institutional processes.

The appropriate contribution of the present study is therefore to clarify the relations that require observation and to provide a vocabulary through which their future transformations can be analyzed.

Section 20 concludes the paper by restating the central argument and its implications for public knowledge, epistemic capitalization, artificial intelligence, subject formation, attention, and generative justice.

20 Conclusion

This paper has examined knowledge-capital expansion under modern conditions and the intensification of epistemic capitalization through artificial intelligence. Its central argument is that the contemporary transformation of knowledge production cannot be understood through growth in informational output alone. Public knowledge increasingly enters infrastructures capable of absorbing, recombining, testing, extending, and recursively reproducing epistemic resources at machine scale. The resulting transformation concerns the relations among knowledge, capital, infrastructure, labor, attention, inquiry, human formation, and future generative capacity.

The historical analysis situated artificial intelligence within a longer trajectory of epistemic externalization. Writing made portions of knowledge durable across generations. Archives and libraries organized preservation and retrieval. Printing expanded reproducibility. Universities and scientific publication institutionalized distributed epistemic production. Databases, networked information, search systems, and platforms progressively increased the scale at which accumulated knowledge could be organized and encountered. Contemporary AI extends this trajectory by externalizing increasingly complex knowledge-generating operations. Models, agents, retrieval systems, compute, robotics, and automated laboratories can now participate in extended sequences of question generation, analysis, experimentation, evaluation, and subsequent revision.

This transformation enlarges the practical capitalizability of public knowledge. An epistemic resource that once required substantial linguistic, disciplinary, computational, or organizational effort to use can increasingly be translated, explained, implemented, compared, and integrated through machine-mediated infrastructure. Public knowledge therefore becomes capable of supporting larger and faster cycles of epistemic production.

Equal access to public knowledge does not imply equal capitalization capacity. Actors differ in prior knowledge, time, language, models, compute, laboratories, institutional position, financial resources, networks, retrieval infrastructure, and capacity to conduct empirical inquiry. AI can reduce some of these differences while increasing the importance of others. The same public epistemic field can consequently generate substantially different future productive capacities for different actors.

This distinction supports the paper's political-economic account of knowledge-capital expansion. Capital-like expansion describes a dynamic through which epistemic resources recursively enlarge future generative capacity. Knowledge-capitalist and epistemic-proletarian positions describe relations to

the means and conditions through which that expansion occurs. A researcher can become substantially more productive while simultaneously becoming more dependent upon models, platforms, compute, laboratories, or institutions controlled elsewhere. Productivity and control can therefore follow different trajectories.

Artificial intelligence also changes the scale at which capital can be converted into epistemic exploration. Compute supports parallel candidate trajectories. Agentic systems coordinate extended research workflows. Robotic laboratories and scientific instruments increase the number of empirical interactions that can be performed. Capital can therefore purchase greater capacity to search conceptual and empirical possibility spaces. The emerging scarcity can reside increasingly in the capacity to absorb, recombine, test, evaluate, and extend public knowledge at scale.

The analysis also identified attention as a distinct limiting resource. Machine-scaled production can increase epistemic output more rapidly than human attention expands. Public availability, retrievability, visibility, attention, and epistemic uptake consequently become distinct stages of circulation. Knowledge can remain legally and technically public while becoming weakly connected to active inquiry.

This attention structure creates possibilities of epistemic crowding, recursive visibility advantage, symbolic authority, framing power, and definitional power. Repeated visibility can influence which concepts become familiar, which sources become authoritative, and which frameworks become default interfaces for future inquiry. Under these conditions, preservation of a resource does not guarantee preservation of its effective generativity.

The paper has therefore distinguished three broad loci of possible concentration: epistemic resources themselves, the generative infrastructures through which resources are capitalized, and the attention pathways through which resources enter future epistemic relations. A public knowledge commons can remain open at the first level while displaying substantial concentration at the second and third.

The epistemological analysis showed that knowledge-emergence processes are heterogeneous. Some formal, computational, and standardized empirical operations can exhibit substantial operator invariance. Other processes are operator-sensitive, relation-dependent, or participant-constitutive. Interviews, apprenticeship, shared historical experience, cultural transmission, collective memory, and other situated practices can depend upon the identities, histories, or relations of participating subjects. Automation therefore requires analysis of particular generative relations rather than a single boundary between human and machine knowledge.

This heterogeneity also clarifies the distinction between epistemic production and human knowing. Artificial systems can produce valid and valuable knowledge while particular human recipients undergo limited epistemic transformation. Conversely, learners can reconstruct established knowledge and experience substantial development without increasing the global stock of epistemic outputs. Social knowledge production and individual epistemic formation therefore constitute analytically distinct processes.

The Generative Relational analysis developed this distinction through four dimensions of participation and four dimensions of generativity. Executional, directional, reflective, and existential-generative participation can vary independently. Epistemic-output, epistemic-capacity, subject-formative, and relational generativity can likewise follow different trajectories.

The resulting distinction is especially important under AI mediation. Extensive machine execution does not imply weak human generative participation. A subject can delegate almost every executable operation while remaining deeply involved through experience, problem formation, judgment, resistance, interpretation, and revision. Extensive human execution likewise provides no guarantee of deep generative participation when activity remains highly routinized or externally organized. The degree of AI involvement and the degree of subject participation must therefore be evaluated separately.

This framework supports a relational account of epistemic alienation. Alienation arises when epistemic production continues while the subject's relation to the generative processes of questioning, encounter, judgment, revision, and formation becomes progressively thinner. Delegation itself does not establish this condition. AI can also reduce repetitive labor, increase accessibility, support disabled participants, expand inquiry, and release time for other generative relations.

The broader consequence is a possible redistribution of subject formation. Human subjects are

formed through epistemic relations alongside relations of care, love, art, religion, politics, community, embodiment, place, and other forms of situated participation. Reduced direct epistemic execution can therefore produce different outcomes depending upon the relations into which released time and attention subsequently enter.

Curiosity remains relevant within this wider structure because human questions frequently emerge from situated encounters with uncertainty, practical difficulty, injustice, vulnerability, beauty, wonder, or other forms of salience. Inquiry can then become a recursive process in which questions, answers, resistance, failure, and revision transform the subject capable of asking the next question. AI can generate valuable questions of its own and can substantially amplify such inquiry. The continuing human significance of curiosity therefore lies in preserving conditions through which encounters can still become personally generative questions and through which inquiry can continue to transform the subjects participating in it.

The justice analysis consequently extends beyond access to information. Access justice concerns the ability to obtain epistemic resources. Capitalization justice concerns the capacity to convert those resources into future generativity. Attention justice concerns realistic opportunities for epistemic contributions to enter subsequent relations of inquiry. Infrastructural justice concerns control over the systems through which knowledge is absorbed, processed, tested, circulated, and reproduced.

The concepts of generative extraction, generative return, and commons regeneration provide a further temporal dimension. Public knowledge can support private generative capacity without depleting the original informational resource. The relevant normative question concerns the effects of this capitalization upon the continuing generative conditions of contributing persons, communities, institutions, and commons. Unequal benefit alone is insufficient to establish extraction. Stronger judgments require analysis of contribution, control, dependency, reciprocity, and the future generativity of the relevant relational field.

The paper has deliberately stopped before proposing a complete governance architecture. Questions concerning licensing, public infrastructure, competition, attribution, retrieval design, attention allocation, educational practice, and generative return require further empirical, ethical, jurisprudential, and institutional analysis. Premature specification of a single solution would obscure substantial differences among scientific, cultural, educational, commercial, and community knowledge systems.

The historical direction also remains open. Artificial intelligence can intensify concentration, dependency, attention inequality, and relational alienation. It can simultaneously expand access, redistribute expertise, support previously excluded participants, increase scientific discovery, and create new forms of epistemic and existential freedom. These tendencies can coexist within the same technological environment.

The central concern is therefore the organization of generative conditions. Knowledge-capital expansion becomes socially consequential through the relations determining who can encounter knowledge, who can capitalize upon it, who controls the infrastructures of inquiry, whose contributions remain visible, how subjects participate in the generative trajectory, and whether the resulting system preserves possibilities for subsequent revision and regeneration.

Under conditions of increasingly abundant machine-generated knowledge, the future of epistemic life will depend increasingly upon the organization of these relations. The challenge is to understand how rapidly expanding epistemic capacity can coexist with heterogeneous human formation, open inquiry, relational continuity, epistemic plurality, and regenerative public knowledge commons. The present paper provides a conceptual vocabulary for that inquiry while leaving its institutional and historical resolution open.

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