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Article

Project-Based Learning in the Era of Generative Artificial Intelligence: Toward a Hybrid Epistemic Governance Framework for Undergraduate Computer Science Education

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Abstract: The integration of generative artificial intelligence technology (GenAI) within higher education contexts is changing the epistemology associated with educational settings. In undergraduate computer science programs, project-based learning (PBL) has traditionally been considered one of the core pedagogical approaches to teaching based on constructivist epistemologies that emphasize purposeful knowledge construction and artifact production. The introduction of AI systems that can generate programming codes, designs, documentation, and feedback undermines the traditional association of cognitive work with epistemological development. This study presents an integrative theoretical approach referred to as Hybrid Epistemic Governance (HEG) in which PBL is rethought in relation to AI learning environments. Based on the principles of sociocultural theory, activity theory, distributed cognition, sociomaterialism, cognitive load theory, and the existing literature on AI literacy, this paper argues that the epistemological axis of pedagogy in the age of AI must shift from being production-centric to governance-centric. Through the HEG framework, this research explores four interrelated dimensions—epistemic discernment, algorithmic reflexivity, governance agency, and authenticity reconstruction—which collectively examine the ways in which learners engage with AI technologies through project work. This study analyzes the structural conflicts that typify the project-oriented nature of work environments facilitated by AI and articulates a set of principles for governance pedagogies along with an approach to future validation through a methodology. By framing project-oriented education as governance of hybrid human-AI knowledge systems, this research contributes to theory development in relation to generative AI technologies in higher education and offers a pragmatic framework for undergraduate computer science education.

Keywords: Generative AI; Project-Based Learning; Computer Science Education; Epistemic Governance; AI Literacy; Distributed Cognition

1. Introduction

Generative artificial intelligence technology (GenAI) has evolved from being a technological wonder to becoming a key part of the university curriculum. Technologies such as large language models, code generation, and design assistance tools have become embedded in the process of university learning, with special focus on computing programs. These technologies are not used to assist in tangential areas but are involved in core practices such as writing algorithms, designing architectures, debugging, and producing documentation.

Project-based learning (PBL) has traditionally been identified as an educational paradigm which has significant influence on the teaching of computing-related subjects [1-4]. Through the process of dealing with complex issues by way of designing, working collaboratively, and reflecting on experiences, PBL aims at achieving deep learning and professional competence among learners. However, there is an implicit epistemology associated with PBL, and this is that deep learning occurs through hard cognitive work in building artifacts.

GenAI puts this assumption to the test directly. If the systems of AI have the ability to create substantial amounts of functional code or entire architectural blueprints based on little input from human minds, then the simple link between work effort and knowledge becomes a problematic concept. It may be a sign of true comprehension, but it could equally well be a result of effective prompting. The issue of pedagogy is not an insignificant one: How does one conceive of and assess learning when intelligence is shared between human and machine?

The current strategies employed in tackling GenAI problems in education mainly deal with cases of academic integrity and plagiarism [5-7]. Even though these problems need to be addressed, there is a lack of attention to underlying problems. The key problem here, which will be tackled in this essay, is the restructuring of epistemic agency in learning processes. In situations where AI becomes an active participant in generating knowledge, the main question is not if cheating took place but whether learning occurred.

The study argues that a learning process within AI-aided project spaces requires moving away from production-based pedagogy wherein the validity of learning was measured by construction made by the learners to governance-based pedagogy where learning would be seen as validation through governance by learners. To further develop the argument, this study introduces the Hybrid Epistemic Governance (HEG) model. Based on sociocultural theory, activity theory, theories of distributed cognition, sociomateriality, cognitive load theory, and contemporary studies on AI literacy, the HEG model identifies four interdependent governance dimensions including epistemic discernment, algorithmic reflexivity, governance agency, and authenticity reconstruction to form the theoretical foundation for a reconceptualized version of PBL.

The study proceeds as follows. Section 2 considers how GenAI reconfigures epistemic labor. Section 3 highlights three epistemological presuppositions associated with conventional PBL that are undermined by GenAI. Section 4 contrasts production- to governance-oriented epistemologies. Section 5 presents the HEG approach. Sections 6 and 7 evaluate structural conflicts and formulate design principles. Section 8 sets out a methodology for empirical testing. Sections 9-11 explore boundary considerations, implications, and conclusions.

2. Generative Artificial Intelligence and the Reorganization of Epistemic Labor

2.1. Acceleration and Compression of Procedural Cognition

GenAI systems reduce procedural processes to an extent where the timing of the learning process is altered. The coding software can generate syntaxes that work within seconds. While such efficiencies will provide more cognitive capacity to engage in higher-level thinking, there is also the potential to limit productive struggle that facilitates deep learning [8-9].

According to cognitive load theory, automation could lower extraneous cognitive load, though germane processing might be negatively affected if learners dissociate themselves from the underlying conceptual frameworks. The danger, however, lies not in how AI simplifies learning but rather in how it condenses the procedural challenges that are necessary for the building of schemata.

2.2. Expansion of the Design Search Space

Generative approaches extend the space of solutions by suggesting alternative architectural designs. Students might come across techniques or methods that fall outside their existing knowledge base. While such an approach could help enhance creativity [10-11], it could prove too much for students unless it is regulated through epistemic regulation.

When working on designing a database, a student can find AI-generated suggestions for different models, from traditional relational databases to advanced graph databases. In the absence of scaffolding for the assessment of alternative models, such an abundance can contribute to superficial selection decisions.

The design search space thus becomes more expansive yet more volatile.

2.3. Redistribution of Authorship and Agency

The most significant change is that of authorship. In the event that AI contributes to the creation of an artifact, the final product will be considered a collaborative construction. The concept of distributed cognition [12] provides an excellent approach; nevertheless, the emergence of GenAI brings about a unique form of cognitive engagement through algorithms.

However, critical research has shown that such engagement could end up masking epistemological opaqueness and accentuating biases [13-14]. Within the sphere of computing education, the above challenge could manifest itself in the form of AI-generated coding that by default relies on outdated techniques that were gleaned from old data sets or codes laden with cultural assumptions. When reflective inquiry does not take place, the learners are at risk of perpetuating such algorithms without comprehending the constraints involved. As shown in Figure 1, the movement from traditional PBL to AI-enabled PBL involves three connected areas of tension, namely struggle compression, obscure authoring at the intermediary design stages, and increasingly disparate artifact quality and real comprehension. In this case, the underlying epistemological assumptions associated with traditional PBL become increasingly unstable.

The above phenomena point to the need for a new pedagogy which stresses governance more than consumption. In this respect, Figure 1 shows that this particular pedagogy in AI-Governed PBL (HEG) entails re-structuring along four dimensions of governance rather than the five cognitive dimensions related to procedures involved in traditional PBL project cycles, namely, procedural coding, debugging and testing, architectural design, evaluation, and artifact production, and the learner-AI dynamic moves from mere assistance to critical mediation.

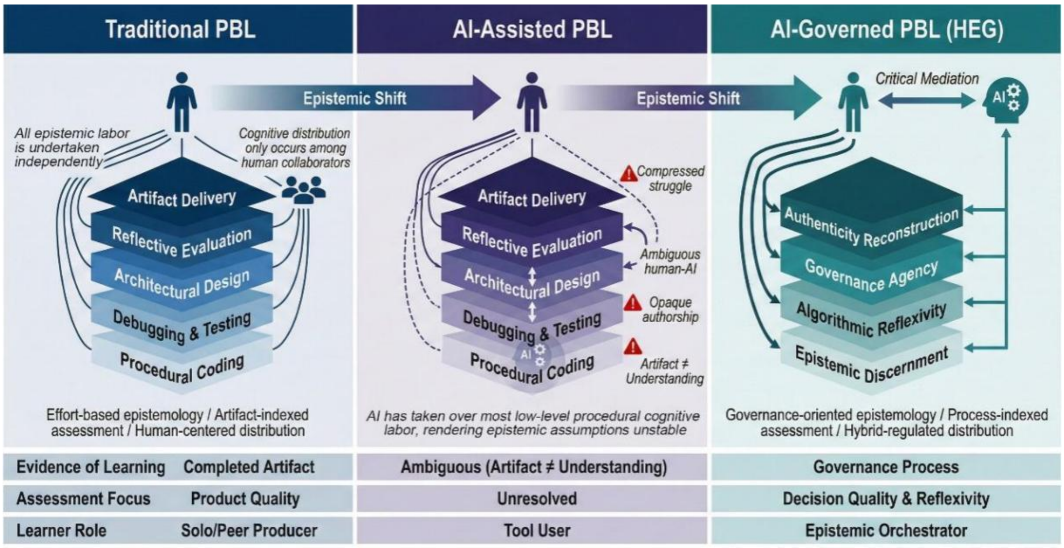

Figure 1. Conceptual mapping of epistemic labor redistribution across three PBL paradigms in AI-mediated learning environments

3. Project-Based Learning in Computing Education: Foundations and Limitations

Project-Based Learning is grounded in experience-based pedagogical models [15-16] that emphasize problem-solving, collaboration, reflection, and design. As applied to teaching computing, PBL has been found effective in developing students' computational thinking and skills at abstracting [17-19].

The effectiveness of PBL, on the other hand, is contingent on several epistemological assumptions that are rarely stated. There are three epistemological assumptions that need to be explored specifically within the domain of GenAI: effort-based epistemology, the notion that effort leads to learning; artifact-indexed knowledge, the notion that knowledge has been mastered when an artifact is created; and human distribution of cognition, where cognition is distributed only among human collaborators (Table 1).

Table 1. Foundational assumptions of traditional PBL and their destabilization by generative AI

Assumption	Traditional PBL Logic	Challenge Posed by GenAI
Effort-Based Epistemology	Productive struggle through coding, debugging, and refinement drives schema construction	AI compresses procedural difficulty; effort–understanding link becomes ambiguous
Artifact-Indexed Understanding	Artifact quality serves as proxy for conceptual mastery	AI-generated artifacts can be functionally correct yet epistemically hollow
Human-Centered Distribution	Cognition distributed among human peers; tools remain passive	AI acts as epistemic participant, shaping representations and constraining design space

When operating in environments highly impacted by the presence of AI, artifacts lack reliable ways of indexing understanding and cognition gets distributed to the algorithms. In this case, PBL must extend beyond an epistemology that centers on production. The question to be answered is not one of whether the inclusion of AI is permitted or forbidden in projects, but rather which epistemic framework enables real learning in this environment.

4. Toward a Governance-Oriented Epistemology

The main thesis of this research suggests that the use of AI requires the shift from production-oriented epistemology to governance-oriented epistemology. In production-oriented epistemology, learning is validated by building artifacts; the result is viewed as knowledge, and the assessment question asked is: "What did you build?" Models emphasizing governance, however, place learning within the ability to govern, examine, and be accountable for distributed cognitive processes involving human-AI collaboration. Questions asked during assessment include, "How was the process of construction governed, and why were AI inputs accepted, altered, or excluded?"

This development is consistent with emerging AI literacy models that highlight critical thinking, ethical analysis, and recognition of algorithms' limitations [20-23]. It also aligns with trends within assessment theory favoring process rather than product [24-25], as well as sociomaterial theories that consider the agency of non-human actors as knowledge producers [26-27]. Yet it is important to point out that governance epistemology should not be seen as a replacement of production altogether; rather, it should be seen as insufficient epistemologically without governance in an AI-rich world.

5. The Hybrid Epistemic Governance (HEG) Framework

Building upon the theoretical foundations outlined above, this study proposes the **Hybrid Epistemic Governance (HEG) framework** as a structural reconceptualization of project-based learning in AI-mediated environments.

Hybrid Epistemic Governance is defined as:

Pedagogic development in the context of regulating, questioning, integrating, and ethically orchestrating human-AI distributed cognitive systems in project-based learning ecologies.

Instead of thinking about AI as a device that should be controlled or even optimized, HEG proposes to think about learning as the governance of hybrid epistemic assemblages, where the position of the learner shifts from being an exclusive producer to epistemic conductor.

This model consists of four dimensions that are interrelated to one another, as shown in Figure 2. Though the focus of each individual dimension is different in terms of enhancing governance capabilities, the dimensions work together as a system. The evaluation base for the dimension of algorithmic reflexivity is provided by epistemic discernment, while governance agency converts these bases into actions.

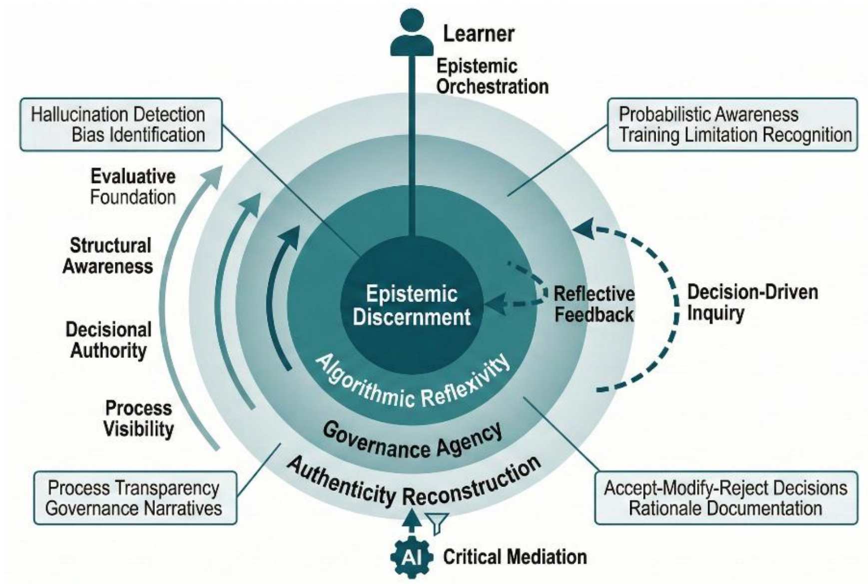

Figure 2. The Hybrid Epistemic Governance (HEG) framework: four interdependent dimensions and their structural relationships

5.1. Epistemic Discernment

Discernment of epistemic information refers to the capability of the individual to evaluate the results generated by the machine learning algorithms. The generative models operate on probabilities and might generate results that are feasible but wrong [13]. With regards to computer science education, this could manifest in the form of codes that are syntactically accurate but structurally flawed.

Discernment requires:

- Detection of hallucinated outputs
- Identification of biased assumptions
- Evaluation of computational efficiency
- Verification against domain knowledge

This domain draws on the research base of metacognitive regulation [28] and requires direct teaching scaffolds. Without opportunities to develop the skill of output evaluation, learners are not likely to develop discrimination skills automatically—particularly when AI-produced output appears plausible at first glance.

5.2. Algorithmic Reflexivity

Reflexivity in algorithmic systems extends beyond simply evaluating their outputs, as it involves understanding the architecture of the algorithm and its limitations during training. Students should recognize that generative AI algorithms do not use human-type logic to reason, but rather predict token sequences based on statistics.

Reflexivity involves:

- Understanding probabilistic generation
- Recognizing training data limitations
- Identifying bias amplification risks
- Evaluating system uncertainty

This dimension relates to literature on AI literacy [21]and ethics in AI [14]. This distinction needs to be made clear, because while discernment asks the question “Is the output right?” reflexivity on the other hand asks “Why was the output produced by the system in such a way and what is there in the structure of the system which makes it wrong?” The later concept requires a deeper understanding of algorithms than the former.

5.3. Governance Agency

The governance authority highlights the need for maintaining human accountability in distributed systems. Even though the AI creates the code, learners should exercise their final decision-making power.

Governance agency includes:

- Accepting, modifying, or rejecting AI suggestions
- Integrating outputs into coherent architectures
- Documenting rationale for decisions
- Maintaining authorship accountability

According to activity theory [29], the agency of governance is responsible for alleviating conflicts associated with automation and human domination. The principle is consistent with Luckin's (2018) notion of "intelligence augmentation," which states that AI ought to complement rather than replace human intellectual dominance [30]. In essence, governance agency ensures that the AI-enabled framework does not succumb to dependence.

5.4. Authenticity Reconstruction

Assessment in problem-based learning traditionally focuses on artifact assessment. Yet in scenarios where AI is used, the notion of authenticity needs to be redefined so that the focus moves to epistemic practices as well.

Authenticity reconstruction entails:

- Process transparency
- Prompt documentation
- Version control justification logs
- Reflective governance narratives

Assessment is reconceived in this context as an assessment of epistemic regulation, not artifact exclusivity. Such a reconception aligns well with Boud and Falchikov's (2007) [24] argument that sustainable assessment requires the development of learners' evaluative judgments, as well as Dawson's (2020) [25] model of ensuring the security of assessment through process evidence rather than product evidence alone.

6. Structural Tensions in AI-Saturated Project Ecologies

Incorporation of AI into the curriculum produces structural conflicts that need to be taken into account in the governance approach to curriculum design. They are not simply minor irritations but represent deeper contradictions between the capabilities of AI and project-based learning as an epistemological goal. Unattended, each conflict is liable to undermine one or several elements of HEG theory.

6.1. Efficiency versus Epistemic Depth

As stated in Section 2.1, generative AI is able to overcome procedural challenges before learners become involved in dealing with any concepts involved in them. Without proper reflective thinking, learners would be involved in completing tasks as part of projects at surface levels, producing correct answers but failing to construct robust models in their minds. This highlights the role of epistemic discernment in the framework of HEG: the absence of difficulty prevents learners from exercising judgment.

6.2. Assistance versus Dependency

AI can be used without regulation to develop a culture of dependency. There is a need for control measures that will ensure that learners act as cognitive beings and not mere consumers of the AI product. This issue is particularly important in initial classes since learners do not have enough domain knowledge to make judgments on the contribution of the AI system [17]. Failure to regulate AI could impair the governance competence that HEG aims to build.

6.3. Creativity versus Homogenization

Since generative models often resort to common architectural templates, this makes the likelihood of arriving at converging solutions higher for student submissions. This is because where there are multiple prompts from different students using the same model that bear resemblance, the output generated is bound to show structural resemblance that would not otherwise have been possible. The above overlap raises concerns not only about the validity of testing but also about developing algorithmic reflexivity since students who continue getting similar outcomes may start considering AI advice as an absolute truth instead of just another alternative among others.

6.4. Automation versus Accountability

Authorship that is distributed does not clarify responsibility for any design decision unless it is explicitly accounted for. In the conventional form of PBL, authorship is still identifiable as it is conducted through collaboration via commit logs, design discussions, and peer evaluations. The process becomes more complicated when the contributions of AI are mixed with those of humans at a finer level of granularity.

Table 2 maps each tension to the HEG dimension most directly implicated in its resolution.

Table 2. Mapping of structural tensions to HEG framework dimensions

Structural Tension	Primary HEG Dimension
Efficiency vs. Epistemic Depth (§6.1)	Epistemic Discernment
Assistance vs. Dependency (§6.2)	Governance Agency
Creativity vs. Homogenization (§6.3)	Algorithmic Reflexivity
Automation vs. Accountability (§6.4)	Authenticity Reconstruction

7. Design Principles for Governance-Oriented Project-Based Learning

To operationalize HEG within undergraduate computer science education, the following design principles are proposed.

7.1. Structured AI Interaction Protocols

Students should engage AI within predefined phases:

- Ideation phase
- Exploration phase
- Evaluation phase
- Integration phase

Every stage includes reflective pauses whereby the learners have to document their thinking before proceeding further. Arranging the AI engagement in such a way helps solve the efficiency-depth dilemma through built-in interruptions in rapid processes.

7.2. Mandatory Rationale Documentation

Students must document:

- Prompt construction logic
- Output evaluation criteria
- Modification decisions
- Architectural integration rationale

The process of documentation serves a double purpose. It promotes the formation of the governance agency by forcing the students to explain the logic behind their decisions, and it provides the basis for authentication in the evaluation process.

7.3. Prompt Transparency Requirements

Prompt engineering becomes part of the evaluation process by design. Prompt logs must be submitted along with final products. This requirement transforms prompting into something that can be evaluated, which makes visible the deliberation process that shapes AI contributions [31].

7.4. Process-Oriented Rubrics

Assessment rubrics allocate significant weight to:

- Decision transparency
- Reflective analysis
- Error identification
- Ethical awareness

In this case, it differs significantly from the conventional method of evaluating PBL work, which mostly focuses on how functional the product is and how complete it is. The process rubric directly evaluates the automation-accountability problem by evaluating the quality of governance and not just that of the product. This type of rubric complies with Wiggins's (1998) criteria for effective educative assessments [32].

7.5. Reflective Governance Journalss

Journals that are reflective in nature help foster metacognition and assist in developing epistemic discernment. They allow the students to record the inputs from the AI and how they critically examined them and either accepted or refused them, along with their reasons. These journals serve as longitudinal documentation of the growth in governance competence throughout the course of the project.

8. Methodological Blueprint for Empirical Validation

Even though theoretically grounded, HEG is empirically testable. The four dimensions of the framework—discernment, reflexivity, governance, and reconceptualization—are distinct theoretically but must be operationally defined before measurements can be undertaken. This chapter provides a methodology map that will direct future research.

8.1. Latent Constructs

Future studies may operationalize the following constructs:

- AI Engagement Intensity
- Governance Competence
- Metacognitive Regulation
- Authenticity Perception

The mapping of each construct on to one or more HEG dimensions enables scholars to evaluate the validity of the theory's internal consistency and predictive power.

8.2. Analytical Strategies

Recommended analytical methods include:

- Structural Equation Modeling (SEM)
- Multilevel Modeling (MLM)
- Cross-lagged panel designs
- Latent Profile Analysis
- Mixed-method artifact trace mining

Longitudinal research designs would be ideal in examining how the capacity for governance skills develops. There should be at least three data collection points within one academic semester for the study to be successful.

9. Boundary Conditions

The implementation of HEG is contingent upon several contextual variables:

- Baseline disciplinary knowledge
- Institutional AI policy frameworks
- Instructor governance literacy
- Task complexity level

Without an enabling institutional structure, governance-based frameworks may degenerate into either outright bans or total adoption—opposites which HEG seeks to avoid.

10. Implications for Undergraduate Computer Science Education

There are structural considerations inherent within HEG for the reform of undergraduate computer science curricula. Four areas should be considered.

10.1. AI Literacy as Core Competency

AI literacy should extend beyond being a set of skills to use AI to a level where AI is interrogated and governed. At present, most curriculum programs regard AI as a knowledge area (in machine learning classes) or productivity tool (in software engineering classes) but not an epistemic object. Including HEG practices in current subjects will ensure that AI literacy is developed in all programs rather than just within elective courses [20-21].

10.2. Prompt Engineering as Epistemic Practice

The design of prompts should not only be viewed as a technical ability but as an intellectual ability as well. The ability to prompt effectively involves skills that relate to the dimensions of epistemic discrimination and algorithmic self-reflection of HEG.

10.3. Assessment Reform

Assessment procedures need to examine epistemic governance procedures and not just concentrate on the novelty of products. This entails incorporating the process-based criteria, transparency mandates, and governance reflection journals outlined in Section 7 into assessment structures. These measures conform to trends towards authentic assessment in academic institutions [32-33].

10.4. Faculty Development

There is need for the educators to be equipped with training on AI facilitation, ethics, and governance-based pedagogy. If the faculties are not well-prepared, HEG may continue to remain an academic concept and fail to become a pedagogic practice. Training should include both technical AI competency and pedagogical skill needed to design governance-relevant activities [34].

11. Conclusion

While GenAI is not an end to project-based learning, it transforms the epistemological basis on which such learning was previously grounded. Project-based learning relies on three premises, namely effort epistemology, artifact-based understanding, and human-centric distribution, all of which become untenable once AI is allowed to participate actively in the epistemology of projects.

The Hybrid Epistemic Governance paradigm emerges as a theoretically-driven approach to ensuring rigor, authenticity, and accountability in computer science education that incorporates AI technologies. The four-dimensional framework of epistemic discernment, algorithmic reflexivity, governance agency, and authenticity reconstruction enables a conceptualization of project-based learning in terms of distributed intelligence among human and machine entities.

Through conceptualizing the process of learning as the governance of cognitive systems composed of human and artificial intelligence components, HEG transcends the simplistic views of technological disruption towards developing a promising paradigm for the future of epistemic ecologies. There are limitations to the theory that must be taken into consideration, such as the need for practical application and testing; its success is contingent upon meeting certain contextual boundary conditions; and finally, it needs to be studied outside computer science education.

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