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Scaling Complex Thinking: A Conceptual Framework for AI-Supported Inquiry-Based Learning

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ABSTRACT

As higher education faces the realities of technological advancements, institutions face the challenge of fostering high-level cognitive competencies while maintaining scalability. This paper proposes a holistic framework that integrates inquiry-based learning (IBL) with artificial intelligence (AI) to support learning. While traditional IBL is pedagogical and resource-intensive, the proposed model utilizes AI as a scaffolding layer, transitioning its use from an output generator to a metacognitive coach. Utilizing a conceptual framework methodology, the study maps the approaches between the stages of inquiry and AI interactions. In addition, the paper explores the institutional implications for teacher training and technological governance, arguing that the sustainability of such a system depends on shifting assessment from content mastery to measurable complex thinking skills. This contribution provides a cohesive foundation for administrators and educators seeking to implement active pedagogies in this era of AI.

Keywords: inquiry-based learning, AI, metacognition, scaffolding

INTRODUCTION

In the aftermath following the disruption caused by the COVID-19 pandemic, UNESCO (2022) invited stakeholders to consider a new vision for education to reimagine pedagogy with learner-centered approaches grounded in the idea that education is a public good rather than a commodity. Similarly, Ramírez-Montoya et al. (2022) argued for shifting pedagogies that recognize complex thinking as a necessary competency for the future, meaning critical, creative, scientific, and systemic thinking that allows learners to navigate uncertainty in a digital-first society, but pose the question regarding how that might be accomplished at scale. This study defines complex thinking as an overarching competency that synthesizes critical, creative, and systematic thinking. While critical thinking focuses on evaluating evidence and systems thinking focuses on interconnected structures, complex thinking is the capacity to integrate these modes to solve problems. Metacognition functions as the backbone of this process.

Inquiry-based learning (IBL) is one such learner-centered approach that is widely recognized for accomplishing student-led construction of knowledge. Rather than passively receiving information from a teacher, the student actively asks questions, investigates problems, analyzes evidence, and develops explanations (Hmelo-Silver et al., 2007). This means the teacher is responsible for guiding and scaffolding in support of the learner. While IBL has been shown to be ideal in many ways, scaffolding requires instructors to continually assess individual students' understanding and provide tailored support (Lazonder & Harmsen, 2016). This is a time-intensive process that does not scale well to large numbers of students. Artificial Intelligence (AI) has been touted as the answer to personalized learning (Yu & Chauhan, 2024), but it has been unclear how best to implement AI to support learner needs. The authors of this paper propose that AI tools be integrated into IBL as a way to scale that scaffolding.

To position inquiry-based-learning as a pedagogy for the development of complex thinking skills, the following research questions are the focus of this paper: 1) How do the stages of IBL support complex thinking? 2) How can a new framework integrating AI support the implementation of IBL at scale? A conceptual framework methodology will be utilized since the focus is on understanding rather than on predicting (Jabareen, 2009). To operationalize this, a problem space was defined, which identified the tension between scaffolding and scalability, and literature was selected using seminal and recent peer-reviewed sources focusing on IBL mechanics, complex thinking definitions, and educational AI interfaces. These sources were mapped to group technological capabilities with specific cognitive demands. These synthesized concepts were integrated into a new framework and discussed in the form of implications for the field. This approach involves developing a network of interrelated concepts through the synthesis of literature to guide interpretation for the phenomenon being investigated through the research questions (Jabareen, 2009).

Although current literature addresses isolated AI tools for personalized learning (Yu & Chauhan, 2024) and the importance of scaffolding in IBL (Lazonder & Harmsen, 2016), there is a lack of any frameworks that combine the two to solve the scalability problem. This paper addresses that gap by presenting a framework that maps AI interactions onto the stages of IBL.

THEORETICAL FOUNDATION

In their comprehensive synthesis of inquiry-based learning, Pedaste et al. (2015) positioned IBL as a cyclical process consisting of orientation, conceptualization, investigation, conclusion, and discussion, emphasizing the iterative process of learning across phases. Their research situates inquiry as a driver of complex and metacognitive thinking by requiring learners to plan, monitor, evaluate, and reflect on both their understanding and the inquiry process itself. The main tenets of IBL include a strong focus on active learning, scaffolding of tasks, and the possibility of individual or group learning (Ernst et al., 2017), and a lifelong love for learning (Sam, 2024). Hattie's (2023) prominent meta-analysis research highlighted that unguided discovery learning has a lower impact than guided inquiry, which supports the idea that scaffolding is necessary for IBL to be effective. Aditomo et al. (2013) emphasized the disciplinary variation in how inquiry is enacted, meaning that IBL cannot necessarily be scaled using a one-size-fits-all model but rather requires discipline-appropriate task design. This framework, therefore, remains flexible across disciplines.

Some of the actions associated with IBL are experimenting, thinking, asking, working with ideas, promoting curiosity, collaborating, and engaging (Ernst et al., 2017; Sam, 2024). Sam (2024) described IBL as a way to help students construct their personal understanding, and declared such an approach to be possible and beneficial across disciplines and differing education levels. Likewise, Bell et al. (2010) characterized collaborative inquiry learning as engagement that promotes students' ability to monitor, evaluate, and reflect on their reasoning. The very essence of IBL is the manner in which students are situated at the very core of the teaching-learning process and experience (Adeyele & Ramnarain, 2024). A systematic review of IBL across a range of educational settings revealed efficacy and positive impacts on students' motivation levels, critical thinking abilities, and academic performance (Sam, 2024).

One of the key considerations and factors regarding IBL efficacy was technological integration (Sam, 2024). This is not a new idea as Bruce and Bishop's (2001) study on language learning positioned IBL as a social process in which learners use the web to pose questions, access multiple perspectives, and construct meaning through exploration and dialogue, framing this form of inquiry as a catalyst for metacognitive thinking. The role of metacognition must be accounted for at a time when students have an added temptation to allow technology to essentially think for them or replace the personal onus regarding the learning process. It has been shown that IBL has a positive impact on students' metacognitive abilities (Lelasari et al., 2021; Pambudi et al., 2022), and in the pursuit to preserve the human connection to the learning process, the relationship between IBL and metacognition presents as a key area of interest in the quest for appropriate AI use in education.

Rather than view AI integration with apprehension, this paper advocates for AI-supported IBL that preserves and enhances metacognitive thinking. Adeyele and Ramnarain (2024) mentioned ways in which students' relationship with learning is increasingly impacted by AI, and that tasks previously only described in human terms (i.e., learning, decision-making, etc.) are now described using AI prompts and outputs. New pedagogical approaches, founded upon a research-based argument for the efficacy of IBL when fostering students' metacognitive abilities, must be utilized so that the possibilities associated with AI in education can be harnessed for good. The conceptual model illustrates relationships between AI interaction, metacognitive processes, and learning outcomes.

PROPOSED AI-SUPPORTED IBL FRAMEWORK

In a commentary on machine learning and human intelligence, Luckin (2018) described how AI can help with metacognition and highlighted the need to "*invest in the development of the AI systems to support and evaluate our students' meta-intelligence*" (p. 131). While early meta-analyses confirmed that digital scaffolding significantly enhances cognitive outcomes in online higher education (Doo et al., 2020), recent developments in AI have further extended this by driving complex thinking through real-time, adaptive support (Álvarez-Icaza et al., 2025). For example, Álvarez-Icaza et al. (2025) showed how AI can trigger skills like creativity in ideation. Moreover, when used ethically, AI "*enhances scalability in grading and feedback, particularly in large-scale online or hybrid environments"* (Álvarez-Icaza et al., 2025, p. 2). In a recent white paper by Anthology, it was proposed that Bloom's taxonomy be reframed for the age of AI to address "*cognitive complexity, such as interrogating machine outputs*" (Clark, 2025, p. 6). AI-mediated scaffolding differs from teacher-led scaffolding in its timing and scale. Traditional scaffolding relies on an intervention by an instructor who diagnoses a student's performance after a task is completed. In contrast, AI scaffolding provides an instant intervention during the task itself. While human instructors must balance the needs of an entire cohort, AI provides an individualized approach that adapts instantly to the specific learning journey of a single learner. Building upon these studies, the authors of the current paper propose an AI-supported framework for IBL.

This framework (see **Table 1**) improves complex thinking by transforming technological outputs into internal cognitive processes during each phase. In the question phase, the AI's critique compels the student to clarify or improve their reasoning. In the Investigate and Create phases, AI prompts self-evaluation, allowing the student to justify or refine their own thinking. During the Discuss and Reflect phases, the AI introduces conflict, challenging the student's assumptions or logic. In doing so, the student develops a deeper understanding of the content.

Table 1. AI-Supported Framework

Traditional IBL Approach	Examples of AI IBL Approaches	Nature of Interaction
Question	Use AI for iterative dialogue in critiquing research questions	AI acts as a challenger, forcing the student to defend their inquiry's scope
Investigate	Use AI for systems thinking/synthesis	Student provides raw data, AI suggests patterns, student validates/refutes
Create	Use AI for concept mapping	AI helps externalize relationships among ideas, proposes alternative organizational structures, and prompts the student to justify or revise conceptual connections
Discuss	Use AI for bot conversations	AI adopts multiple stakeholder or theoretical perspectives, prompting the student to compare viewpoints, clarify assumptions, and refine arguments
Reflect	Use AI for metacognition	AI summarizes the student's own logic back to them to highlight cognitive gaps.

IMPLICATIONS FOR TEACHING AND LEARNING

AI integration is not a topic for the short term; rather, it represents the future of education, learning processes, pedagogical approaches, and the manner in which instructors and students interact with content. Practitioners are advised to view AI as more than a content editor or output generator, but as a coach to guide decision-making. IBL, as a learning approach, must take into account the role of AI and how, not if, instructors and students can adapt. While some stakeholders remain concerned about large language models, others are ready to move on to an acknowledgement of the reality of a new learning landscape. Rather than throw out tested and confirmed pedagogical approaches, one being IBL, ways to integrate and capitalize on AI capabilities are proposed as a better route.

One suggestion regarding a path forward that protects and still promotes the benefits of inquiry as a catalyst for learning is to prioritize AI tools that scaffold questions rather than just provide answers or outputs. Encouraging students to ask questions of AI for the sake of learning rather than output regurgitation is one way to help preserve curiosity, a key component of learning (Wade & Kidd, 2019). Prompts that are more reflective can be helpful if the goal is to incorporate a metacognitive component and deep learning, an aspect of the learning process that many instructors fear will be eroded by irresponsible AI use (Clark, 2025).

As has been argued in this paper, metacognition must remain a point of focus for practitioners, and AI can be used by curriculum developers to produce reflective prompts in this direction. Schools, districts, and HEIs would be wise to consider training opportunities for instructors and curriculum developers to shift from simply teaching content by way of AI outputs to facilitating IBL by way of AI-generated prompts focused on human ethics and metacognitive discoveries. Along these lines, new frameworks for assessing whether student learning outcomes are being met should be developed with a proactive acknowledgement of AI rather than a reactive attempt to mitigate AI use. Rather than measure learning according to content mastery, learning should be measured in terms of levels of complex thinking, which can be accomplished when metacognitive skills are fostered, and IBL is utilized.

Practically, this shift in assessment can be operationalized using existing methodologies. For example, instructors can implement rubrics that grade the quality of argument and reasoning depth found within a student's documented AI chat logs, rather than grading the final essay. Likewise, students could complete brief recorded audio reflections detailing how and why they chose to challenge or accept an AI's critique. AI can be a partner in these efforts if practitioners are encouraged to approach it with a realistic and opportunistic mindset rather than a fearful or reactive attitude (Clark, 2025).

The sustainability of this system requires a robust governance model due to ethical challenges associated with AI in education. Institutions must address structural risks like algorithmic bias, data privacy, and academic integrity, and ensure that the AI tools used for IBL scaffolding are transparent, data-secure, and pedagogically aligned. Left unmanaged, these issues actively undermine the pedagogical goals of the framework. This involves creating systems where instructors maintain oversight of AI interactions, ensuring that the technology promotes digital equity rather than widening the achievement gap. Likewise, using this model would require institutions to overcome any AI literacy disparities among students and faculty. If AI tools are restricted by budgets, uneven access could widen the digital divide. Managing this technology could introduce workload challenges, so faculty would need to be given the time and training to pivot to this model.

LIMITATIONS & FUTURE RESEARCH

Because this study is limited by its conceptual nature, it is suggested that new original research be conducted that asks the following research questions: (1) How can AI-enabled tools be designed and integrated to effectively scaffold the iterative steps of inquiry-based learning? (2) To what extent does this AI-supported IBL approach enhance students' complex thinking skills compared to traditional IBL? (3) How does AI-supported IBL affect students from underrepresented backgrounds? One idea might be a mixed-methods approach, utilizing a quasi-experimental design across multiple course sections. The intervention group could use a platform incorporating AI-supported feedback, perhaps using custom generative pre-trained transformers (GPTs), question-refinement tools, and conceptual mapping during their inquiry projects. Quantitative data, such as pre/post-tests on critical thinking or the metacognitive awareness inventory (MAI), could be complemented by qualitative data from student interviews to understand the impact of the AI tools on their learning process. The findings would provide validation for the proposed framework, thereby offering scalable, practical strategies for embedding complex thinking and metacognitive skills using technology.

CONCLUSION

The transition toward the future of education requires a fundamental shift from passive content delivery to the cultivation of complex thinking within technology-based learning systems. This paper has demonstrated that inquiry-based learning (IBL) provides the pedagogical rigor necessary for this evolution, while AI offers the scalable scaffolding previously missing from student-led inquiry. By integrating AI not as an answer-giver but as a metacognitive partner, institutions can resolve the tension between personalized instruction and large-scale enrollment. The proposed AI-supported IBL framework serves as a foundation for this new era, emphasizing that the value of educational technology is not in the automation of tasks but in supporting critical reflection. Ultimately, the successful integration of these systems depends on a proactive governance approach that prioritizes ethical interaction and shifts the metrics of success from rote information retention to the mastery of complex thinking.

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