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Designing an AI-Augmented Knowledge Synthesis Tool for Collaborative Learning

Xinran Zhu, Bo Shui, Ishita Asnani, Liam Magee
xrzhu@illinois.edu, boshui2@illinois.edu, iasnani2@illinois.edu, lmagee@illinois.edu
University of Illinois Urbana-Champaign

Abstract: Knowledge synthesis involves the deliberate integration of diverse information to generate new insights and creative solutions. In CSCL, it is both a process—where students advance collaborative knowledge—and a product that facilitates ongoing learning. We introduce a novel technology that scaffolds students' knowledge synthesis in collaborative learning environments augmented by generative AI. The poster presents its design rationale, technical details, and future directions for iterative development and classroom implementation to support knowledge synthesis in CSCL.

Introduction

Knowledge synthesis refers to the deliberate and strategic integration of diverse strands of information to foster conceptual innovation and design creative solutions (Deschryver, 2014; Morabito & Chan, 2021; Qian et al., 2020). It is a higher-order cognitive process that extends beyond remembering and understanding (Bloom et al., 1956), playing a central role in human learning and knowledge production. Broadly, knowledge synthesis drives conceptual change in science learning (Chi et al., 1994), fuels innovative scientific discoveries (Morabito & Chan, 2021), and sustains knowledge building processes that enable learners to rise above peers' ideas to advance shared understanding and foster innovation within communities (Scardamalia & Bereiter, 2014).

Knowledge synthesis plays a vital role in collaborative learning. Consider an undergraduate class where students engage in online discussions about their readings before coming to class. By synthesizing these discussions, students analyze and build on their collaborative knowledge, and the resulting synthesis artifacts help guide in-class dialogue to further deepen their thinking. In this sense, knowledge synthesis serves both as a *product* that reflects what students have learned and as a *mediator* that supports ongoing learning (Zhu et al., 2026). The quality (e.g., clarity, depth) and format (e.g., visual representation of ideas) of these synthesis artifacts are associated with how effectively they support ongoing learning. Effective synthesis artifacts not only capture key ideas but also make them easier to revisit, build upon, act on, and share in future collaborative tasks (Morabito & Chan, 2021; Zhu et al., 2026). However, creating effective syntheses is both rare and challenging due to the cognitive demands involved as well as inadequate support from information systems (Morabito & Chan, 2021; Qian et al., 2020; Zhu et al., 2026). In our previous study, the synthesis artifacts created by students tended to lack cognitive complexity and contextual information, limiting their potential for reuse and further evolution in computer-supported collaborative learning (CSCL) (Zhu et al., 2026).

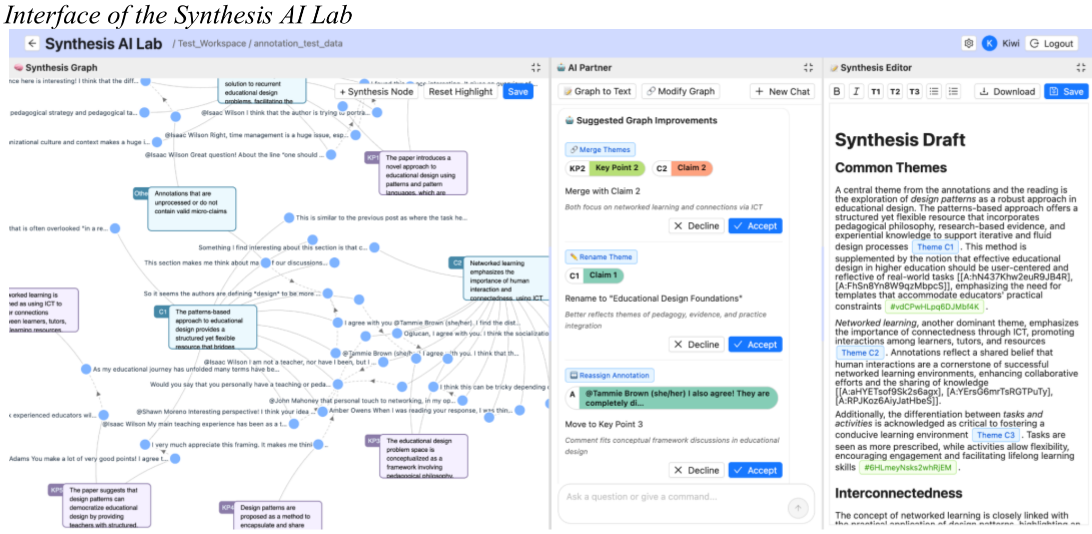
To address these challenges, we present *Synthesis AI Lab* (SAIL), an AI-driven learning platform informed by CSCL and HCI research (e.g., Morabito & Chan, 2021; Qian et al., 2020; Scardamalia & Bereiter, 2014; Tricco et al., 2011). SAIL is designed to scaffold the complex cognitive work involved in synthesis. It helps students connect ideas, include sufficient contextual information, and produce synthesis artifacts that are actionable and generative for future learning. In our context, SAIL is designed for a CSCL environment that begins with social annotation. Social annotation refers to the practice of reading shared texts on digital platforms such as Perusall, where students highlight passages, write annotations, and respond to one another. This process makes students' emerging ideas visible and creates a foundation for collaborative learning. SAIL then supports students in synthesizing these ideas into more integrated forms that can inform later in-class discussions, group work, or writing tasks.

The Innovation: Synthesis AI Lab (SAIL)

SAIL is an extension to the Synthesis Lab, which is a web-based application developed by our team to support students in synthesizing their contributions from social annotation activities (Zhu et al., 2023). It breaks down the complex process of synthesizing knowledge into smaller, manageable steps, such as distilling ideas from annotations and categorizing peers' ideas into conceptual building blocks. SAIL extends the Synthesis Lab in three ways, as shown in Figure 1. First, it introduces a *Knowledge Synthesis Graph* (Shui & Zhu, 2026) that visualizes the current state of student knowledge reflected in their annotations as a graph (left panel). Second, it introduces an *AI partner* that scaffolds the knowledge synthesis process by suggesting thematic links, surfacing conceptual gaps, and prompting reflection to engage in productive knowledge building activities (middle panel). Third, a *Synthesis Editor* is integrated with the graph and AI partner, enabling the automatic generation of text-based syntheses from the graph, which students can further edit (right panel).

As illustrated in Figure 1, the graph is structured around *individual annotations* (nodes), *synthesis nodes* (rectangles) representing higher-level ideas synthesized from related annotations, *epistemic relations* linking these elements, and metadata such as reply threads and author information. The graph is generated using large language models (LLMs). In the current prototype, GPT-4o (Hurst et al., 2024) was prompted at a low temperature (0.2).

Figure 1
Interface of the Synthesis AI Lab



SAIL's AI system generates an initial synthesis graph by processing data extracted from the social annotation platform Perusall. This graph then serves as a knowledge artifact for student interaction and refinement. Students can further analyze annotations by reassigning them to different synthesis nodes, create new synthesis nodes, revise existing ones, and refine the epistemic relations. They can also document their reasoning as contextual information for later use. Throughout this process, the AI Partner can support students in advancing the graph. It is powered by multiple AI agents that interact dynamically with the synthesis graph and annotation data via structured JSON files. These files encode the key elements of the graph, providing context for the LLMs. Working in coordination with the graph and the synthesis editor, the agents support the synthesis process as a form of human-AI collaboration. All the agents and workflows are incorporated with the Chain-of-Thought (Wei et al., 2022) technique to enhance LLM in reasoning capability and context information retrieval from the graph.

Three core features of the AI partner include: (1) In-Sync Interaction: As users engage with the graph, such as by clicking on a node, the system automatically highlights related elements (e.g., annotations, synthesis nodes, and linked replies). The AI partner provides summaries and follow-up prompts in the chat interface, encouraging focused and deeper thinking on the highlighted threads. (2) Reflection Promotion: Beyond manual graph interaction, the Modify Graph agent suggests actionable improvements. Users can accept or reject these suggestions or continue the dialogue to reflect and extend their thinking during the knowledge building process. (3) Connected Synthesis: The Graph-to-Text agent generates written syntheses from the synthesis graph and AI interactions. The synthesis text is linked to both the graph and the AI partner through automatic references to source annotations, making idea development traceable and preserving important contextual information. The resulting synthesis—a written document complementing the graph view—serves as an alternative representation of collaborative knowledge. Students iteratively refine this document to articulate connections, tensions, and emerging ideas from the annotations, as well as actionable next steps for their ongoing collaborative work.

Next steps

Future work will iteratively evaluate and refine the SAIL platform through design-based research. One example use case of SAIL is to help students synthesize annotations before class and use these syntheses to support in-class discussion. Classroom implementation studies will examine how the system supports human-AI collaboration in CSCL, offering empirical insights into AI-augmented learning and collaboration.

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