

The Evolution of Shared Artifacts in CSCL: A Knowledge Synthesis Intervention for Productive Collaborative Discourse

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Abstract: In CSCL, productive collaborative discourse requires continual advancement of student ideas, often through the creation and modification of digital artifacts. To support this process, this study proposes a knowledge synthesis intervention, supported by technological and pedagogical designs, to facilitate the continual development of digital artifacts in a graduate class. To examine the enactment of this intervention, we asked: How did the knowledge synthesis artifacts facilitate the progression of collaborative discourse? How did they facilitate the development of shared group artifacts? Findings revealed diverse ways in which synthesis artifacts facilitated discourse navigation, fostered various knowledge practices, and facilitated the evolution of group artifacts. This study contributes to CSCL and online learning research by facilitating knowledge synthesis and examining its role in deepening collaborative discourse, generating technological and pedagogical designs applicable in broader contexts.

Introduction

Collaborative discourse is one central focus in computer-supported collaborative learning (CSCL) emphasizing the creation and advancement of students' ideas through interactions (Paavola & Hakkarainen, 2005; Scardamalia & Bereiter, 2006). These ideas, considered *conceptual artifacts* emerging from discourse (Bereiter, 2002), can be represented as digital entities (e.g., discussion posts), allowing intangible ideas to be materialized, articulated, shared, connected, and extended over time (Hakkarainen, 2009). In CSCL, the continual advancement of digital artifacts is essential for maintaining productive discourse and fostering deeper collaborative inquiry (Damşa, 2014; Knorr Cetina, 1997; Paavola & Hakkarainen, 2021). However, continually improving these artifacts through discourse remains a challenge for learners. First, the advancement of these artifacts requires deep engagement, which can be particularly difficult when a large volume of digital artifacts emerges across different platforms (Dillenbourg et al., 2009; Suthers et al., 2010). Meanwhile, there is a lack of intentional pedagogical and technological support to help students effectively work with these artifacts, which are often "trapped" in specific tools and cannot easily move across platforms and contexts to support emerging knowledge goals. These artifacts often remain in their preliminary forms without being supported to go through stages of synthesis to morph into something of greater significance. More work is needed to develop CSCL designs that support continual advancement of digital artifacts across different contexts and throughout their lifespan.

To address this need, we propose a *knowledge synthesis intervention* designed to support collaborative discourse activities on a social annotation platform. Knowledge synthesis is one important form of human cognition. It is defined as the process of skillfully and strategically weaving together diverse strands of information to foster conceptual innovation, generate novel knowledge, and design creative solutions (Morabito & Chan, 2021; Nonaka & Takeuchi, 1995; Qian et al., 2020). Through the design and enactment of the knowledge synthesis intervention, we aim to achieve two primary goals: (a) to support students in creating and advancing their ideas through knowledge synthesis, and (b) to investigate how student-generated syntheses promote interaction and deepen discourse. To achieve these goals, the intervention included both a technological tool—*the Synthesis Lab*—and pedagogical support designed to facilitate knowledge synthesis in collaborative discourse activities. This study advances CSCL and online learning research by articulating the concept of knowledge synthesis within CSCL and developing both technological and pedagogical innovations applicable in broader contexts.

Facilitating productive discourse through knowledge synthesis

Research from various disciplines has examined processes and concepts related to knowledge synthesis, sometimes under different terms or in implicit manners. For example, information science scholars have studied how researchers synthesize literature both individually and cooperatively for scientific inquiry (Morabito & Chan, 2021; Qian et al., 2020). In the context of education, Linn (2006) demonstrated the benefits of knowledge synthesis, referred to as knowledge integration, in supporting learners to construct a more comprehensive and nuanced understanding of scientific subjects. Moreover, the Knowledge Building model emphasizes the notion of "rise above" to build on previous ideas, leading to the development of novel knowledge (Scardamalia & Bereiter, 2014). While research from various fields has highlighted various facets of knowledge synthesis, these insights



are dispersed and yet to be fully leveraged by CSCL. Efforts are needed to conceptually articulate, support, or empirically investigate knowledge synthesis in CSCL. To address this need, this study marks an initial effort through the design and implementation of the knowledge synthesis intervention. Drawing from the literature, we define knowledge synthesis in the context of collaborative discourse as *the process of connecting, analyzing, and integrating ideas from discourse to foster conceptual innovation, generate novel knowledge, and create solutions.* Through this process, students produce synthesis artifacts—syntheses of their ideas drawn from discourse—which serve both as building blocks for new artifacts and as mediational tools for ongoing collaborative learning.

The present study

This paper reports on a knowledge synthesis intervention enacted in a graduate course on learning and teaching at a research-intensive university in Fall 2023. Ten out of twenty-two students consented to participate. In this class, collaborative discourse occurred weekly across two spaces: asynchronous online discussion focused on course readings and in-person class activities that extended those discussions. The asynchronous discussion was supported by Hypothesis, a social annotation tool used across educational levels to support learning and instruction (Zhu et al., 2020). In this class, students used Hypothesis to engage in social reading by highlighting text, creating annotations, and responding to peers' annotations on about two required readings each week. A variety of artifacts were generated throughout the class, including annotations, syntheses, and documents co-created by students during in-person sessions.

Following a co-design approach (Roschelle et al., 2006), we collaborated closely with the course instructor to develop both pedagogical and technological components of the intervention. The intervention aimed to: (1) support the continual advancement of students' ideas from social annotation to in-person discussions through knowledge synthesis, and (2) deepen in-person discussions by leveraging student-generated synthesis artifacts, i.e., syntheses of their annotations. The pedagogical design included two main components: (1) *a synthesis session* with a lecture on knowledge synthesis and its role in collaborative learning; and (2) two *synthesis weeks* during the semester, in which students revisited prior weeks to synthesize ideas explored in the readings. These individual syntheses were then fed into in-person small-group discussions, where students' synthesis-making processes, we developed a web application named the Synthesis Lab, which is programmed to interface with Hypothesis (but can be extended to support other discussion environments). The Synthesis Lab scaffolds two key synthesis processes: categorizing peers' ideas into conceptual building blocks (Morabito & Chan, 2021) and developing a synthesis of the annotations. For a detailed description of the design, see Zhu et al. (2023).

This study focuses on the second synthesis week, which was selected based on pragmatic considerations. In this week, students reviewed a range of teaching theories covered in previous weeks. During class, the ten participants were organized into three groups, each containing three to four members, to create a synthesis of their individual work. Additionally, they were asked to redesign a "problematic" learning situation underpinned by their group synthesis. Each group recorded their ideas in a shared Google Doc, referred to as the group artifact.

Research questions

To examine the enactment of the intervention, this study investigated the extent to which the knowledge synthesis artifacts facilitated collaborative discourse. Specifically, we asked two research questions (RQs): (1) How did the knowledge synthesis artifacts facilitate the progression of collaborative discourse? and (2) How did the knowledge synthesis artifacts facilitate the development of shared group artifacts?

Analytical approach

To address the RQs, we collected video recordings of in-person class activities from three student groups during the second synthesis week. These included both camera footage capturing students' interactions and screen recordings capturing their engagement with various artifacts (e.g., annotations, individual syntheses). To support the interpretation of this data, we also collected qualitative data from student-generated artifacts, including individual synthesis artifacts and the group artifacts produced during group activities. For both individual and group syntheses, we examined their format (e.g., organization of ideas) and depth (e.g., cognitive complexity, as defined by Granello, 2001). We expected productive syntheses to demonstrate evidence of identifying common themes, exploring interconnections, uncovering overlooked ideas, and linking concepts to broader disciplinary contexts or real-world applications.

To analyze the video data, we conducted interaction analysis (IA) (Jordan & Henderson, 1995; Powell et al., 2003). The analysis included group activity recordings from all three groups, with each session lasting approximately 60 minutes. Relevant events (Linell, 2009) were identified and coded using an adapted scheme comprising three dimensions of group interaction: epistemic, regulative, and other (Damşa, 2014; Damşa et al.,



2010). These events were then analyzed in depth, focusing on dialogue, content, use of synthesis artifacts, development of the group artifacts, and the interplay among these elements. Through this analysis, we aimed to examine how individual synthesis artifacts were leveraged to facilitate ongoing discourse.

Results

Characteristics of students' individual knowledge synthesis artifacts

Before examining how synthesis artifacts facilitated collaborative discourse, we first reviewed the characteristics of students' individual synthesis artifacts to gain an overview of their format and depth. Most syntheses remained at a surface level, often using bullet points to list key ideas without integrating themes or connections. However, the quality and format of syntheses varied across groups. Students in Groups 1 and 3 generally produced concise summaries using bullet points. In contrast, Group 2 students created more sophisticated syntheses, emphasizing connections across readings and peers' annotations. Additionally, while Groups 1 and 2 showed variation in depth and format among group members, Group 3 maintained a consistent format and depth across all students.

Leveraging knowledge synthesis artifacts to facilitate the progression of discourse

Findings from the interaction analysis revealed that students' use of individual synthesis artifacts facilitated the progression of collaborative discourse in two key ways. First, these artifacts played a central role in navigating discourse by (a) *initiating group discussions* and (b) *guiding the flow of group work*. For example, at the beginning of Group 2's discussion, students reviewed their individual syntheses in silence, without a shared plan or interaction. This shifted when one student shared her synthesis, which prompted others to engage, review their own work, and begin building on each other's ideas. While this example highlights how individual syntheses can spark initial group interaction, one episode from Group 3's discussion illustrates how they can guide the structure and direction of collaboration. Early in their conversation, the group agreed to identify common themes across their individual syntheses. This shared goal led them to actively reference one another's syntheses, transition between subtopics, and collaboratively build toward their group synthesis. In both cases, the synthesis artifacts supported not only the initiation but also the sustained progression of collaborative discourse.

Second, the use of synthesis artifacts was closely associated with a range of knowledge practices observed in the discourse, referred to as epistemic actions in the coding scheme. These included (a) *sharing knowledge*, (b) *building shared understanding*, and (c) *generating and advancing ideas*. Knowledge sharing involved students contributing information drawn from their individual syntheses to support group progress. For example, Group 1's interactions were characterized by frequent knowledge sharing, with Ava (all participant names are pseudonyms) taking a leadership role in driving the discussion. In this group, synthesis artifacts were often used as quick reference tools to share relevant points but were less frequently used for deeper deliberation or negotiation. Beyond knowledge sharing, synthesis artifacts facilitated the co-construction of shared understanding of key disciplinary concepts. This process involved various epistemic actions, such as offering explanations, organizing ideas, questioning assumptions, and reframing the group's focus. In addition, the collaborative discourse revealed frequent instances of idea generation and advancement, which often fed directly into the development of the group artifact. These actions reflected a dynamic inquiry process in which participants built on each other's contributions, revisited earlier ideas, and creatively integrated insights from multiple sources. Idea generation occurred both spontaneously and in response to peers' comments, while advancement involved elaborating, refining, and linking concepts across individual syntheses and the emerging group artifact.

Leveraging knowledge synthesis artifacts to improve the shared group artifacts

During the group synthesis activity, the evolution of group artifacts was closely tied to students' individual syntheses. Three key patterns emerged: (1) *direct copying of individual syntheses*, (2) *elaboration and advancement through discussion*, and (3) *integration of multiple syntheses*.

In the direct copying pattern, students transferred their own ideas into the group artifact with minimal modification, often accompanied by brief knowledge sharing actions. This pattern demonstrated the role of synthesis artifacts as "ingredients" of the group artifact. The effectiveness of this approach often depended on the quality and format of the individual syntheses, as well as the productivity of the group discussion. While direct copying could be effective when students had already developed high-quality syntheses, it benefited from strategic regulative actions to promote deeper engagement and idea advancement before integration into the group artifact. The second pattern, elaboration and advancement through discussion, involved ideas from individual syntheses being shared, elaborated, negotiated, and collaboratively refined before being added to the group artifact. In this pattern, individual syntheses served as "catalysts" for collaborative idea development. The resulting group artifact reflected collective contributions, leading to richer and more nuanced content. This highlighted the importance of



active discussion and negotiation in advancing group artifacts and transforming individual ideas into a cohesive group understanding. The third pattern involved the integration of multiple individual syntheses into a cohesive group artifact. This approach reflected deep knowledge synthesis, as students actively engaged with one another's work to co-construct something novel and more comprehensive than any single synthesis alone. It emphasized the collaborative process underlying the evolution of group artifacts and showed how collective efforts could elevate the quality and depth of group artifacts.

Overall, the evolution of group artifacts highlighted the flow of knowledge from individual syntheses to a more integrated whole. The quality of the final products was often tied to the quality of the individual syntheses. However, even less-developed syntheses were leveraged by group members in various ways to facilitate the progression of discourse, leading to group work that expanded upon and built from individual ideas.

Discussion

Knowledge synthesis plays a crucial role in human cognition and knowledge production. Through the processes of connecting, analyzing, and integrating information from diverse strands of sources, it forms the foundation for diverse intellectual endeavors. These processes drive conceptual change in science education (Chi et al., 1994), foster explanatory coherence in the integration of complex theories (Thagard, 1989), catalyze innovative scientific discoveries (Morabito & Chan, 2021), and drive revolutionary shifts in scientific paradigms (Kuhn, 1962).

In CSCL, knowledge synthesis facilitates sustained collaborative discourse and helps structure the intersubjective knowledge that groups of students build together (Stahl et al., 2014; Trausan-Matu & Slotta, 2021). Recognizing the need for designs that explicitly support knowledge synthesis in CSCL, this study designed a knowledge synthesis intervention and investigated its enactment by exploring the role synthesis artifacts played in facilitating collaborative discourse. The results showed that the intervention created a pathway for student ideas—initially embedded in a social annotation platform—to be synthesized into written artifacts. These artifacts were then used to support and deepen collaborative discourse by steering discourse navigation, facilitating knowledge practices, and driving the evolution of group artifacts.

Our findings also highlight that creating effective syntheses is both rare and challenging, primarily due to the cognitive demands involved and the often inadequate support provided by existing tools and information systems (Morabito & Chan, 2021; Qian et al., 2020). We found that most individual syntheses lacked cognitive complexity and sufficient contextual information, which may have limited their potential for reuse and weakened their support for key ideas. These results suggest a need to improve future designs by providing support for contextualizing ideas, maintaining conceptual links, and scaffolding deeper synthesis practices.

Another significant aspect of knowledge synthesis regards its role in deepening collaborative discourse. Our findings suggest several factors that may contribute to a more generative discourse in which students continuously share and advance their ideas. First, group artifacts became more elaborated and complex when individual synthesis artifacts demonstrated higher cognitive complexity. Moreover, reviewing each other's syntheses during discussion appeared to encourage more generative actions, as students worked to integrate ideas from all group members rather than focusing solely on their own. This reflects the role of knowledge artifacts as focal points for joint attention, helping to establish the conditions for productive collaboration (Hmelo-Silver et al., 2007). Finally, strategic regulation—efforts to prompt members to share and build on one another's ideas—was essential. Collectively, the findings highlight that the knowledge synthesis intervention effectively facilitated collaborative discourse, but the process depended on both intentional group effort and the quality of individual synthesis artifacts.

In conclusion, our study contributes to CSCL research by providing both practical and theoretical insights for facilitating productive collaborative discourse. Through the design and enactment of the knowledge synthesis intervention, we have articulated the concept of knowledge synthesis within CSCL and developed both technological and pedagogical innovations applicable in broader contexts. Furthermore, we have empirically investigated the role of knowledge synthesis in CSCL settings, offering insights that can inform future CSCL designs. Future work will focus on refining the design while incorporating larger and more diverse samples to validate and expand upon these findings.

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