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Examining the impact of teacher scaffolding in the knowledge building environment: Insights from students' interaction patterns, social epistemic networks, and academic performance

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Abstract
Promoting progressive discourse and sustained inquiry is a focus area of knowledge building research. Although different approaches for scaffolding productive discourse have been documented, the experimental investigation into the impact of teacher scaffolding on students' knowledge building processes and outcomes in technology-supported environments is limited. Therefore, we designed a quasi-experimental study to examine the impact of teacher scaffolding on students' interaction patterns, social-epistemic networks, and academic performance. Over a 14-week course, data were collected from undergraduates' online interactions, discourse in the Knowledge Forum, and their group artifacts. We employed lag sequence analysis, social epistemic network signature, and the Kruskal-Wallis test to analyze the data and compare the differences between the control and experimental groups. Findings demonstrate that teacher scaffolding can effectively enhance students' reflective behaviors, foster social and epistemic engagement, and improve academic performance within technology-supported knowledge building environments. This study provides valuable insights into the design and implementation of teacher scaffolding to facilitate student knowledge building processes and outcomes.

Keywords Knowledge building · Teacher scaffolding · Interaction patterns · Social-epistemic networks · Academic performance

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1 Introduction

In the current Knowledge Age, it is crucial for educators to promote students' creative thinking, enhance their participation in productive discourse, and reflect on their learning and inquiry (Lei & Chan, 2018). Knowledge Building (KB) provides a framework through which to accomplish these goals. It is a pedagogical approach emphasizing knowledge creation and innovation through collective endeavors. In the KB process, students assume a collective responsibility to work collaboratively and creatively with ideas (Scardamalia & Bereiter, 2006; Hong & Lin, 2019) through productive discourse that aligns with the designated educational purpose (Chai et al., 2023).

Despite a rich literature exploring the implementation of KB processes on the Knowledge Forum (a computer-supported collaborative learning platform), students still struggle to engage in productive discourse for creative knowledge building (Tong & Chan, 2023). Student discussion threads tend to exhibit brevity, fragmentation, and incoherence (Calvani et al., 2010), demonstrating an information-sharing discourse rather than knowledge creation, resulting in a lack of sustained inquiry and productive interactions or collaborations. Due to this, researchers have employed different approaches to scaffold productive discourse, including peer scaffolding (Lai & Law, 2006; Pifarre & Cobos, 2010), teacher scaffolding (Hmelo-Silver & Barrows, 2008; Zhu & Lin, 2023), and hard scaffolds, i.e., the use of technology tools and resources (Shin et al., 2020b; Tong et al., 2023). In all these cases, the researchers focused on task performance rather than the fine-grained process of KB, thus neglecting to draw out the nuanced aspects influencing this collective knowledge creation endeavor. Recently, many KB studies have focused on hard scaffolds, such as technology-supported reflective assessment (Yang et al., 2020b), which relegated the teacher to being an "outsider" rather than an "insider" within the KB process. These studies raise the question, how would students' processes and outcomes be affected if the teacher scaffolding is integrated within technology-supported KB environments rather than being sidelined?

Previous studies on the effect of teacher scaffolding within KB environments showed inconsistent results. Few studies were conducted using experimental designs that simultaneously considered the effect of teacher scaffolding on interaction patterns, social-epistemic networks, and outcome perspectives. Therefore, this study employs a quasi-experimental design and considers all three aspects at once to probe the impact of teacher scaffolding in a technology-supported KB environment. The study featured a combined teacher-plus-technology scaffolding context and examined process-related and outcome differences with technology-only and teacher-only scaffolding conditions. Such an approach overcomes the limitations experienced with an aggregated-level (i.e., across the entire learning session) ex-post-facto research design (e.g., Yang et al., 2022b; Zhu & Lin, 2023), which lacked a comparison group and so could not draw definite conclusions about the impact of teacher scaffolding on students' KB. The following three research questions were investigated:

Q1: What types of student interaction patterns will emerge in experimental and control groups, respectively, under the intervention of teacher scaffolding?
Q2: Will there be differences between control and experimental groups on the social-epistemic networks when teacher scaffolding is used in the KB process?
Q3: Will teacher scaffolding during the process of KB lead to better academic performance?

The significance of this study is twofold: (1) The current fine-grained analysis provides a deeper understanding of how students learn within different scaffolding contexts, and researchers can gain a holistic picture of students' KB inquiry trajectories; (2) On a broader level, the present study sheds light on how to better support teachers in their efforts to scaffold students' productive discourse and to determine which aspects of scaffolding need adjustments. These insights contribute to teacher scaffolding research and inform future teacher support in a KB environment.

2 Literature review

2.1 Approaches to scaffolding KB

Scaffolding can be understood as the cognitive and social support that adults or experts provide to students to enable them to achieve their highest performance potential (Wood et al., 1976). Intrinsically tied to Vygotsky's sociocultural theory (1978) and particularly to his Zone of Proximal Development (ZPD), scaffolding accentuates the significance of social interaction (e.g., peer interaction, teacher-student interaction, and student-tool interaction) as a propellant for student development (Zhu & Lin, 2023). Prior research has recorded the effective use of diverse scaffolding approaches in advancing KB progress, including peer scaffolding, teacher scaffolding, and hard scaffolds, with a predominant focus on academic performance (Lei & Chan, 2018). For example, research has pointed out that peer scaffolding could be an effective strategy to promote productive discourse when learners recognize a gap between their own ideas and experiences and those of their peers (Shin et al., 2020a). By engaging in peer scaffolding practices, specifically, statistical results confirmed that this type of scaffolding positively impacts individual and group achievement (Shin et al., 2020b). Furthermore, teacher scaffolding is crucial to the success of dialogue and collaborative learning. Evidence demonstrates that teachers' employment of uptake and authentic questioning can significantly enhance students' on-task discourse, culminating in elevated levels of student achievement (Kraatz, 2021).

Hard scaffolds are premeditated technology tools and resources designed by teachers or researchers that are employed to support students' KB process. Most research on hard scaffolds employed Knowledge Connection Analyzer (KCA), Analytical Toolkit, and Knowledge Building Discourse Explorer (KBDeX) as technology-supported reflective assessment tools within a KB environment. For instance, Yang's (2021) research found that KCA can help students with their reflective assessment and bolster their KB inquiry. Moreover, some quasi-experimental studies have underscored that analytically supported reflective assessment tools (e.g., KBDeX and the Analytical Toolkit) aid experimental groups in conducting more sustained collaborative KB inquiry (Yang et al., 2022a, b). Students would, therefore, understand concepts more thoroughly than their control counterparts. A collaboration script is an additional tool that specifies the guidelines and instructions required to direct and assist students in behaving during KB. One study, for instance, found that using a collaboration script to scaffold group awareness helps the regulation of emotions and skills and that it may be viewed as a way of offering direction to encourage participation in beneficial KB processes (Hadwin et al., 2018).

The aforementioned approaches—including peer scaffolding, teacher scaffolding, and hard scaffolding—exert a positive influence on KB inquiry. However, these studies often ignored the specific aspects of KB, i.e., interaction patterns and social-epistemic networks, focusing instead on students' academic achievement. KB is a progressive inquiry process with a temporal sequence but flexible micro-level activity transitions between phases, making it crucial to analyze process-based aspects for its dynamic nature.

Recently, a growing number of studies have focused on hard scaffolds, which can be regarded as an effective way to facilitate productive collaborative KB inquiry. However, over-reliance on technological tools without teacher involvement may result in the so-called "replace-by-technology" concern (Mäkitalo-Siegl et al., 2011). Teachers can miss opportunities to provide responsive and personalized support in response to changing student needs. Consequently, the role of the teacher will change from "insider" to "outsider" within the KB process, raising the question: What is the effectiveness of teacher scaffolding in a technology-supported KB environment?

2.2 Teacher scaffolding in KB environment

Teacher scaffolding can be viewed as the ways in which teachers make learning activities more accessible to students by reducing the scope for failure (Mercer, 2000). We argue that teacher scaffolding extends beyond simply directing students toward a definitive answer. Rather, teachers are actively involved in the KB process to ensure a cognitively, epistemically, and socially appropriate environment for the students (Raes & Schellens, 2016), thereby allowing students to embrace their epistemic agency and collective responsibility during learning.

To achieve this outcome, previous research has shown that three types of teacher scaffolding techniques can be used, including *idea-centered*, *suggestion-centered*, and *task-centered* prompts. Among them, the first two prompts are concerned with cognitive and epistemic aspects, while the last pertains to the social aspect.

In *idea-centered* techniques, teachers enhance students' ideas through questioning, aiming to aid groups in the generation and refinement of ideas, improving their quality, coherence, and creativity (Ouyang et al., 2021, 2022). For example, some prompts can be used for group members to question, challenge, and contribute ideas, such as *"Is this idea novel and interesting?"*, *"Can we improve the idea in any way?"*, and *"Is this idea relevant?"*.

Besides the *idea-centered* techniques, *suggestion-centered* techniques are proposed based on idea advancement and task progress, which might provide helpful directions for students' KB. It refers to teachers' further and complete suggestions or advice for student inquiry, varying as per the specific needs of the student groups. For example, *"It is an excellent and innovative idea, and you can obtain additional information online to support it."*, *"You need to improve…"*, and *"It may be worth considering…"*.

Finally, researchers have paid increasing attention to *task-centered* techniques (i.e., metadiscourse) within the KB context (Tong & Chan, 2023; van Aalst, 2009). Specifically, metadiscourse emphasizes that individuals mainly use a metacognitive strategy in dialogue with group members to identify goals, make plans for further inquiry, and then monitor the community knowledge development collectively (Wang et al., 2023). For instance, some prompts aim to remind groups about the main goal, timing, and progress, such as *"What is the goal of your group's knowledge building this week?"*, "*How is your group going?"*, and *"What are the problems and difficulties you encountered during the progress of knowledge building?"*.

Previous studies found inconsistent effects of teacher scaffolding on KB. Regarding the positive effect, teachers' scaffolding in questioning, metadiscourse, and suggestion can both encourage students to contribute ideas and maintain a dynamic KB process. For example, research by Ng et al. (2022) demonstrated that KB performance can be enhanced when teachers assume an "insider" role, not only monitoring student progress but also actively intervening to engage students, assisting them in idea synthesis, and maintaining a vibrant exchange of ideas. In that case, teacher scaffolding is positive and crucial for fostering deep conceptual understanding and yielding favorable results.

Conversely, there are some situations in which teacher scaffolding may have a negative effect on students' KB. First, students' KB may be frustrated by an inappropriate time or direction. Specifically, premature teacher scaffolding can limit students' creativity and diversity of ideas because students simply follow the ideas introduced by the teachers; moreover, it is time-consuming for teachers to analyze each group KB process (Rodríguez-Triana et al., 2020), and teachers may not fully perceive the group's goal with the KB process. Given that, the ideas presented by teachers can be misleading, leading to a deviation from a group's initial KB goals. Second, Cohen and Lotan (2014) argued that if students were on-task, a teacher should monitor students' work without intervening, as excessive teacher scaffolding could disrupt student autonomy and interdependence. Above all, it is more challenging for teachers because they are not used to and often not well prepared for embedding innovative and suitable prompts, which undermines learner agency in the KB environment.

2.3 KB process: Student interaction patterns and social-epistemic networks

Online interaction behaviors are key drives for learning, and they can also be seen as a fundamental part of the process of learning and KB (Yücel & Usluel, 2016). These interactions provide an enduring and reliable record of the ideas postulated and pedagogical strategies deployed, thus making engagement and participation in the KB process integral. Moreover, the analysis of online learners' behavioral patterns offers insights into their nuanced learning characteristics (Ben-Eliyahu et al., 2018).

In this study, we build upon the framework proposed by Yücel and Usluel (2016) and categorize interaction behaviors into four types: *"notes created," "notes edited," "notes read,"* and *"build-on created." Notes created* refers to student-created notes. *Notes edited* means that students rewrite their own notes or the notes created by their group members. *Notes read* indicates that students read the existing notes of their group. *Build-on created* means that students built on their group members' notes in the KB environment. Given the KF is an open space, students could potentially interact with other groups (e.g., they can also read other groups' notes). However, this research only considers behavior patterns between intergroup members. Lag sequence analysis (LSA), which is a statistically significant analysis that can indicate the likelihood that one behavior would occur after another, has been widely used in the literature to find the pattern of temporal interactions (Wu et al., 2022). This study will use LSA to explore interaction patterns between different groups.

There are also other key dimensions of KB that need to be considered, specifically social and epistemic aspects (Gašević et al., 2019; Swiecki & Shaffer, 2020). As explicated by Chen and Hong (2016), a key component of KB involves interwoven conceptual factors, such as epistemological and social factors. Specifically, the epistemic dimension of KB conceptualizes ideas as tangible entities of discourse, subject to creation, analysis, and refinement by individuals. During this process, a community plays a dual role: it provides a forum for KB and serves as a setting where knowledge workers and ideas can interact. The social element is essential for assimilating students into a culture where they begin collectively improving ideas. KB is underpinned by epistemological and social factors, which provide theoretical support for our study. By examining these aspects, we can glean a more granular understanding of the KB processes.

Beyond the aforementioned theoretical underpinnings, Hoppe (2017) introduced a methodological guide, referred to as the "trinity of methods framework," for the examination of KB communities. This framework includes (1) sequence analysis of processes; (2) network structures, including actor-actor (social) networks; and (3) content analysis or other artifact analysis methods (see Fig. 1). Notably, previous studies also verified the importance of having a mix of the above approaches and analysis techniques "at hand" to gain better insight and understanding of the determinants of KB communities (Daems et al., 2014; Wise et al., 2016). Building on theoretical and methodological frameworks, this study aims to examine how teacher scaffolding impacts students' interaction patterns and social-epistemic processes.

2.4 KB outcomes: Student task performance

Among the myriad of indicators that could be leveraged to gauge KB performance, students' activities and artifacts (e.g., group products, such as papers and reports) were mostly used. While students' activities could be regarded as a formative

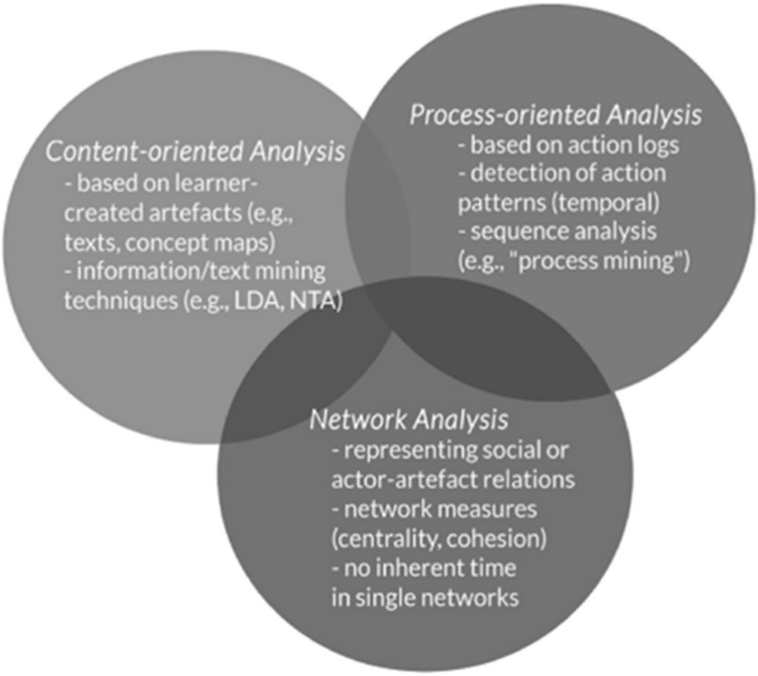

Fig. 1 The "trinity" of methodological approaches (Hoppe, 2017)

indicator for academic performance, students' artifacts accurately reflected their KB outcomes. For instance, Lei and Chan (2018) examined students' participation activities using the Analytical Toolkit (ATK). Students' artifacts took various forms. In Chai and Zhu's (2021) research, group lesson plans were scored to represent the performance of the group. In addition, essay writing was also scored to measure their academic performance. Besides, in the science, technology, engineering, and mathematics (STEM) context, the final STEM products (i.e., umbrella) were evaluated in terms of novelty, resolution and elaboration, and synthesis to reflect their performance (Hong et al., 2019). The ultimate goal of KB is the formation of knowledge products, which are directly related to their group artifacts, so this research mainly focuses on groups' artifacts to represent their KB performance.

2.5 Knowledge Forum (KF): A KB environment

Some technologies are designed to support students' KB practices. KF, a networked software environment, could support knowledge processes and make KB principles apparent to teachers and students. Within this environment, students are provided the opportunity to partake in the continuous refinement of ideas, thereby enhancing collective knowledge. People who belong to the same community share familiar goals or interests. To achieve shared goals, they work together to identify understanding-related problems and put out diverse ideas in the form of public notes to promote continuous progress and produce new knowledge (Bereiter & Scardamalia, 2014).

This environment permits students to harness an array of resources, such as books, videos, online information, and personal experiences, to enhance community knowledge. Additionally, learners can reflect on the pathway that the KB process has taken to calibrate progress with the aid of some discourse reflective tools, such as the KBDeX and Idea Thread Mapper. These features of KF, as validated by previous research, construct a supportive environment that facilitates students in the continual advancement of their knowledge (Hong et al., 2011).

3 Methodology

3.1 Participants

This research undertook a quasi-experiment to assess the impact of teacher scaffolding within the collaborative KB environment. Twenty-five second-year undergraduate students (14 males, 11 females) participated in the course "Design Thinking" over a period of 14 weeks at a key university in Guangzhou, China. The subjects were from several schools of the university, and they majored in software engineering, financial management, web and new media, French, and cultural industries management. This course was designed to develop students' design thinking competency through engaging in creative idea improvement activities.

Participants were randomly divided into six different groups through free teaming ($NG_1=5$; $NG_2=4$; $NG_3=3$; $NG_4=5$; $NG_5=4$; $NG_6=4$). The instructor had a Ph.D. in education technology and six years of teaching experience using the KB approach.

3.2 Procedure

3.2.1 Course design and implementation

The course spanned 14 weeks and consisted of three phases. In Phase 1 (weeks 1 to 2), the lecturer explained the concepts, models, principles, and five steps of design thinking (i.e., empathy, define, ideate, prototype, and test). The primary objective of this phase was to equip students with a fundamental understanding of design thinking to enable practical application and lay a solid foundation for their subsequent studies. In Phase 2 (weeks 3 to 10), the lecture began by introducing the basic functions of the KF platform, the use of customized design thinking scaffolds (e.g., *"users' concerns are…"*, *"the issues we need to address are…"*, and *"tools for creating models are…"*), and the use of the KF platform for collective KB. During the remaining time, students selected a practical problem that related to their personal and professional experiences, selected a topic for a group project, and developed a product according to the five steps of design thinking. In Phase 3 (weeks 11 to 14), each group created and delivered a PowerPoint on their collective products in week

11. After that, the products were continually iterated and improved based on feedback from both teachers and peers during weeks 12–13, and a final presentation was submitted in week 14.

The KF was mostly used by students to carry out KB activities and to create group products. Every week before class, students could view videos and read articles uploaded by teachers, as well as participate in online discussions in the KF. During class, the teacher briefly introduced the activities that the students were expected to complete (*note.* Table 1 shows details of the weekly activities). Moreover, if students did not complete the week's activities in class, the KF allowed them to continue their group products and online discussions after class.

3.2.2 Experimental design

As shown in Fig. 2, participants were randomly divided into three conditions: experimental groups A: the teacher scaffolding and reflective assessment tools were all used to intervene G1 and G2; experimental groups B: G3 and G4 only used reflective assessment tools; and the control groups C (i.e., G5 and G6), which was the same as the two experimental groups in all respects except for not receiving the intervention of assessment tools.

As for teacher scaffolding, this research used *idea-centered* (i.e., questioning), *task-centered* (i.e., metadiscourse), and *suggestion-centered* techniques. Details were as follows: (1) *Idea-centered* prompts included *"Is this idea novel and interesting?", "Can we improve the idea in any way?", "Is this idea workable?", "Is this idea relevant?"*, and *"Is this idea specific to the problem to be solved?"* (2) *Task-centered* prompts included *"What is the goal and plan of your group's knowledge building this week?", "How is your group going?", "What are the problems and difficulties you encountered during the progress of knowledge building?", "What is the gap between the current progress in knowledge building and the desired goal, and how do you want to address it next?"*, and *"Does your final product meet the requirements of the task?"* (3) *Suggestion-centered* prompts refer to suggestions and advice provided by teachers to students based on their weekly discussions. The teacher sent those prompts to both experimental groups A and the control groups via their respective WeChat groups. Additionally, the teacher constructed these prompts in their KB views (i.e., each group had a designated KB space on KF) in accordance with their progress.

The KBDeX program was also used in this study as a reflective assessment tool to encourage students' inquiry. Its graphical user interface's main view is shown in Fig. 3, with four windows: (a) a discourse viewer displaying a summary of the discourse with the selected words (top left); (b) the network structure of learners (top right); (c) the network structure of discourse units (bottom left); and (d) the network structure of selected words (bottom right). The students were provided with videos in advance, which demonstrated how to use KBDeX and how to interpret the results of its data analysis to help them fully understand the meanings of these views before sending them. Afterward, based on their discussion, the teacher sent the above views to groups A and groups B's WeChat group and their KB view every week (from weeks 3 to 10).

Table 1 The detailed information about the weekly activities (weeks 3–10)

Steps & time	Activity objectives	Activity requirements	Evidence required
Empathy (Weeks 3–4)	Selecting the practical and actual problems	Selecting a practical and actual problem from a real-life situation and event and then determining the topic of the group	The discussion on KF to determine the group's design topic
	Surveying targeted users' needs and requirements	Conducting the interviews and questionnaires with targeted users; Analyzing their profiles	User's canvas; Users need reports
Define (Week 5)	Defining the problem and users' need	Reframing and redefining the problem from a human-centered perspective	The framework for the product solution is based on the existing information
Ideate (Weeks 6–7)	Creating ideas; Evaluating and selecting ideas	Creating a variety of ideas that can address the problem during the conceptualization stage; Selecting the best solutions, ideas, and strategies to develop product solutions	The more possible and complete product solutions
Prototype (Weeks 8–9)	Prototyping and designing products	Implementing ideas into tangible forms; Designing product prototypes using a hands-on approach	Products prototype
Test (Week 10)	Testing products	Testing the product with users and learning from their experiences in order to generate further ideas for improving it	Testing reports from users

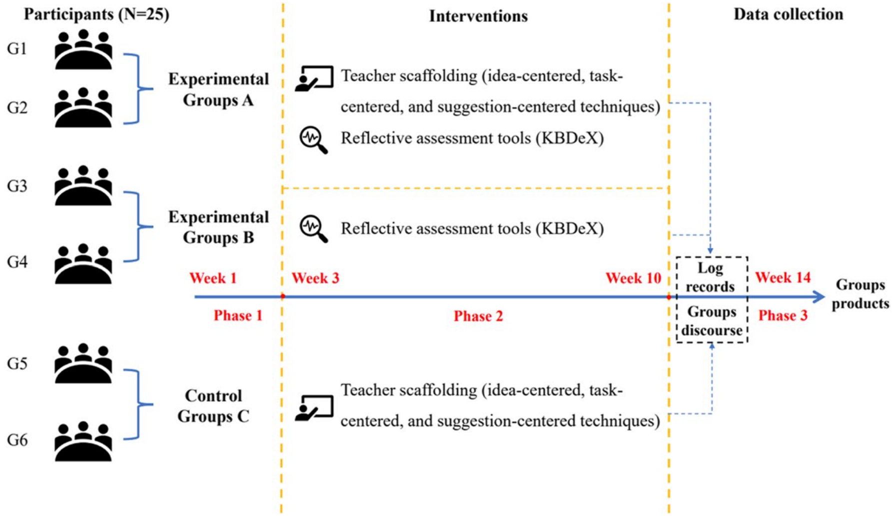

Fig. 2 Experimental design

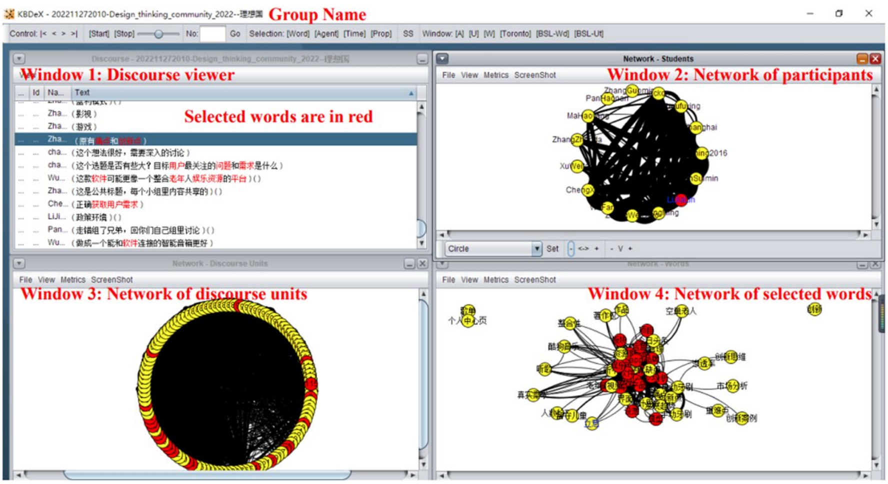

Fig. 3 The main view of KBDeX

3.3 Measures

This study proposed an analytical framework to examine the differences among the three groups from the process and outcome perspective (see Fig. 4). Following this, each data analysis approach was explained in the subsequent sections.

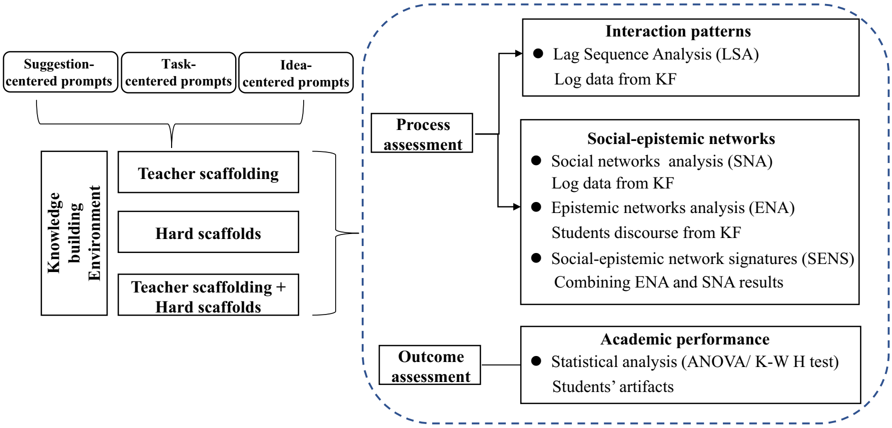

Fig. 4 Analytical framework for data analysis

3.3.1 Interaction patterns of KB

To answer the first question regarding the interaction patterns that emerge in experimental and control groups and the differences between them, we analyzed the log data from KF and then coded it based on a self-developed coding framework (i.e., *notes created* = 1; *notes edited* = 2; *notes read* = 3; *build-on created* = 4). In the next step, LSA was used to compare interaction patterns between the experimental (i.e., groups A and groups B) and control groups (i.e., groups C) using GSEQ 5.1.

For the interaction patterns, the frequency of each KB behavior code immediately followed by another was calculated into the frequency transition table. Then, the adjusted residuals tables (Z-score table) of the three groups were inferred. According to Bakeman and Gottman (1997), if the Z-value of a sequence is greater than 1.96, the connectivity of this sequence reaches statistical significance ($p < .05$).

Finally, the three adjusted residuals tables were visualized to compare the differences in interaction patterns between experimental and control groups.

3.3.2 Social-epistemic networks of KB

Analysis of social structure using social networks Numerous researchers have sought to discover social characteristics using Social Network Analysis (SNA) (Marcos-García et al., 2015). SNA helps identify communities of learners who interact more with each other than with the rest of the network (Gašević et al., 2019), making it a mature method for analyzing social structures. To examine students' social interactions in relation to different groups, we conducted an SNA using Ucinet 6.0 based on the aforementioned three interactive behaviors (i.e., *notes edited*, *notes read*, and *build-on created*).

Specifically, each student was represented as a node in a directed graph with multiple edges ("direct" means that the edges have a direction). Edges symbolize the connection or relationship between nodes, initiating from the originator of the behavior to its recipient. When any of the three interactive behaviors mentioned above occur between two nodes, an edge (or connection) has been established. Importantly, we did not incorporate the *note-created* behavior as it does not establish a connection between nodes.

Moreover, the edges can vary in their connection strength, also referred to as edge weight, indicating whether the relationship is strong (commonly visualized with thick edges) or weak (usually visualized with thin edges). In this study, an edge's weight was determined by the frequency of that edge's occurrence between two specific nodes. For instance, if student A read student B's notes ten times and built on B's notes twice, then the edge weight from A to B would be 12.

Additionally, we used SNA to compute global characteristics such as *weighted density*—defined as the sum of the weighted connections within the network divided by the number of potential connections—and the *degree centrality* of each group member (Zhu et al., 2021).

Finally, to determine whether significant differences exist among the three groups based on their *weighted density* and *degree centrality*, we employed ANOVA or non-parametric tests, such as the K-W test.

Analysis of epistemic networks using ENA Given the intricate interplay between social and epistemic processes—which are functionally interlinked and mutually supportive (Liu & Matthews, 2005)—reliance solely on the SNA methodology is inadequate for capturing the complexities of interactions between social and epistemic dimensions emerging from social ties and collaborative discourse.

To surmount the limitations inherent to the aforementioned methodology, Epistemic Network Analysis (ENA) was employed (Shaffer et al., 2016) to investigate students' epistemic discourse during collaborative learning scenarios. ENA is engineered to model the structure of connections amongst various coded elements—knowledge, skills, and other epistemic elements, for instance—and to represent them in a dynamic network model. Within these models, the co-occurrence of codes within specifically defined data segments is quantified, thereby illustrating the structure and intensity of the connections, termed connection coefficients or weights. Importantly, the nature of the most salient connections in the models could be represented by the position of its centroid (Shaffer & Ruis, 2017; Shaffer et al., 2016). By utilizing these features, salient properties of networks, including networks generated by different teams, can be compared.

To obtain the epistemic networks of different groups, we used the coding framework for content analysis. As for the coding framework, we first used some of the existing frameworks for content analysis (Chai et al., 2023; Yang et al., 2020a; Zhu et al., 2023) to determine the pre-structure. Starting with the above pre-determined coding structure, two researchers then analyzed KB discourse by combining inductive and deductive qualitative approaches (Armat et al., 2018). Finally, the coding framework was developed, having two categories (i.e., progressive discourse and metacognition dimensions) and eight subcategories. The descriptions of these codes are described in Table 2. Notes may fall into more than one category. All notes ($N = 330$) during the eight weeks were coded by two researchers using the coding scheme. We calculated the average agreement using the Kappa coefficient (Kappa = 0.930 > 0.750), which indicated a good consistency of coding results. Then, they discussed the disparities in their understanding and eventually agreed on each note.

To plot the epistemic networks of groups, we used the *condition* and *group* as an analysis unit to conduct ENA based on the above coding results. Notably, the nature of the most salient connections in the models could be represented by the position of its *centroid*. Consequently, an independent sample *t*-test was used for pairwise comparisons based on their centroids, including SVD1 (*x*-axis) and SVD2 (*y*-axis).

Finally, to determine what factors account for this difference among the three groups, we further compared the subtracted networks. These networks were constructed by subtracting the mean connection strengths for the participants in one condition from the mean connection strengths for participants in another condition.

Analysis of social-epistemic networks using SENS While ENA offers robust mechanisms for evaluating epistemic processes and establishing connections with pertinent collaborative learning traits, it lacks rigorous methods for assessing the roles actors embody within collaborative activities and the structures that emerge during the process of collaborative learning (Morris et al., 2008). As previously discussed, SNA is capable of yielding insights of this nature. Consequently, in this study, we leveraged a blend of SNA and ENA—a methodology termed Social and Epistemic Network Signatures (SENS)—to appraise the collaborative learning process, drawing on both the social attributes and the content of collaborative discourse (Gašević et al., 2019).

To address the second research question concerning the variations in social-epistemic networks between experimental and control groups, we synthesized the outputs of ENA and SNA to depict each group's social network within the ENA space. Specifically, we crafted weighted network graphs reflecting the communication frequency among individuals within each group. Unlike in traditional SNA, where node placement is arbitrary, the nodes in these graphs correspond to the positioning of individuals within the ENA space, i.e., their ENA scores. Ultimately, we used the networkx package (https://networkx.org/) in Python to delineate the social-epistemic networks. These illustrations encapsulate both the social structure of group interactions, as evidenced by the edges, and the epistemic structure of discourse connections, as indicated by the locations of the nodes.

3.3.3 Academic performance of KB

To answer the third question regarding whether teacher scaffolding during the process of KB led to better academic performance, we first designed a rubric based on a previous relevant study (Besemer & Treffinger, 1981) for assessing group products

Table 2 Coding framework for the analysis of students' discourse

Category	Subcategory	Description & examples
Progressive discourse (Towards ideas)	Contributing diverse ideas (CI)	Students contribute diverse ideas/theories to an issue or question. *(e.g., [Due to the rapid aging of our population and the growing elderly population, we can provide them with more comprehensive audio-visual entertainment resources, including plays, old movies, and e-books, in order to meet their spiritual and cultural requirements.])*
	Advancing ideas (AI)	Students add new ideas and advance the discussion to a higher level. *(e.g., [Our products can be tested and iterated by collecting opinions from the elderly at home, giving them the products to test, completing a questionnaire survey after the initial testing, and optimizing the products in terms of function and art.])*
	Achieving shared understanding or goals (AG)	Discuss or adjust group goals if peers raise new questions, considerations, or concerns. *(e.g., [After discussion, our product is positioned as an app that helps college students stay focused on their studies. Most of the members of this group have the following characteristics: 1) they are not yet fully independent financially. However, they have certain financial capabilities; 2) they have a lot of studies and activities, and they need to concentrate in order to complete tasks efficiently; 3) their self-discipline abilities are uneven, so they require a study tool with a "timer" feature.])*
	Rise above (RV)	Rive above diverse ideas to achieve new syntheses. *(e.g., [Based on the discussion above, we can conclude that our Mini Program consists of the following sections: home page, work interface, user communication interface, personal space, contribution channel, contribution review, customer service feedback, and work recommendation.])*

Table 2 (continued)

Category	Subcategory	Description & examples
Metacognition (Towards metadiscourse)	Setting goals and making plans (SP)	Group members first consider the goals of tasks and make feasible group plans through discussions, such as allocating the time slots and subtasks, as well as assigning roles for members. *(e.g., [Our next work schedule is as follows: 1) Complete the prototype model before Saturday; 2) Create the product display video by Sunday.])*
	Reviewing inquiry process (RP)	Reflecting on the inquiry process and ideas constructed, identifying high points or gaps, and regulating collaborative efforts to move to a new state of inquiry or to achieve high-level conceptualization. *(e.g., [The following issues must be resolved in the next phase: 1) How can we grasp the real needs of users? 2) How can we obtain the copyright of audio and video resources?])*
	Coordinating the group efforts (CE)	Group members spontaneously (and collectively) take responsibility for regulating and coordinating the group's efforts (such as inviting participants to participate and contribute more ideas) to create a positive environment for achieving the goals of Knowledge Building. *(e.g., [So how do we motivate users to use our app? From the app's interface, functionality, or something else? What features and advantages should our app have to make users choose to use it? Please discuss these issues further.])*
	Commenting on ideas or products (CP)	Group members comment on the contribution of ideas and whether the designed products achieve the desired outcomes. *(e.g., [To achieve the purpose of helping users manage their time effectively, this app is mostly focused on providing personalized and customized services, providing users with the most natural and personalized experience.])*

Table 3 The rubric of groups' artifacts

Criteria			Weight
Novelty (30%)	Originality	The product is unusual or infrequently seen in a universe of products made by people with similar experience and training.	15%
	Surprise	The product has outstanding characteristics (such as shapes and functions) that can exceed people's expectations.	15%
Resolution (40%)	Value	The product fits and answers enough of the needs of the problematic situation.	10%
	Logicalness	The product or solution follows the accepted and understood rules for the discipline.	10%
	Usefulness	The product is judged worthy by users, listeners, or viewers because it fills a financial, physical, social, or psychological need.	10%
	Comprehensibility	The product has clear and practical applications.	10%
Elaboration & synthesis (30%)	Organic qualities	The product has a sense of wholeness or completeness about it.	15%
	Elegance	The product is expressed in a refined, understated way.	15%

(see Table 3) and then calculated the average scores as academic performance for each group. Then, as we had a small sample size, the Shapiro-Wilk test was used to test whether the data followed a normal distribution. The ANOVA was used if the data followed a normal distribution; if not, then the Kruskal-Wallis *H* test was used.

4 Results

4.1 Interaction patterns observed in experimental and control groups

The adjusted residual table for the three groups is shown in Table 4. In general, Table 4 shows that groups A and B exhibit similar interaction sequences. They had six sequences that reached the level of significance, namely Created/ Edited, Edited/ Edited, Edited/Read, Read/Read, Read/Created, and Build-on created/Build-on created. Besides, five interaction patterns also emerged in groups C, including Created/ Edited, Edited/ Read, Read/Edited, Read/Created, and Build-on created/Build-on created. Based on the results above, transformation diagrams were then generated (see Fig. 5).

Table 4 Adjusted residual table in three conditions

	Groups A				Groups B				Groups C			
	1	2	3	4	1	2	3	4	1	2	3	4
1	-.4.57	27.44*	-18.87	-4.63	-3.49	20.73*	-15.26	-3.00	-.44	10.82*	-9.97	-1.55
2	-6.93	7.02*	2.39*	-8.36	-6.75	4.98*	2.10*	-6.15	-6.77	-19.75	23.86*	-6.32
3	11.11*	-17.14	16.17*	-13.81	8.97*	-12.82	10.73*	-8.66	6.63*	17.74*	-17.98	-5.52
4	-4.59	-8.32	-13.98	43.52*	-2.20	-6.12	-9.20	33.49*	0.54	-6.82	-5.78	37.72*

Note. 1=notes created, 2=notes edited, 3=notes read, 4=build-on created; $^{*}p < .05$

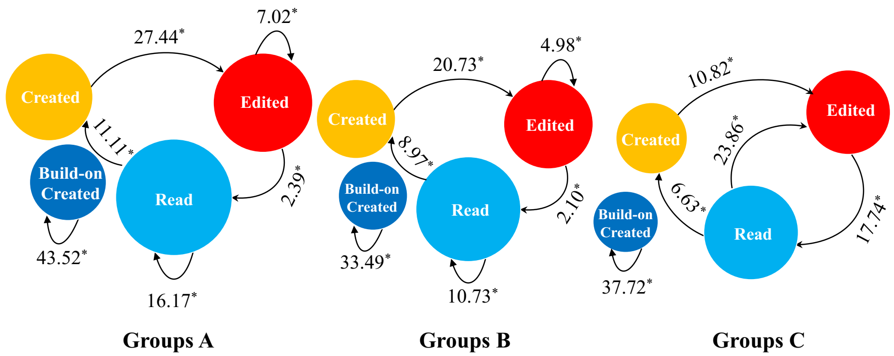

Fig. 5 The interaction patterns under three conditions. *Note*. The node size represented the frequency of behavioral code; the number on the link represented the adjusted residual; the arrow indicated the transitional direction

Furthermore, to explore the different sequential patterns under three conditions, we compared the statistically significant behavioral sequences. The results demonstrated that all three groups had the behavioral patterns as Created/ Edited, Edited/ Read, Read/Created, and Build-on created/Build-on created. However, differences were observed in the sequences of Edited/Edited, Read/Read, Read/Edited between the first two groups (i.e., groups A and B) and group C.

As Fig. 5 shows, the sequence Created→Edited→Read→Created in groups C indicates that note creation behavior served as a starting point during the process of KB. After this point, students were inclined to modify existing notes, followed closely by reading group members' notes, and ultimately created new notes. It was obvious that there was a lack of further interpretation and reflection on existing notes by participants before they created new ones. Although a bidirectional transition of Edited and Read (Edited→ Read and Read→ Edited) emerged in groups C, less reflective behavior was observed compared to groups A and B. Specifically, the sequence Created→ Edited→ Edited→ Read→ Read revealed that the students in experimental groups tended to constantly modify and reflect on existing notes instead of creating new ones. Consequently, they were more likely to incorporate their efforts into a note by revising and reading it repeatedly. While groups A and B emerged with the same behavior sequences, comparing node size revealed that groups A exhibited the above sequences more frequently than groups B.

4.2 Differences of social-epistemic networks under three conditions

4.2.1 Differences of social networks under three conditions

The descriptive statistics of the three groups for the weighted degree centrality and network density are shown in Table 5.

Table 5 Three groups' network density and weighted degree centrality

Group	Weighted degree centrality				Density
	Indegree		Outdegree		Mean (*SD*)
	Mean (*SD*)	Range	Mean (*SD*)	Range	
A1	138.40 (23.11)	100.00-165.00	138.40 (13.08)	121.00-161.00	34.60 (6.56)
A2	160.25 (35.02)	122.00-216.00	160.25 (23.03)	134.00-193.00	53.42 (17.80)
B1	30.33 (12.28)	16.00–46.00	30.33 (9.74)	17.00–40.00	15.17 (11.14)
B2	60.00 (12.55)	35.00–68.00	60.00 (19.92)	32.00–88.00	15.00 (6.78)
C1	20.75 (14.20)	7.00–44.00	20.75 (5.30)	15.00–27.00	6.91 (5.20)
C2	22.50 (8.65)	15.00–37.00	22.50 (3.35)	17.00–26.00	7.50 (3.40)

First, Levene's test revealed inhomogeneous network density and weighted degree centrality for students in all three conditions ($p < .05$). As a result, the K-W test was selected for use in this situation. As for the weighted degree centrality, a K-W H test indicated a statistically significant difference among the three groups (H (2, 25) = 19.74, $p < .001$). In addition, post hoc tests were conducted based on Bonferroni correction, as shown in Table 6. The test results demonstrated significant differences in weighted degree centrality between groups A and C ($p < .001$) as well as between groups A and B ($p = .02 < .05$). The rest of the group pairs were not significantly different ($p = .23 > .05$). In contrast, network density did not differ significantly among the three groups (H (2, 25) = 4.57, $p = .10 > .05$).

The results of statistical tests for the weighted degree centrality and network density were further corroborated by the plot in Fig. 6. From the results, it was clear that the weighted degree centrality was significantly higher in groups A versus groups B ($p < .05$) and group A versus group C ($p < .01$). This finding suggests, on average, that the nodes in the network of groups A were more closely interconnected to each other. In weighted degree centrality, not only the number of connections a node has but also its strength is taken into account. Hence, a higher mean value further indicated that this group's network was more densely connected, and its nodes were more influential compared to the other two groups. Similarly, groups A also showed the highest network density (Mean (SD) = 44.01 (9.41)) compared to groups B and groups C (Mean (SD) = 15.09 (0.09) and Mean (SD) = 7.20 (0.30), respectively). The results indicated that students in group A

Table 6 Pairwise comparison of three groups on the network degree centrality

Group pair	H	df	p-value
C-B	6.50	2	0.23
C-A	15.70	2	$<0.001^{***}$
B-A	9.25	2	0.02^{*}

H, results from K-W H test with Bonferroni correction; df, degree of freedom; C, groups C; B, groups B; A, groups A; $^{*}p < .05$; $^{***}p < .001$

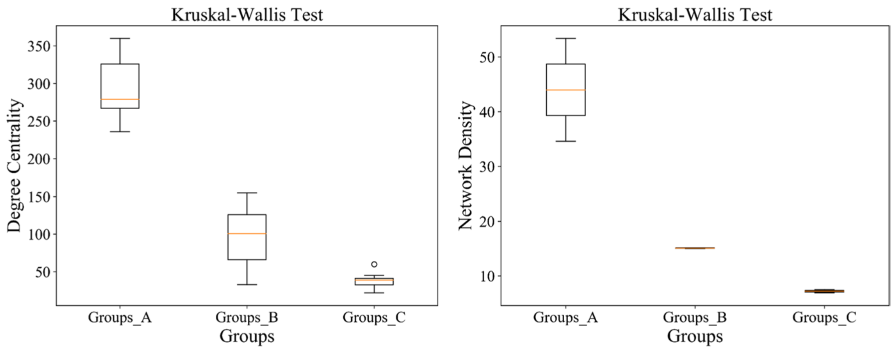

Fig. 6 Boxplots visualizing among-group difference

were more likely to interact (e.g., Read, Edit, and Build-on) with other members of the group than students in groups B and C.

4.2.2 Differences of epistemic networks under three conditions

Figure 7 displays a plot of connections of the discourse moves (i.e., progressive discourse and metadiscourse) of the experimental groups and the comparison groups, as well as the subtracted epistemic networks among the three groups. Specifically, the different colored dots represent the centroids of each condition, respectively. The squares denote the average centroids for all points within each group, and the rectangular outlines signify the 95% confidence interval for each dimension (see Fig. 7a).

To determine whether there is a significant difference among the three conditions, we conducted an independent sample *t*-test for pairwise comparisons along the *x*- and *y*-axis (see Table 7). For the experimental groups A and B, there was a significant difference between the two groups according to independent-sample

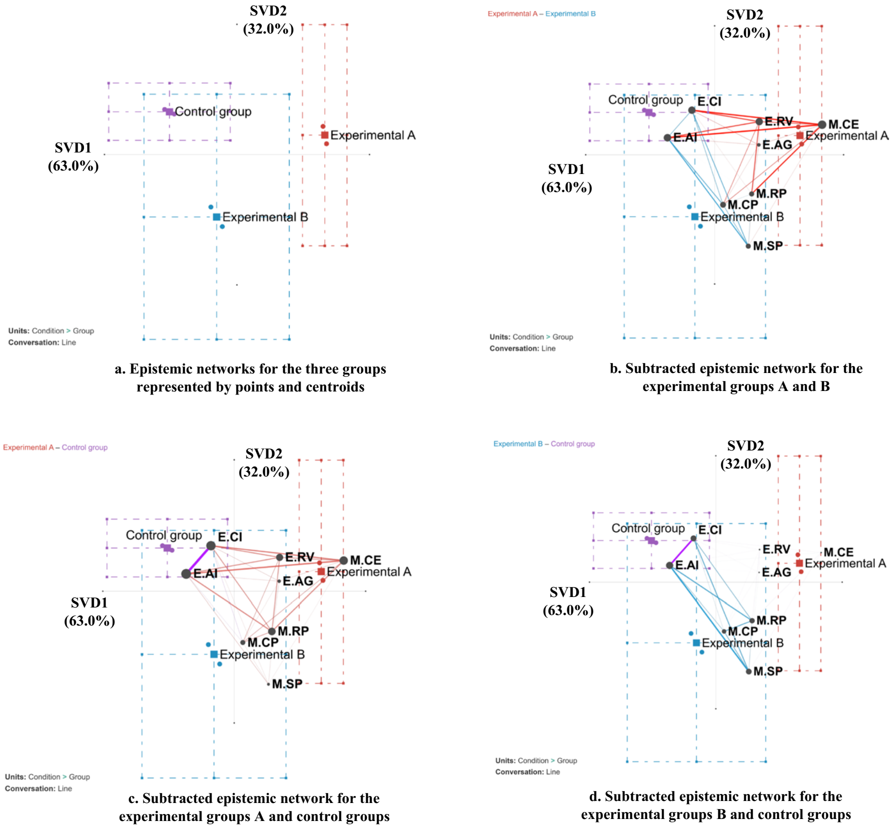

Fig. 7 Mean and subtracted networks among three groups

Table 7 Pairwise comparison of three groups along the *x*- and *y*-axis

Group pair		*X*-axis (SVD 1)			*Y*-axis (SVD 2)		
		Mean (*SD*)	*p*-value	Effect size	Mean (*SD*)	*p*-value	Effect size
A-B	A	2.27 (0.06)	0.02*	18.08	0.51 (0.32)	0.03*	6.29
	B	-0.52 (0.21)			-1.64 (0.36)		
A-C	A	2.27 (0.06)	0.01*	30.48	0.51 (0.32)	0.21	2.60
	C	-1.74 (0.17)			1.13 (0.08)		
B-C	B	-0.52 (0.21)	0.03*	6.33	-1.64 (0.36)	0.05*	10.60
	C	-1.74 (0.17)			1.13 (0.08)		

A, groups A; B, groups B; C, groups A. $^{*}p < .05$

t-tests (assuming unequal variances) for both dimensions. Similarly, the independent sample *t*-test also reveals that groups B and C differ significantly along the *x*- and *y*-axis. In the case of groups A and C, the differences on the *x*-axis are significant but not on the *y*-axis in comparison to the above results.

The subtracted networks (see Fig. 7b and c, and 7d) were compared to examine salient connections that contributed to the aforementioned differences among the three groups. Notably, on one dimension (i.e., *x*-axis), the left side held connections to codes related to low-level epistemic engagement (e.g., contributing diverse ideas (CI) and advancing ideas (AI) (Yang et al., 2022a), while the right side had connections to high-level epistemic engagement (e.g., rise-above (RV) and achieving shared understanding (AG) (Zhang et al., 2022). On another dimension, toward the bottom, there were connections to setting goals and making plans (SP), reviewing the inquiry process (RP), and commenting on ideas or products (CP), which related to discourses aimed at tasks and ideas levels. In contrast, toward the top of the space, there were connections to high-level epistemic engagement and coordination of group efforts (CE), which related to discourses aimed at the social or community levels. Based on the subtracted networks for groups A and B (see Fig. 7b), it appeared that groups A established more connections to high-level epistemic engagement and the social level of metadiscourse, while groups B established stronger connections to low-level epistemic engagement and metadiscourse, with a greater focus on tasks and ideas.

Figure 7c depicts the subtracted network for groups A and C and reveals that the former group made more connections to higher-level epistemic engagement and metacognitive discourse about monitoring task progress and coordinating group collaboration. In contrast, compared to groups A, groups C tended to focus more on low-level epistemic engagement. Similarly, Fig. 7d shows that, compared to group C, students in groups B made more connections to the metacognitive discourse at the ideas and tasks level, such as CP, RP, and SP. In contrast, students in groups C established more connections between AI and CI, indicating low-level epistemic engagement.

4.2.3 Differences of social-epistemic networks under three conditions

Figure 8 shows SENS networks for three group-scenario with the dimensional interpretations added. The dimensions of this space correspond to those of the ENA space depicted in Fig. 7a, and the position of the nodes corresponds to the individual's ENA score.

According to Section 4.2.2, the $X+$, $X-$, $Y+$, and $Y-$ axes of this 2D space represent different epistemic properties of students. Specifically, the $X+$ axis represents students who exhibit high-level epistemic engagement, with a stronger focus on synthesizing and summarizing individual ideas. Conversely, the $X-$ axis represents students demonstrating low-level epistemic engagement, tending to contribute and simply elaborate ideas. The $Y+$ axis indicates that participants were more focused on social-centered metadiscourse, while the $Y-$ axis signifies students were more likely to engage in idea- and task-centered metadiscourse. Additionally, the edges corresponding to social connections between individuals were calculated by SNA.

Taking into account network density, weighted edges, and epistemic properties, it was clear that groups A had a denser and more symmetric SENS compared to the other two conditions. In this group, members were more interconnected, and those connections were more evenly distributed among them. Moreover, this group scenario predominantly fell in the first quadrant, indicating that the participants were more engaged in high-level epistemic and social-centered discourse. In contrast to groups A, members of groups B were less interconnected, and their connections

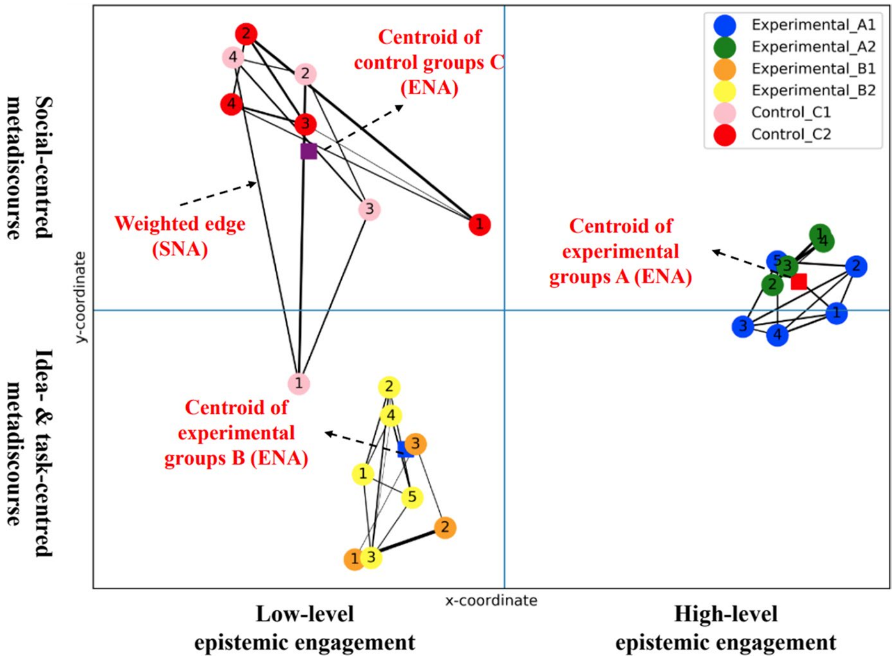

Fig. 8 Social-epistemic networks (SENS) among three groups

were less balanced. Some members frequently interacted with others, while some interacted less frequently. Furthermore, its centroid was located in the third quadrant, suggesting that participants were more involved in low-level epistemic and idea- and task-centered discourse.

Finally, it was evident that, among the three groups, groups C's SENS was the sparsest and most asymmetric, potentially leading to power imbalances or information disparities. Additionally, students in this group were more focused on elaborating and contributing ideas compared to the two experimental groups, resulting in the centroid falling into the second quadrant.

4.3 Differences in academic performance under three conditions

The Shapiro-Wilk test was performed and showed that the distribution of academic performance departed significantly from normality ($W = 0.894$, $p = .008$). Based on this outcome, the K-W *H* test was used. This test revealed that there was a significant difference among groups A, B, and C (H (2, 25) $= 9.39$, $p = .009$). Additionally, the results of post hoc tests are shown in Table 8.

Furthermore, the differences among groups were visualized using boxplots (see Fig. 9). Our results demonstrated that the academic performance was higher in groups A versus groups B ($p = .06$) and groups A versus groups C ($p < .01$). In addition, the academic performance of groups B was also higher than that of groups C ($p = .28$).

Table 8 Pairwise comparison of three groups on the academic performance

Group pair	*H*	*df*	*p*-value
C-B	3.94	2	0.28
C-A	10.74	2	$<0.01^{**}$
B-A	6.80	2	0.06

H, results from K-W *H* test with Bonferroni correction; df, degree of freedom; C, groups C; B, groups B; A, groups A; $^{**}p < .01$

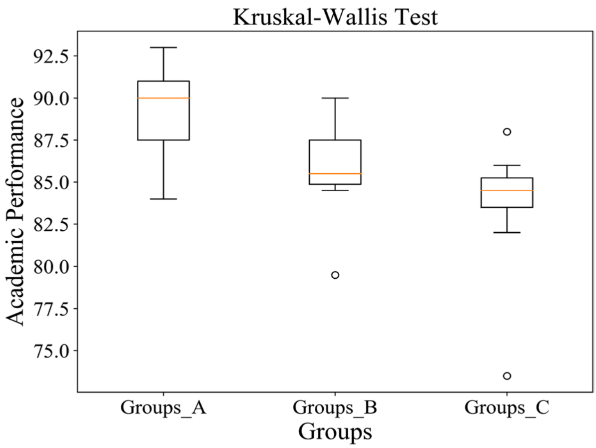

Fig. 9 Boxplots visualizing among-group difference

5 Discussion

This study examined the impact of teacher scaffolding on KB processes and outcomes within technology-supported environments by analyzing students' interaction patterns, social-epistemic networks, and academic performance under three different conditions. To evaluate the processes, we employed a combination of computational and statistical methods, including LSA and SENS, as well as the K-W test to evaluate the outcomes.

Regarding the first research question, evidence from groups C's interaction patterns indicates that when solely teacher scaffolding is present, students tend to forsake their ideas, lacking further reflection. According to Piaget (2002), the existence of unequal power dynamics between teachers and students could stifle student voices. Robinson and Taylor (2013) attributed this to teachers' access to authoritative resources, controlling student interactions. Students might accept the teachers' suggestions unquestioningly, unaware of underlying power dynamics (Vaara & Whittle, 2022). The teachers' authority limits discussions and leads students to conform to teacher-approved topics or ideas, echoing findings by Hübscher-Younger and Narayanan (2023). Another reason may be that teacher scaffolding at the group level is time-consuming, and teachers do not have sufficient time to engage deeply in the KB process, which impedes their understanding of students' inquiry trajectories. This situation, i.e., "outsiders" guiding "insiders", might lead to teachers unintentionally dominating student inquiries according to their own assumptions, resulting in less reflection behavior. To mitigate these issues, future research should consider fostering learners' democratizing knowledge and developing a collaborative metacognitive culture.

Additionally, reflective assessment tools have been shown to help students evaluate and improve their ideas (Hong et al., 2019; Yang et al., 2020a), a finding corroborated by our study, which reveals that groups B exhibited more reflective behaviors compared to groups C. Concurrently, teachers could harness these assessment tools to gather data pertaining to students' inquiry progression and, informed by this information, provide pertinent and timely feedback and support effectively (Järvelä et al., 2020). This is further supported by our findings that groups A emerged with more frequent reflective behavior sequences than groups B. The results of our study suggest that teacher scaffolding could indeed yield positive impacts. Students are more likely to engage in reflection on their inquiry when they consider feedback from both teachers and assessment tools.

For the second research question, the SENS findings showed teacher scaffolding is effective in technology-supported settings. It could enhance group interaction and engagement in the high-level epistemic and social-centered discourse during knowledge-building inquiries. Compared to groups B, students in groups A are more inclined to actively participate and make a contribution to high-order and social discourse. This result is linked to learner agency, which is strongly associated with active participation (Luo et al., 2019). Students tend to be more motivated and engaged in cooperative learning environments with high-level learner agency. As postulated by Biesta and Tedder (2007), learner agency emerges through the complex interplay between personal, contextual, and structural factors. Our finding aligns with prior research indicating that teacher scaffolding could be regarded as an essential contextual factor (Chong, 2021). It could provide affordances or opportunities that learners can utilize to enhance their learning agency, thereby improving their social and high-level epistemic engagement.

However, the results above were not observed in the groups containing only teacher scaffolding (i.e., groups C). Compared to the other two groups, groups C had the lowest level of epistemic and social engagement. This is partly because teacher scaffolding alone may add limited new information to students' KB inquiries, primarily focusing on repetitive, routine questions about judgment, timing, and management. This finding is consistent with the conclusions of some studies (Ouyang et al., 2022; Wu et al., 2021). They pointed out that such repeated information contributes minimally to KB. Routine task-centered prompts often act as unproductive reminders, potentially hindering the development of collective ideas and deep student expression. While suggestion-centered prompts can elicit new and improved ideas (Ouyang & Xu, 2022), their effectiveness hinges on deep teacher involvement. However, as indicated earlier, teachers may lack sufficient time to understand students' inquiries deeply. Group discussions in KB are dynamic and diverse, making it challenging for teachers to timely grasp students' collaborative status and provide appropriate content. Consequently, groups C's epistemic engagement remained low, which might lead to reduced social interaction. This finding further validates Liu et al.'s (2023) study, which demonstrated that lower-order epistemic notes typically prompt fewer social interactions compared to higher-order ones.

Significantly, groups B exhibited higher epistemic and social engagement than groups C, suggesting that technology-only scaffolding (e.g., KBDeX) is more effective than teacher-only scaffolding. This aligns with Yang et al. (2022a) findings that reflective assessment tools enhance engagement during KB inquiries. Moreover, hard scaffolds, as suggested by the *Information Entropy theory*, may offer greater *information gains* compared to teacher scaffolding (Wu et al., 2021). This is potentially due to our use of KBDeX, which provided weekly reflections on students' social and epistemic engagement. We presented their status using key terms, aiding in assessing individual contribution and community knowledge advancement (Oshima et al., 2012; Wu et al., 2021). This reflection not only acted as a prompt but also enhanced collective awareness and goal-setting for further inquiry, fostering knowledge growth in groups. Our interpretation corroborates Sandoval's (2005) view that KB inquiry without reflection is limited, as mere participation or following instructions is not enough. Deep reflection is essential to prevent superficial discussions in online inquiries.

For the third research question, we found that a combination of teacher-led and technology-embedded scaffolding led to greater performance than either teacher-only or technology-only scaffolding scenario, echoing findings in CSCL studies (Hong et al., 2020; Raes & Schellens, 2016; Yang et al., 2022a). Teacher scaffolding still plays a vital role in enhancing student performance in environments with embedded scaffolding and reflective tools. This effectiveness is understood through the *information gain* perspective, as previously discussed. Combined scaffolding allows students to access a broader range of external information (idea-centered, task-centered, suggestion-centered, and reflection-centered information), enriching their KB. Although some information types may have a limited impact, the constructivist view holds that knowledge is developed through interaction with its contexts (Scheer et al., 2012). Diverse context information aids in broadening perspectives and developing collective knowledge (Kimmerle et al., 2010). Furthermore, this course requires students to submit conceptualized artifacts that are not explicitly implemented. More information gathered about the artifacts will reduce uncertainty about their formation, which in turn will result in improved performance, such as novelty and usefulness (Schöggl et al., 2017).

Our study confirmed the effectiveness of teacher scaffolding in a technology-supported KB environment. It could enhance students' reflective behavior, social and epistemic engagement, and academic performance, thereby enriching KB literature and practices. First, our study is one of the few examining the effects of combined teacher-plus-technology scaffolding, adding to research primarily focused on hard scaffolds like reflective tools (Tong et al., 2023; Yang et al., 2024; Zheng et al., 2023). Second, our study provides in-depth analyses of students' interaction patterns and social-epistemic engagement, enriching previous research on teacher scaffolding's effects on KB discourse (Zhu & Lin, 2023), epistemic emotions (Zhu & Lin, 2023), and domain understanding (Chen et al., 2023). Third, previous studies on teacher scaffolding mainly concentrated on cognitive and epistemic prompts. This study extends these practices by placing more attention on social and metacognitive aspects. It guides practitioners in employing different prompts—idea-centered, task-centered, and suggestion-centered—to scaffold student discourse. Simultaneously, our study underlines the necessity for instructors to recognize the strengths and weaknesses of these prompts and to leverage reflective assessment tools for timely and effective student feedback.

6 Conclusion

This study highlights the crucial role of teacher scaffolding in the presence of embedded technology tools. It demonstrates that teacher scaffolding effectively enhances students' reflective behaviors, fosters social and epistemic engagement, and ultimately improves collaborative learning performance. The findings underscore the importance of avoiding a scenario where "outsiders guide insiders" by solely relying on teacher scaffolding. Conversely, when teachers and reflective assessment tools work together, they stimulate greater information acquisition, foster learner agency, and transform teachers into "trusted outsiders" equipped with invaluable "inside knowledge."

Our findings offer significant theoretical, practical, and methodological implications for KB design, implementation, and research. Theoretically, this research underscores the indispensable role of teachers in technology-supported KB environments. This insight enriches the existing literature in the field. Practically, the prompts provided for teacher scaffolding can serve as valuable guidance for designing interventions aimed at advancing knowledge and enhancing artifacts.

Practitioners can utilize these prompts, for instance, to formulate appropriate plans and scaffolding strategies for fostering an open knowledge environment. Methodologically, combining multiple methods, especially LSA and SENS, allows for a holistic understanding of students' KB characteristics, which lays the groundwork for using a variety of computational methods in the KB field.

Admittedly, this study has several limitations. First, the data collected from a certain course at a single university in China may limit its generalizability to other universities, contexts, or subjects. Despite similar samples in previous studies (e.g., Liu et al., 2023; Chai & Zhu, 2021; Ouyang et al., 2021), future research should increase sample size and focus on other educational levels and subjects to improve the generalizability of the research. Second, not all participant interactions may have been captured in the KF discourse, as some discussions could have taken place face-to-face. Future studies might consider capturing students' online and offline KB discourse more comprehensively. Third, the lack of qualitative data (e.g., students' perceptions of teacher scaffolding) may affect the study's credibility. Future studies could include them to provide a "thick description" and validate the current findings, enhancing the research's robustness.

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Data availability The datasets used or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests The authors declare no potential conflict of interest in the work.

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