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Promoting higher-order thinking through online collaborative concept map recomposition

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Abstract

This study evaluated the effectiveness of online collaborative kit-build concept mapping (CKB) in promoting higher-order thinking (HOT). Online collaborative kit-build concept mapping is a method of synchronous collaborative learning that applies the kit-build concept map framework, which proposes the recomposing method. Using a quasi-experimental procedure, sixty-nine undergraduate students were divided into an experimental group performing a CKB activity (n=33) and a control group conducting an online collaborative scratch-build concept mapping (CSM) activity (n=36). All students were assessed on their ability to answer HOT questions about specific learning content before and after collaborative mapping. The results showed that individuals in the CKB group performed better in solving HOT questions than those in the CSM group.

Keywords: Online collaborative kit-build concept mapping, Online collaborative scratch-build concept mapping, Kit-build concept map framework, Higher-order thinking

Introduction

Developing students' higher-order thinking (HOT) is essential in education (Bahr, 2010) and promotes meaningful learning that fosters deeper understanding (Bahr, 2010; Jarvis & Baloyi, 2020; Jensen et al., 2014; Tsai et al., 2020). In the cognitive view, Ausubel et al. (1978) defined meaningful learning as assimilating new concepts into pre-existing familiar concepts, impacting the learners' knowledge structure. Prior studies defined HOT as problem-solving skills, analytical thinking, creative thinking, critical thinking, and metacognitive thinking (Brookhart, 2010; Kwangmuang et al., 2021), while some described HOT as covering the higher cognitive skills of Bloom's Taxonomy (Ghani et al., 2017; Jensen et al., 2014; Muhayimana et al., 2022; Omer et al., 2020; Stringer et al., 2021). The revised version of Bloom's Taxonomy divides cognitive skills into six levels, from lowest to highest, according to complexity: remember, understand, apply, analyze, evaluate, and create (Anderson et al., 2001). For teaching and assessing HOT in the academic environment, cognitive taxonomy is used in curriculum documents such as Bloom's Taxonomy (Brookhart, 2010; Momen et al., 2023; Prakash & Litoriya, 2022; Sharunova et al., 2022). Some researchers have used Bloom's Taxonomy to assess HOT through questions designed for this purpose (Ghani et al., 2017; Jensen et al., 2014; Muhayimana et al., 2022). This study aligns with this approach and uses Bloom's Taxonomy to define HOT.

Employing a learning strategy that could practice students' HOT, such as analytical thinking, could improve the students' abilities to analyze the information effectively following the learning process, including the ability to categorize, forecast, discriminate, and find relationships (Kwangmuang et al., 2021). Thus, developing the appropriate learning strategy to support the development of students' HOT provides vital assistance to the teacher. Prior researchers argued that an individual's critical thinking skills of interpretation, analysis, inference, evaluation, and metacognitive thinking could be activated by creating a concept map (Barta et al., 2022; Baugh & Mellott, 1998; Novak & Cañas, 2008; Rosen & Tager, 2014). Creating a concept map, also called a concept mapping activity, is a learning process that organizes one's understanding of specific knowledge into a concept map. A concept map is a graphical tool that represents a learner's knowledge structure. It comprises concepts connected with linking phrases to represent meaningful statements known as propositions (Novak & Cañas, 2008). Concept mapping activity can support students in advancing their understanding of the learning content from lower cognitive levels, such as remembering and understanding, to higher levels, based on their ability to address problems involving both lower-order thinking (LOT) and HOT, as categorized according to Bloom's Taxonomy (Ghani et al., 2017; Yen et al., 2012). In addition, prior studies have suggested that when performed collaboratively, a concept mapping activity could enhance individual learning performance (Chiou, 2009; Kwon & Cifuentes, 2007; Sam, 2024; van Boxtel et al., 2002). This activity has been defined as a collaborative concept mapping. Various instructional strategies were implemented to support the collaborative concept mapping method, aimed at fostering a deeper understanding and enhancing HOT (Chang et al., 2016, 2017; Farrokhnia et al., 2019); the evaluation of these achievements was based on the student's capability to solve the questions related to the learning domain.

The Kit Build Concept Map (KBCM) framework supports students in creating concept maps by reorganizing provided components, such as concepts and linking phrases. Several studies have demonstrated its effectiveness in enhancing learning (Alkhateeb et al., 2015; Khudhur et al., 2023; Rismanto et al., 2023). Specifically, for individual learning, the KBCM has been confirmed as an effective framework for promoting HOT (Nurmaya et al., 2023). In collaborative learning, the KBCM can facilitate collaborative concept mapping in a synchronous setting, called online collaborative kit-build concept mapping (CKB) (Pinandito et al., 2021). However, the previous study did not distinguish between LOT and HOT. Therefore, the effectiveness of the KBCM in promoting individual HOT through collaborative concept mapping has yet to be evaluated. This study aimed to evaluate the impact of CKB on students' HOT performance in a synchronous online class by comparing students' HOT abilities after learning through CKB with those using online collaborative scratch-build concept mapping (CSM). The assessment of students' HOT abilities was based on their performance on questions related to the learning content and categorized according to the cognitive levels of the revised Bloom's Taxonomy. The design of the questions is detailed in the "*Assessment*" subsection.

Relevant studies

Kit-build concept map

In a traditional concept mapping activity, i.e., the typical activity of constructing the concept map, students can define their own concepts and link them based on their understanding of the learning topic, resulting in propositions (Novak & Cañas, 2008). This traditional mapping activity is defined as a "scratch-build concept mapping" in this study. The nature of this mapping activity may result in different concept maps for the same specific knowledge. Consequently, it becomes challenging to visualize the alignment between students' understanding of the learning content, the teacher's understanding, and the understanding of their peers during the learning process.

Kit-Build Concept Map (KBCM) is a learning framework that supports students in concept mapping activities using the recomposing method, which involves recomposing a concept map from provided components such as concepts and linking phrases. This framework facilitates teachers in creating a concept map that represents their understanding of the learning content, reflecting the understanding that both students and teachers aim to achieve. This teacher-created map is called a "shared goal (SG) map." This map is then decomposed into concept map components, such as concepts and linking phrases, omitting the lines representing the map's structure. These components, collectively called the "kit," are shared with students. Recomposing the SG map from the provided kit is suggested to help students reach the learning goal, i.e., develop a deep understanding of the learning content. Concept mapping activity with the recomposing method is called kit-build concept mapping (Hirashima et al., 2015).

Iterative actions, such as assembling propositions and structuring the map, which can lead to various states, may be encountered by students during the recomposing process. In KBCM, these actions are visualized and can be modified and shared with others. Thus, the

KBCM could be assumed as a problem space where the problem is to find the sequence propositions that lead to the construction of the SG map (goal state), with the given components defined as an initial state. Since the constructed propositions reflect the result of actions performed by students, which also represent their understanding of a specific part of the content, it could be assumed that KBCM could visualize students' understanding. As a result, it is possible to facilitate the sharing of this understanding with others and accommodate adjustment by others. Furthermore, teachers can automatically analyze the students' concept maps and identify misconceptions that may appear in them. Thus, KBCM could become a shared problem space that can be applied to collaborative learning. Figure 1 shows the illustration of KBCM as a problem space.

Regarding the cognitive processes involved in concept map construction, scratch-build concept mapping induces low and high cognitive skills such as evaluation and synthesis (Chevron, 2014; Gorman, 2018). Both concept mapping activities involve similar processes, such as reading, assembling propositions, and structuring the concept map despite the differences in how components are prepared, created by students in scratch-build concept mapping and provided by teachers in kit-build concept mapping. Thus, kit-build concept mapping may also involve high-level cognitive processes. For example, in kit-build concept mapping, after understanding the connections among the provided components and the content of the learning material, composing a proposition may initiate a metacognitive process. This process may raise the students' awareness as they evaluate the alignment between the learning content and their understanding (the composition results), leading to a deeper comprehension.

In an individual learning setting, Nurmaya et al. (2023) confirmed that KBCM could support students in achieving deep understanding, enabling them to solve problems requiring cognitive evaluation in synchronous online classes. The study also demonstrated that the map quality influences students' performance on HOT questions. Successfully recomposing the concept map indicates the students build relevant relationships and

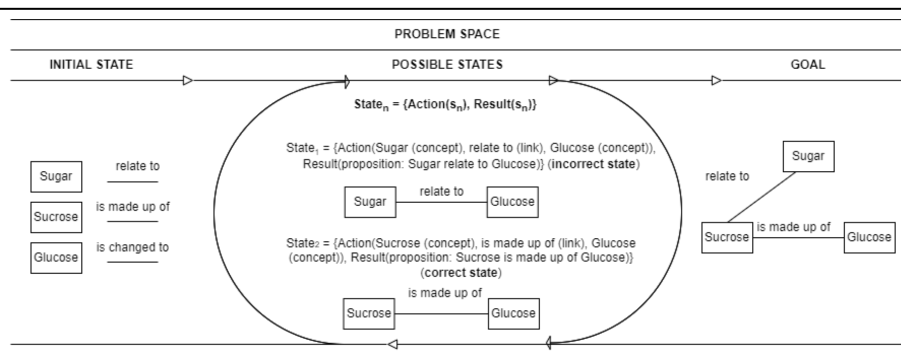

Fig. 1 The illustration of KBCM as a problem space

connections across sub-domains. Building such maps involves HOT, such as "evaluate" and "create" (Cañas et al., 2015), suggesting that the recomposing method facilitates students' practice of individual HOT skills.

Collaborative kit-build concept mapping

Pinandito et al. (2021) extended the use of the KBCM to real-time collaborative learning in an online setting, referred to as CKB. Using HTML with WebSocket, students and their collaborators can recompose the concept map synchronously. Also, text-based communication among group members can be performed within the system. Figure 2 depicts the CKB activity that adapted the KBCM. In CKB, the kit (SG map's components) is shared with a group of students, enabling them to view and interact with the components as a group. They can work with the nodes and the links synchronously and simultaneously to compose propositions. During the process of recomposing the concept map, the students can read the learning content and have real-time discussions through online chat. Figure 3 portrays the interface of the CKB system.

In the context of reading comprehension in an English as a Foreign Language (EFL) study, Pinandito et al. (2021) demonstrated that utilizing CKB enhanced individual learning performance, outperforming online collaborative scratch-build concept mapping (CSM). In CSM, students within a group collaboratively create concept map components

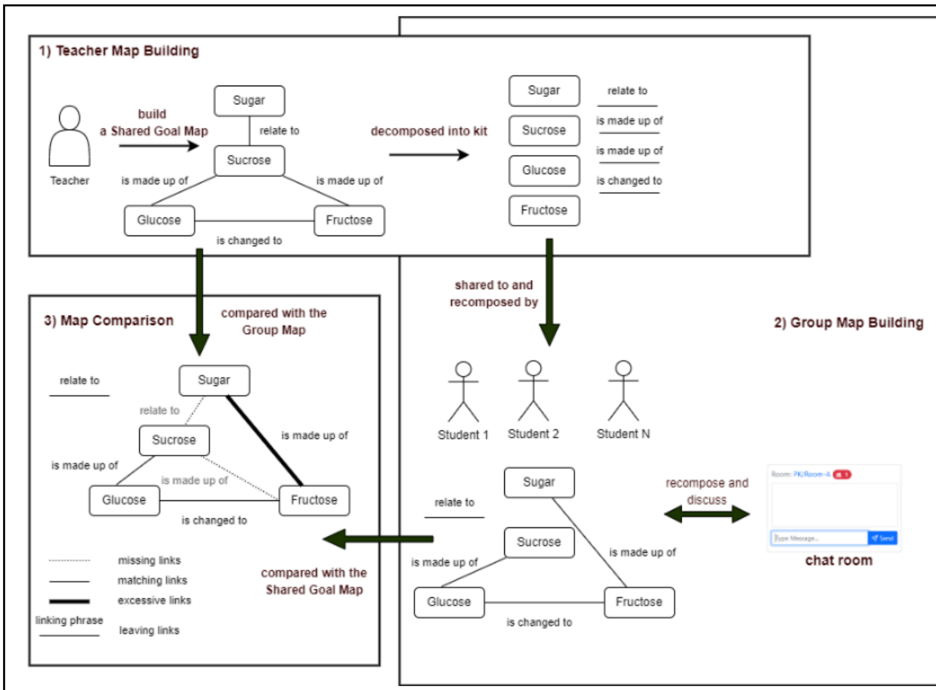

Fig. 2 Online Collaborative Kit-Build Concept Mapping activity adapted KBCM framework

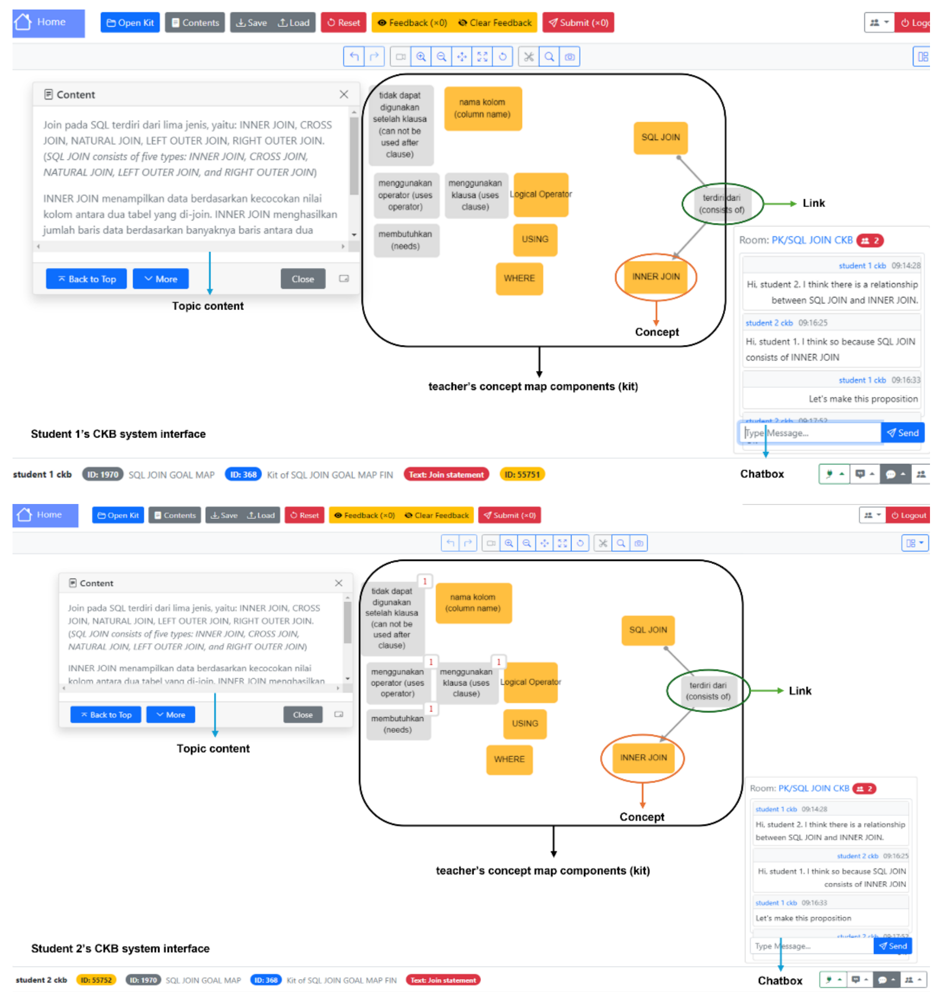

Fig. 3 User Interface of students within a group in the CKB system (in English)

(concepts and links) from scratch and form propositions simultaneously in a synchronous online setting. During the concept mapping activity, they can review the learning content and discuss it online with the group members. Aside from the way concept map components are provided, CKB and CSM involve similar activities, resulting in comparable interfaces in both systems. Figure 4 illustrates the system interface that supports CSM with text-based online communication.

CKB allows the teacher's understanding of domain-specific knowledge to be visualized in concepts and links and shared with the group members. Hence, the members have the same initial states to achieve the learning goal, i.e., comprehending the learning domain. This condition may lead them to share the same problems, i.e., composing specific propositions from the shared components. As a result, it may encourage the members to share their understanding when addressing the problems, and by adapting the KBCM, this

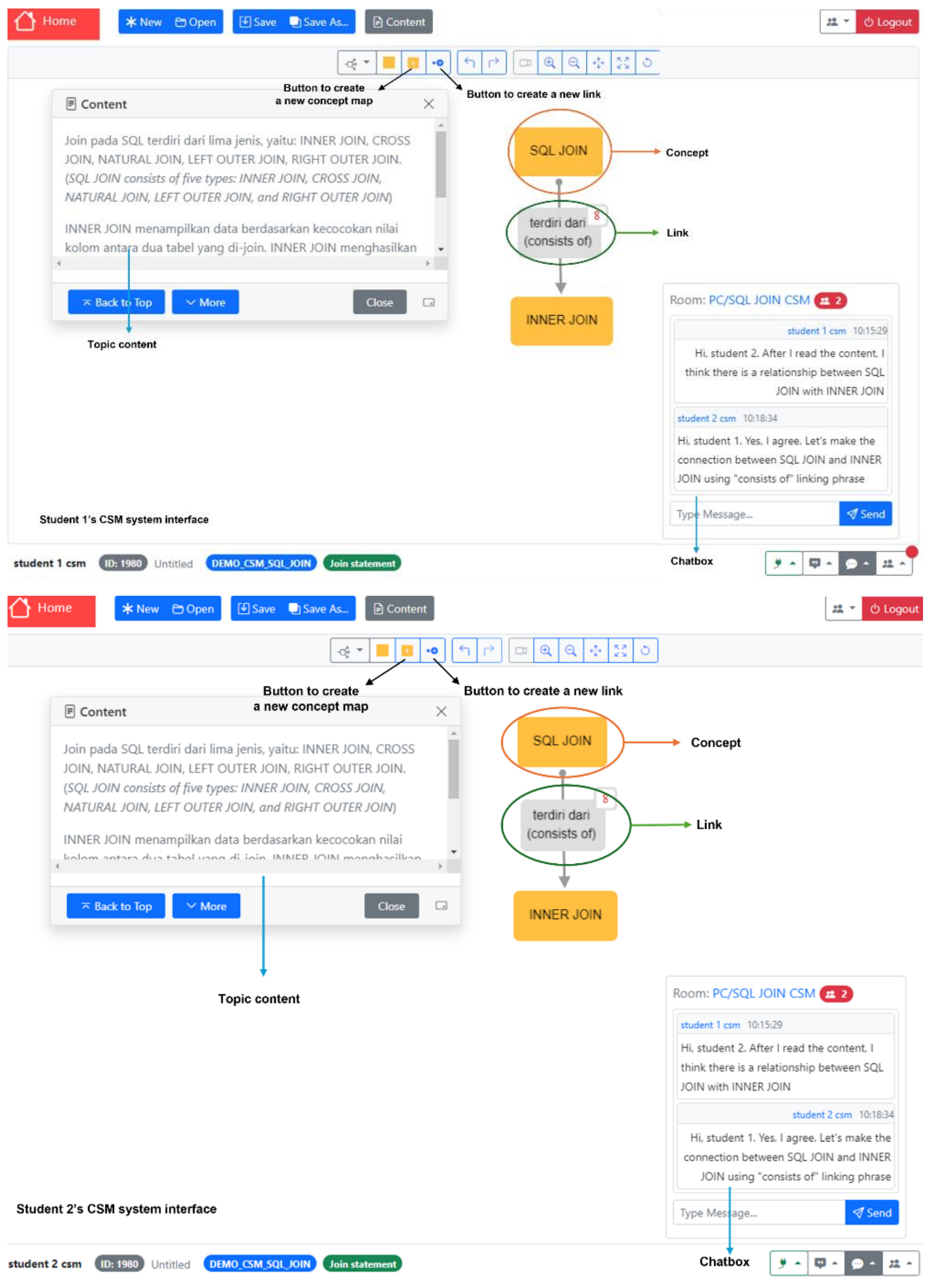

Fig. 4 User interface of students within a group in the CSM system (in English)

sharing understanding could be visualized in shared problem space. Visualizing the other members' understanding may prompt the group members to be aware of each other's comprehension, resulting in improved collaboration performance (Fischer & Mandl, 2005). Based on the findings from Carvalho et al. (2020), being aware of the understanding of other members contributed to the optimal outcomes in developing an individual's deep conceptual understanding. Recognizing different perspectives encourages students to think critically (Cañas et al., 2017; Carvalho et al., 2020), which might trigger them to reevaluate their thinking (Tao & Gunstone, 1999). Moreover, as students become aware of differences in their understanding compared to the teacher's after composing the propositions from the teacher's map components, it may prompt them to analyze these differences critically. This, in turn, may lead them to reflect on their thinking. Therefore, it could be assumed that the CKB has the potential to foster the student's ability to engage in HOT related to a particular domain, and this study attempted to explore and verify this potential.

Higher-order thinking assessment instrument

In the concept mapping study, prior researchers used the test format to evaluate the students' HOT related to their understanding of the domain-specific knowledge after learning with the concept map (Bramwell-Lalor & Rainford, 2014; Chang et al., 2017). Several frameworks for designing content questions based on the cognitive level of the revised Bloom's Taxonomy have been developed in the computer science field, such as E. Thompson et al. (2008) for programming assessment and Imbulpitiya et al. (2021) for the logical data model in the database course.

The multiple-choice question (MCQ) format has been used to deliver the questions that assess the HOT (Downing, 2006; Ghani et al., 2017; Grainger et al., 2018; Maryam et al., 2021; Morrison & Free, 2001). MCQs enable automatic grading, thereby saving teachers time in managing grading for large classes (Morrison & Free, 2001) and providing objective scoring (Shin et al., 2019), while essay scoring may involve subjectivity (Downing, 2006).

As suggested by previous studies, to accurately measure HOT, the MCQs should be designed to assess the application thinking ability and above according to Bloom's Taxonomy or revised Bloom's taxonomy (Downing, 2006; Grainger et al., 2018; Morrison & Free, 2001). Solving a case-based scenario included in the questions' components can encourage students to utilize their HOT (Jerome et al., 2017). Selecting the correct solution from a list of seemingly viable options prompts critical judgments, which then activates HOT (Abdul Rahim et al., 2022; Morrison & Free, 2001; Scully, 2017).

To achieve the objective of this study, an assessment in MCQ format was administered before and after learning with CKB and CSM. The assessment evaluated both HOT and LOT performance to examine the impact of CKB on fostering HOT and supporting collaborative learning through concept mapping.

Experimental design

Participants

Eighty-two undergraduate students from the Department of Informatics at a private university in Jakarta, Indonesia, participated in this study. This private university aims to promote student-centered learning by integrating technology to enhance students' creativity, motivation, and independence in learning to gain knowledge. Most participants were in their fourth semester, taking courses primarily on computation and programming. The learning outcomes for these courses are designed based on Bloom's Taxonomy, which aligns with the department's curriculum, with the expectation that the students achieve at least analytical thinking skills in each course. The participants in the experiment were enrolled in a database class, which was taught by an instructor. In this study, the instructor refers to the teacher who is directly in charge of the class. The class comprised 14 sessions, each lasting for three hours, and was held once a week. Because of the pandemic, the class was held in an online setting. The course was conducted in Indonesian, with all materials and exams provided in the same language. Two students had re-enrolled because they did not finish the course the previous semester.

Tools and materials

This study used two online collaborative concept mapping systems to support CKB and CSM activity, defined as CKB and CSM systems, respectively. Both systems were developed under the same platform. The difference between the systems is that in the CSM system, students can create nodes and links themselves, while in CKB, the provided nodes and links are used. Other than that, the interfaces are the same, and both systems are equipped with a chatbox as a medium through which group members can communicate online. Figures 3 and 4 represent the interface of the CKB and CSM systems, respectively. Using the CKB system, the instructor created the SG map to clarify the goal of understanding for the students and the instructor, which was appropriate for the class context. Furthermore, the SG map had a high probability of having excellent concept map quality characteristics and described the SQL JOIN concept.

The two sub-subjects were also briefly described in the SG map: the SQL SELECT statement and WHERE and OPERATOR clause, which had been given to the students in the previous class. Therefore, the SG map did not describe the two sub-subjects in detail. Figure 5 depicts the part of the SG map used in this study. The whole map was comprised of 33 nodes and 74 links. Thus, the number of possible concept maps that could be recomposed using 33 nodes and 74 links is ${}_{33(33-1)}C_{74}$. This means the possible concept map structures were derived from the combination of 74 pairings within the 33x32 pairing of nodes, resulting in numerous potential concept map structures.

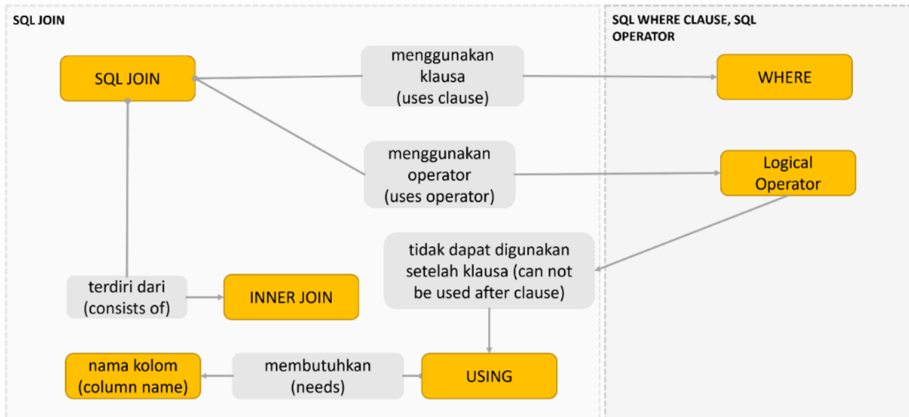

Fig. 5 Part of the SG-map of SQL JOIN subject (in English)

Assessment

The individual assessment was given in two formats: pre-test and post-test. All tests utilized the same set of questions; however, they were delivered at different time points. The instructor and one of the authors, a lecturer in an information system department, collaborated to create the questions. The instructor, with five years of experience teaching database courses, and the assigned author have experience creating questions according to the cognitive level of Bloom's Taxonomy.

The instructor and the assigned author created 20 MCQs for the SQL JOIN domain. The questions were formatted in a case-based format to ensure that MCQs could be appropriately used to assess the higher cognitive levels. The instructor and the assigned author provided several options, appearing credible as potential solutions to the case, to encourage students to use their judgment ability (HOT) in selecting the most appropriate solution.

Developing an assessment to evaluate students' understanding across various cognitive levels, from LOT to HOT, involves several stages.

First, the instructor prepared a draft of questions corresponding to different cognitive levels of Bloom's Taxonomy, relying on the instructor's experience in teaching the database course and understanding of the framework. Second, following the draft preparation, the instructor and the assigned author reviewed the questions to ensure they accurately addressed this study's cognitive levels categorized as LOT and HOT. The instructor and assigned author used Bloom's Taxonomy for CS assessment (E. Thompson et al., 2008) as a reference during their discussion to evaluate the draft questions, ensuring the questions aligned within the correct cognitive categories as intended. This reference was used because it addressed the assessment of the programming course based on the cognitive levels of revised Bloom's Taxonomy, which is relevant to the current learning topic of SQL programming. During the discussion, content questions were changed based on mutual agreement between the instructor and the assigned author.

Referring to E. Thompson et al. (2008), this study decided to assess the “remember” level by evaluating students’ ability to recall content covered in the learning materials, while the “understand” level examined students’ ability to interpret the provided SQL structures and infer how to adjust them to reach the desired outcome. For the “apply” level, the assessment evaluated students’ ability to apply what they learned to the new problems. At the “analyze” level, the assessment focused on evaluating students’ ability to analyze SQL structure, including understanding the functions of various SQL components and how different SQL JOIN types and structures affected the outputs.

The assessment was designed up to the “analyze” level without extending to the two highest cognitive levels of the revised Bloom’s Taxonomy, namely the “evaluate” and “create” levels. This decision was made because assessing these two advanced levels was challenging in the context of this study, representing a limitation. The instructor argued that to effectively assess the “evaluate” and “create” levels related to this learning topic, students needed to develop the skills to evaluate the most effective queries and formulate their solutions. Sufficient practical experience in SQL programming was needed to acquire these skills, which could be developed through frequent hands-on practice.

Lastly, after the assessment questions were finalized, three raters were assigned to categorize them according to the cognitive level of the revised Bloom’s Taxonomy and determine whether they were LOT or HOT questions based on the cognitive level they addressed. The three raters are lecturers in the informatics field who have experience teaching for more than six years. Two are from the same university, while the other comes from a different university. Before the categorization was started, the assigned author explained the learning content delivered in the class and the content questions. The reference (*Bloom’s Taxonomy for CS Assessment*) (E. Thompson et al., 2008) was given to the raters as a guideline for categorizing the questions based on the cognitive levels of Bloom’s Taxonomy. A discussion with the raters regarding the cognitive levels involved in LOT and HOT was also conducted, referring to Crowe et al. (2008) and T. Thompson (2008).

Fleiss’ kappa statistic for inter-rater reliability analysis (Fleiss, 1971) revealed substantial agreement among the raters ($K = 0.8, p < 0.001$) (Landis & Koch, 1977) that 11 questions belong to HOT, and 9 questions belong to LOT. The instructor assigned five points for each question. Therefore, the maximum score for HOT, LOT, and all questions was 55, 45, and 100 points, respectively. According to the categorization, HOT questions were classified as being in the “apply” (5) and “analyze” (6) levels, and LOT questions were classified as being in the “remember” (6) and “understand” (3) levels. Aligned with Crowe et al. (2008) and T. Thompson (2008), this study categorized the “apply” level as HOT.

T. Thompson (2008) argued that test items were categorized as LOT if students were familiar with the problems or solutions presented in class. In contrast, they were categorized as HOT when the problems were unfamiliar, which is defined by Bloom et al. (1981, as cited in T. Thompson, 2008) as a problem that is new to students and cannot be solved simply by recalling a solution or a specific method used in the class or when teacher had not previously taught the solutions. This unfamiliar problem must be utilized to assess higher levels of thinking (Bloom et al., 1956, as cited in T. Thompson, 2008). Therefore, the “apply” level in this study was categorized as HOT because the problems were unfamiliar to the students, and the solutions had yet to be taught in the class. To solve these problems, students needed to understand the SQL JOIN concept, apply this understanding by analyzing relationships between data across tables, and further analyze the results to generate a specific output. Table 1 shows the example of HOT and LOT questions’ categorization according to the cognitive level of revised Bloom’s Taxonomy.

Procedure

This study applied a quasi-experimental procedure where the CKB group acted as an experimental group, and the CSM group acted as a control group. Eighty-two students were equally assigned to the CKB and the CSM groups, each consisting of 20 sub-groups containing two or three students. The experiment was conducted in a regular synchronous online class due to COVID-19. The instructor implemented the CKB and CSM activities in the classroom, recognizing their positive effectiveness as learning methods. While the students were informed about the benefits of CKB and CSM activities, they did not receive information on how these collaborative concept mapping methods would be applied practically in the classroom. Consequently, the students were aware of the advantages of CKB and CSM activities but had no insight into their practical implementation.

For two consecutive weeks before the experiment, all the students practiced collaborative concept mapping with CSM in the first week and the CKB method in the following week. The CSM and CKB systems were used for their respective activities. The topics they learned when practicing collaborative concept mapping were the same as those planned for that week in class. In each practice session, the instructor explained the learning content generally and how it could be represented in the concept map, aiming to give them experience in making concept maps collaboratively.

In the third week, the day of the learning method comparison, the students underwent a pre-test as a preliminary step before embarking on their learning with CKB and CSM. This test had 20 MCQs, with 11 HOT and 9 LOT questions. They had 30 minutes to complete the test. In the following 20 minutes, the instructor briefly explained the class activities, including the subject to be delivered to the students. After the explanation, the students, in their assigned groups, learned the topic that the instructor presented through the use of

Table 1 Example of HOT and LOT questions (in English)

Category	Cognitive Level	Items
HOT	Apply	Given two tables: tabel1 and tabel2. Both tables have the same column, namely the “kolomab,” which connects the two tables. If tabel1 contains 4 rows of data (A, B, C, D) and tabel2 contains 5 rows of data (C, D, E, F, null), how many rows are generated from the following JOIN query? SELECT * FROM tabel1 INNER JOIN tabel2 USING (kolomab) a. 3 b. 2 c. 5 d. 6 e. 1
HOT	Analyze	Given two tables: tabel1 and tabel2. The two tables are linked by a column named “kolomab.” Some rows in tabel1 are missing in tabel2. Which JOIN query can display the matched records between tabel1 and tabel2, along with the records contained only in tabel1? a. SELECT tabel1.kolomab FROM tabel1 LEFT OUTER JOIN tabel2 USING (tabel1.kolomab) b. SELECT tabel1.kolomab FROM tabel1 RIGHT OUTER JOIN tabel2 USING (tabel1.kolomab) c. SELECT tabel1.kolomab FROM tabel1 NATURAL JOIN tabel2 d. SELECT tabel1.kolomab FROM tabel1 LEFT OUTER JOIN tabel2 ON tabel1.kolomab = tabel2. kolomab e. SELECT tabel1.kolomab FROM tabel1 RIGHT OUTER JOIN tabel2 ON tabel1.kolomab = tabel2.kolomab
LOT	Remember	What is the appropriate CLAUSE to be used in LEFT OUTER JOIN for two tables with the same column name? a. ON b. WHERE c. AND d. USING e. ON…WHERE
LOT	Understand	Given two tables jadwal_penerbangan and tujuan_penerbangan with the structures: tujuan_penerbangan (id_tujuan, nama_tujuan) jadwal_penerbangan (id_tujuan, tanggal_keberangkatan) What is the appropriate CLAUSE that can be used for the query JOIN given below so that it can be run correctly? SELECT tp.nama_tujuan, jp.tanggal_keberangkatan FROM tujuan_penerbangan AS tp INNER JOIN jadwal_penerbangan AS jp; a. WHICH tp.id_tujuan = jp.id_tujuan b. WHERE tp.id_tujuan = jp.id_tujuan c. ON tp.id_tujuan = jp.id_tujuan d. AND tp.id_tujuan = jp.id_tujuan e. USING tp.id_tujuan = jp.id_tujuan

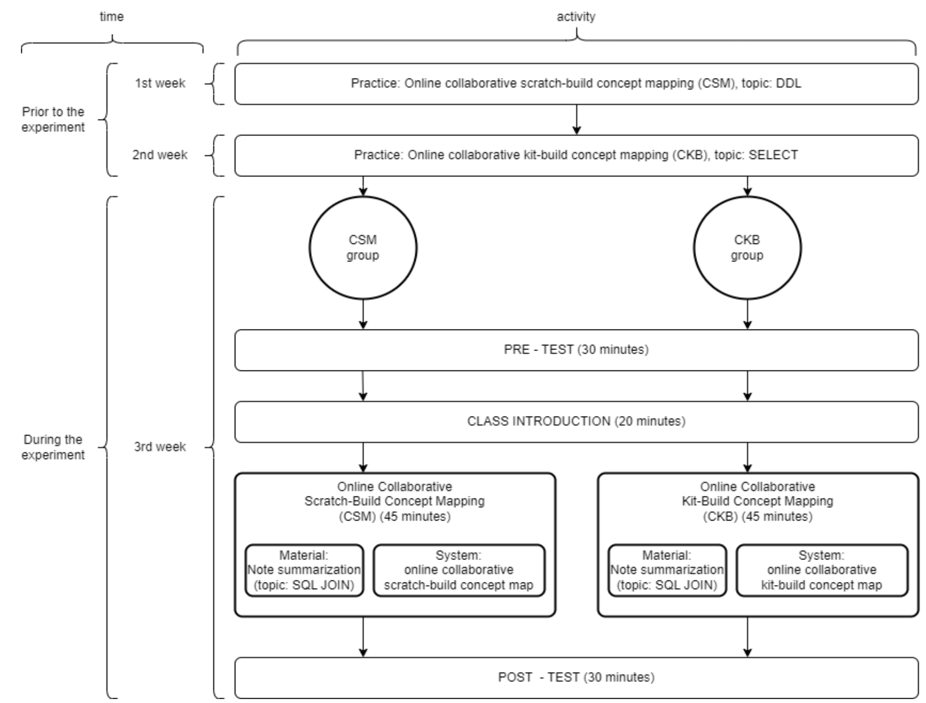

Fig. 6 Experimental procedure

the CKB or CSM for 45 minutes. The learning topic used in this comparative experiment was "SQL JOIN." During the collaboration, the students were instructed to use a chatbox provided in the CKB and CSM systems to communicate with other members while working together to build a map. After completing the collaborative concept mapping, the students took a 30-minute post-test. Figure 6 illustrates the sequential activities carried out prior to and during the experiment.

The experimental procedure for the current study resembled that of previous research (Chang et al., 2017), which investigated the impact of instructional support for collaborative concept mapping on learning performances across multiple cognitive levels, ranging from memorization to HOT. Both studies employed a quasi-experimental design and created an assessment with MCQs that cover different cognitive levels to assess immediate learning performance through post-test evaluation. The assessment created for the study was then evaluated by expert educators. Although there are some procedural differences between the two studies, such as the classification method for HOT and the learning environment, the procedure used in this study may also demonstrate the effectiveness of CKB on HOT performance.

Data collection

This study evaluated students' understanding of SQL JOIN by assigning 20 online MCQs before (pre-test) and after learning (post-test). Questions were designed and classified into

LOT and HOT based on the cognitive levels of the revised Bloom's Taxonomy, following several prior studies (Crowe et al., 2008; E. Thompson et al., 2008; T. Thompson, 2008). Responses and scores for each question were stored in the system database. Participants' answers were categorized by their learning activities (CSM and CKB) and divided further into pre- and post-test groups. The answers in each test were then classified according to cognitive levels and further grouped into LOT and HOT. Thus, each student received both LOT and HOT scores for the pre-test and post-test.

Data analysis

This study's independent variable was the method of collaborative concept mapping (CKB and CSM). The dependent variables include the student's performance on all questions, including LOT and HOT questions related to the SQL JOIN topic in the pre-test and post-test. Two statistical analyses were conducted in this study. First, the Wilcoxon signed-rank test was used to examine learning performance from pre-test to post-test for each collaborative concept mapping method. Second, the Mann-Whitney U test was employed to compare the students' learning performance across methods at the pre-test and post-test. Neither statistical test assumes a normal distribution, and statistical significance for both tests was specified at p-value < 0.05. This study utilized the Pearson correlation coefficient (r) as a measure of effect size (Cohen, 1988), with thresholds categorized as small (0.1 to 0.3), medium (0.3 to 0.5), and large (0.5 to 1.0).

Results

This study excluded from the analysis 8 out of the 41 students who participated in the CKB activity and 5 out of the 41 students who participated in the CSM activity. The students were excluded because they missed the deadline for submitting their test answers, preventing their responses from being recorded in the system. The instructor implemented this policy to address the late submission because the tests were conducted online and synchronously at the students' locations, making it difficult for the instructor to verify whether the late submission reflected genuine effort or guessing when performing the test, given the possibility of disregarding the submission time. Since the experiment was conducted in a regular class setting, this study adhered to this policy and excluded late submissions from the analysis. Therefore, the analysis focused on the learning performance of 33 students in the CKB group and 36 students in the CSM group.

The study analyzed the effectiveness of CKB in enhancing students' learning performance, particularly on HOT, by evaluating their performance before (pre-test) and after learning (post-test) and then comparing these results with those of students who used the CSM method. The analysis was divided into three parts. First, students' performance on all questions (LOT and HOT) was analyzed to examine the ability of CKB to facilitate collaborative learning through the recomposing method. Second, an analysis of students' performance on LOT questions was conducted to validate the impact of CKB on improving LOT. Third, performance on HOT questions was assessed to investigate the effectiveness of CKB in enhancing HOT, which was the primary objective of the study.

Test scores for all questions

The Wilcoxon signed-rank test results revealed significant improvement in pre-test to post-test scores for all questions in both the CKB and CSM groups, as shown in Table 2. The CKB group showed a large effect size, while the CSM group had a small effect size. Figure 7 shows the students' pre- and post-test performances within each group.

Table 2 Descriptive statistics and the Wilcoxon signed-rank test results for the differences in pre and post-test scores of all questions within CSM and CKB groups

	Descriptive statistics				Wilcoxon signed-rank test			
Group (N)	Test	Mean	Median	SD	V	p-value	Sig.	Effect size (*r*)
CSM (36)	Pre	22.2	20	8.82	320	0.03	*	0.29
	Post	27.1	27.5	14.9				
CKB (33)	Pre	23.0	25	10.8	530.5	3.83×10^{-6}	***	0.78
	Post	39.5	40	14.7				

Significant code: ***p-value < 0.001, **p-value < 0.01, *p-value < 0.05

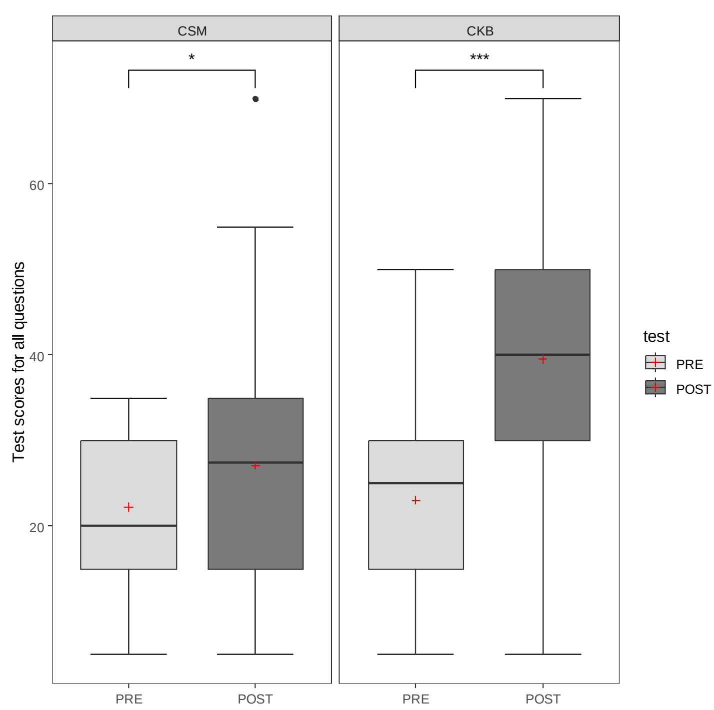

Fig. 7 The comparison of the scores for all questions between the pre-test and post-test of individual students within CSM and CKB groups

Table 3 Mann-Whitney U test results for the differences in test scores of all questions, LOT and HOT questions in the pre-test and post-test between students in CSM and CKB groups

Question	Test	Control – Experimental Group	U	Z	p-value	Sig.	Effect size (*r*)
All	Pre	CSM - CKB	1172.5	0.213	0.83		0.02
	Post	CSM - CKB	1429.5	3.318	6.93×10^{-5}	***	0.39
LOT	Pre	CSM - CKB	1148	-0.086	0.93		0.01
	Post	CSM - CKB	1410	3.093	0.002	**	0.37
HOT	Pre	CSM - CKB	1202	0.583	0.56		0.07
	Post	CSM - CKB	1348	2.360	0.018	*	0.28

Significant code: ***p-value < 0.001, **p-value < 0.01, * p-value < 0.05

Regarding the analysis of the test performance results across groups, as presented in Table 3, the Mann-Whitney U test results showed no significant difference in pre-test performance between CKB and CSM groups. However, after learning, a significant difference was found in post-test performance between the two groups, with a medium effect size. The median post-test score for the CKB group was higher than that of the CSM group, as described in Table 2.

Test scores for LOT questions

According to the Wilcoxon signed-rank test results presented in Table 4, both CKB and CSM groups demonstrated a significant improvement in LOT question scores from pre-test to post-test, with the CKB group showing a large effect size and the CSM group a medium effect size. The pre- and post-test scores of students in both groups are portrayed in Figure 8.

As described in Table 3, the Mann-Whitney U test results for the pre-test of LOT questions showed no significant difference between the CKB and CSM groups. However, significant differences were observed in the post-test between students who applied CKB and those who applied CSM, with a medium effect size. The median post-test score of the CKB group, as shown in Table 4, was higher than that of the CSM group.

Table 4 Descriptive statistics and the Wilcoxon signed-rank test results for the differences in pre and post-test scores of LOT questions within CSM and CKB groups

	Descriptive statistics				Wilcoxon signed-rank test			
Group (N)	Test	Mean	Median	SD	V	p-value	Sig.	Effect size (*r*)
CSM (36)	Pre	10.1	10	6.71	363.5	0.003	**	0.45
	Post	14.4	15	10.1				
CKB (33)	Pre	10.3	10	7.82	449.5	3.82×10^{-6}	***	0.79
	Post	22.6	25	9.85				

Significant code: ***p-value < 0.001, **p-value < 0.01, * p-value < 0.05

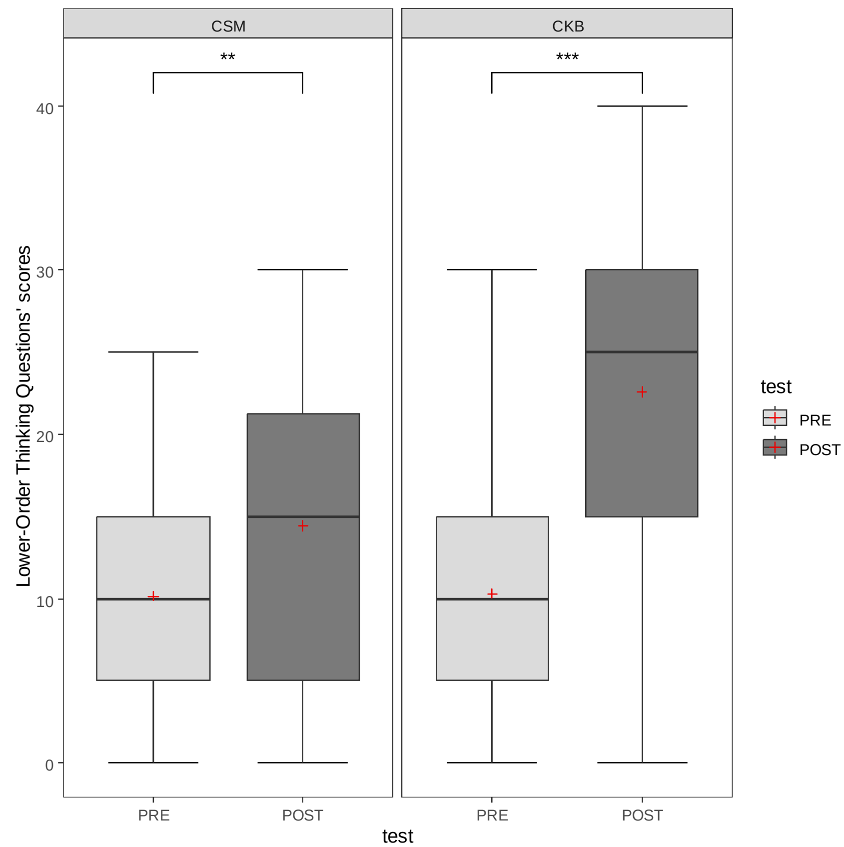

Fig. 8 The comparison of LOT questions' scores between the pre-test and post-test of individual students within CSM and CKB groups

Test scores for HOT questions

The CKB group showed significant improvement in HOT questions between pre-test and post-test with a medium effect size based on the Wilcoxon signed-rank test results in Table 5. However, the CSM group showed no significant improvement, with a small effect size and a slightly higher mean post-test score than the pre-test. Figure 9 illustrates the comparison of HOT test scores between the pre-test and post-test for the CKB and CSM groups.

Table 5 Descriptive statistics and the Wilcoxon signed-rank test results for the differences in pre and post-test scores of HOT questions within CSM and CKB groups

	Descriptive statistics				Wilcoxon signed-rank test			
Group (N)	Test	Mean	Median	SD	V	p-value	Sig.	Effect size (*r*)
CSM (36)	Pre	12.1	10	6.69	213	0.41		0.04
	Post	12.6	10	8.32				
CKB (33)	Pre	12.7	10	5.60	259	0.004	**	0.46
	Post	17.0	15	8.10				

Significant code: ***p-value < 0.001, **p-value < 0.01, *p-value < 0.05

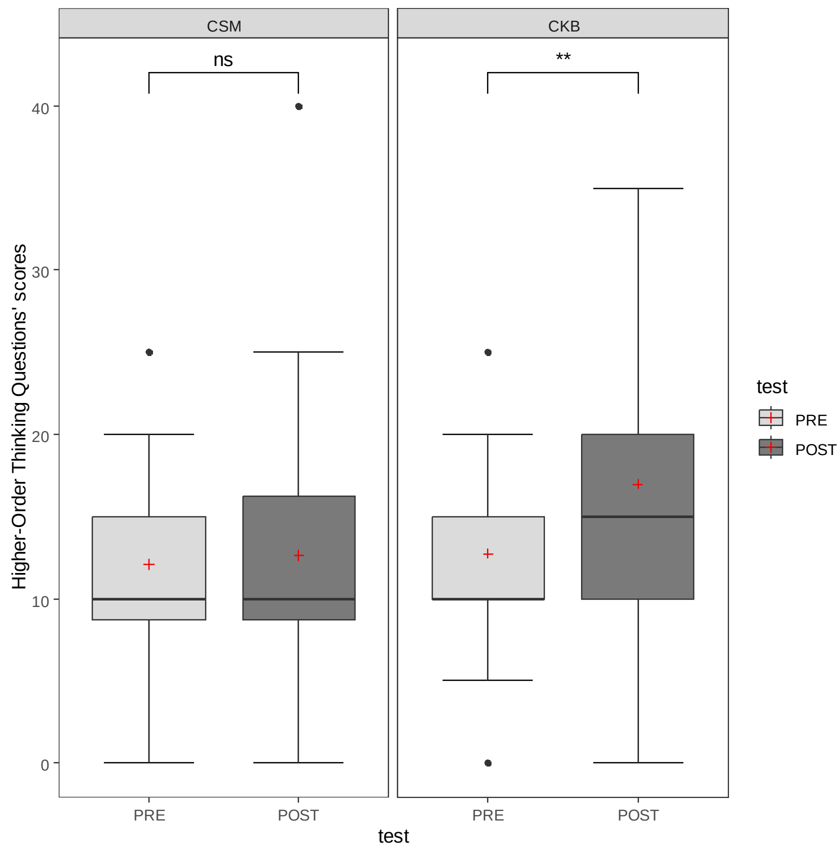

Fig. 9 The comparison of HOT questions' scores between the pre-test and post-test of individual students within CSM and CKB groups

With respect to the learning effect across the groups, Table 3 shows the Mann-Whitney U test results for pre-test performance on HOT questions, revealing no significant difference between the CKB and CSM groups, with a small effect size. However, after collaboratively building the concept map, the post-test performance of the CKB group significantly differed from that of the CSM group, with a small effect size. The CKB group demonstrated a higher median post-test score than the CSM group, as reported in Table 5.

Discussion

This study aimed to evaluate the impact of CKB on students' HOT performance, based on revised Bloom's Taxonomy, in a synchronous online class. CKB's performance results were compared with CSM's to evaluate its effectiveness. The results revealed that learning with CKB significantly improved both HOT and overall learning outcomes, including LOT performance, suggesting that CKB positively impacted students' learning performances. A similar effect was observed when students learned using CSM, as assessed by their ability to answer all questions. Both concept mapping methods (CKB and CSM) effectively enhanced the students' understanding at the cognitive level of "remember" and "understand," categorized as LOT, as shown in Table 1. These results align with the previous studies that found that collaborative concept mapping activities could facilitate collaborative learning (Chang et al., 2017; de Weerd et al., 2017; Farrokhnia et al., 2019; Gijlers & de Jong, 2013; Pinandito et al., 2021) suggesting that CKB has the potential to promote collaborative learning.

Both methods showed varying results in enhancing HOT. CKB effectively facilitated students' progression to higher cognitive levels, such as "apply" and "analyze" (referred to as HOT, as shown in Table 1), while CSM had a modest impact on advancing students to these levels. Since CKB adopted KBCM, the results suggest that KBCM has the potential to facilitate collaborative learning and improve the students' HOT. Furthermore, these findings add a new capability to KBCM by enhancing students' understanding of domain-specific knowledge at higher cognitive levels through concept mapping with the recomposing method in both individual (Nurmaya et al., 2023) and group learning contexts. Thus, KBCM could become a promising learning strategy to enhance understanding of domain-specific knowledge at both LOT and HOT.

LOT performances

CKB showed greater improvement in LOT performance than CSM, indicating that the recomposing method for collaborative concept mapping more effectively enhanced students' ability to remember and comprehend facts in a specific domain than building a map from scratch. Therefore, CKB appears to be a promising method for enhancing LOT performance.

Possessing relevant components (concepts and linking phrases) related to the learning contents could be a key factor in improving students' LOT performance. Utilizing the recomposing method, students are presented with the components, which facilitates their acquisition of key terms related to the learning topic. This acquisition may enhance their ability to identify and understand both the concepts and their relationships, potentially leading to the creation of information relevant to the learning content. Klemm (2007) argued that building the association among related concepts could foster students to remember information more easily as one concept could become a cue to recall other concepts. Furthermore, Klemm emphasized that memorization improved when the associations between concepts generated new information relevant to the learning content. Thus, when students and their partners have the components while using CKB, they may be able to form relevant relationships among concepts through discussion, potentially enhancing both memorization and comprehension. Further investigation is necessary to evaluate the creation of relevant relationships and their impact on LOT in future studies.

HOT performances

Collaboratively recomposing the concept map from the given concepts and linking phrases, with the connecting line omitted, encourages students to determine the appropriate connections between concepts. Constructing relationships among concepts through group discussions encourages students to critically evaluate their understanding, leading them to deepen their understanding (Carvalho et al., 2020). Applying knowledge to address a problem requires a deeper understanding than merely recalling information or procedures (Miller & Krajcik, 2019). Therefore, the improvement in students' ability to answer HOT questions after learning with CKB suggests that they have developed a deeper understanding, enabling them to apply their knowledge and think analytically when solving problems.

The non-significant improvement in students' performance on HOT questions after learning with CSM indicates that students' understanding may have advanced to a higher cognitive level, but the advancement was not statistically significant. This finding may indicate that collaborative efforts in constructing a map from scratch on the learning topic were insufficient to prompt the students to critically analyze, evaluate, or synthesize shared information. van Boxtel et al. (2002) revealed that engaging in direct collaboration while constructing the concept map did not sufficiently motivate group members to elaborate on their understanding at an explanatory level, particularly when they lacked prior experience in elaborating at that level. This explanatory level involves proficiency in articulating the relationship between concepts. To develop this skill, students were required to engage in critical thinking, including analytical processes (Şeker & Kömür, 2008). Since this was the first time the students in this study participated in collaborative learning for the course, their inexperience with collaborative learning may have resulted in a lower ability to elaborate on their understanding at an explanatory level. Consequently, this limitation may have hindered their collaborative efforts in constructing a concept map from scratch. As a result, these efforts may not have been sufficient to encourage them to critically analyze, evaluate, and synthesize the shared information, potentially limiting their deep understanding of the content. This, in turn, may have led to the lack of significant improvement in HOT performance in this context.

Regarding the comparison of methods, the CKB and CSM groups initially showed comparable abilities on HOT questions, with no significant difference between them before the learning intervention. However, a significant difference occurred between the groups after learning, with improvements seen in the CKB group, indicating that CKB has a greater learning effect on HOT questions than CSM. Consequently, CKB may effectively improve students' HOT, particularly in synchronous online classes, which aligns with the goal of this study. The findings from CKB support the suggestion made by Cañas et al. (2023) to implement various strategies in concept map creation for achieving positive learning outcomes. Providing students with a list of concepts as a starting point is one of the strategies for teachers that could be used when they begin using concept maps as a learning method. Cañas et al. (2023) argued that implementing this strategy could help students become proficient concept mappers, fostering the ongoing development of HOT. This suggestion aligns with the condition of this study, in which the instructor has only recently begun using concept maps in collaborative learning in this class. Therefore, to further enhance the practical application of CKB, it is necessary to explore its effectiveness in improving students' HOT across diverse educational settings in future studies.

Another significant theoretical implication of these findings is the foundational role of context in facilitating HOT through concept map recomposition. While previous discussions have focused on cognitive processes such as analysis and evaluation, contextual information plays a crucial role in connecting discrete concepts into a meaningful whole. According to Novak and Cañas (2008), concept mapping inherently relies on the context-dependent selection and integration of nodes and links within specific learning contents. Similarly, Cañas et al. (2005) demonstrates how CmapTools supports the creation of concept maps that incorporate and link extensive domain-specific information. Both studies highlight the importance of context in transforming discrete components into coherent concept maps. The components (concepts and linking phrases) carry individual meanings but lack a contextual link to integrate them with the learning content, leaving gaps in the information. For example, when students engage in concept mapping with KBCM, they must analyze how each provided concept and linking phrase fits into a larger structure, bridging gaps of contextual information. This restructuring process requires students to critically evaluate the relationships among concepts, ultimately constructing a meaningful context that transforms individual components into a coherent understanding of the subject matter. This process of creating context aligns with the higher-order cognitive processes of the revised Bloom's taxonomy (Anderson et al., 2001).

The findings suggest that collaboratively constructing context assists students in deepening their understanding of the learning content. Interaction among students during context construction fosters a deep understanding of the learning content as it involves cognitive activities that stimulate HOT. As demonstrated by Khosa and Volet's (2014) study, engaging in cognitive activities related to high-level knowledge construction during group interaction (e.g., elaboration, justification of the content) contributes to better conceptual understanding than for those who do not engage in such activities. These activities stimulate HOT by encompassing cognitive processes beyond memorization and comprehension, such as analytical thinking (King, 2007). The findings indicate that CKB fosters deep cognitive engagement by enabling students to collaboratively construct context.

Implications for practice

This study highlighted the need for technology to implement KBCM in the classroom. KBCM was integrated into a web-based system (CKB system) to facilitate online synchronous collaborative learning. An internet connection and web browser are required to access the system, similar to previous studies that utilized KBCM in individual settings (Khudhur et al., 2023; Nurmaya et al., 2023; Rismanto et al., 2023). Concepts as nodes and linking phrases were shared by teachers through an online platform and accessed by students. Thus, recomposing activity was conducted online, both individually and collaboratively. Consequently, implementing KBCM in a classroom without technological support will present a challenge. Furthermore, it has not yet been confirmed whether recomposing a map without technological support (e.g., paper-pencil) produces the same learning effect as recomposing it online.

Previous studies on traditional concept mapping, where maps are built from scratch, have shown similar results regardless of whether technology is used, such as in paper-pencil settings (Chiou et al., 2017; Islim, 2018). Therefore, exploring the use of KBCM without technological support is essential for its application in diverse classroom environments. While it has yet to be investigated, KBCM might be feasible in classrooms without technological support. For instance, teachers could provide components in paper form, attach them to the classroom board, or write the components on the board at the front of the class. Students can then recompose the map individually on their own paper. For collaborative work, students could work in small groups, engaging in discussions while collaboratively recomposing the concept map. Teachers would act as facilitators, offering assistance such as clarifying concepts in both individual and group work, while encouraging dynamic interactions among group members during collaborative activities, such as discussing the relationships between concepts and negotiating the connections.

Additionally, preparing for concept mapping requires teachers to first create the SG map to derive the concept map components, whereas traditional methods do not require this step. This additional effort could be a barrier to implementing KBCM. One potential solution to reduce this effort is the development of automated SG map creation.

Limitations and future work

This study showed that using CKB to perform collaborative learning could improve individual student performance in solving HOT and LOT questions. However, this study was only performed in one subject, which is necessary to perform in the various subjects for further replication of results. CKB, which adapts the KBCM framework, has positively impacted students' understanding across various fields, including English as a Foreign Language (EFL) and informatics, particularly in programming topics. Additionally, the application of KBCM in individual learning has been shown to enhance students' HOT (Nurmaya et al., 2023). Therefore, the effectiveness of CKB in enhancing students' higher-level understanding could be extended to other disciplines, such as language or social studies, making them compelling subjects for future research. Furthermore, future studies should investigate the effectiveness of CKB in various educational settings, such as learning environments where students lack technological support, to enhance its practical application. These future results may also provide more information on the inclusiveness of the CKB.

While this study demonstrated the positive impact of CKB on HOT performance, the HOT assessment encompassed only two cognitive levels of the revised Bloom's Taxonomy: "apply" and "analyze." This limitation arose from the complexity of the learning content, making it challenging to incorporate the two highest levels, "evaluate" and "create." Therefore, future research should evaluate HOT performance in subjects that allow for assessing all higher cognitive levels of Bloom's Taxonomy, including the "evaluate" and "create" levels.

During CKB activity, group members may elaborate on and justify the content, exchanging ideas and negotiating meanings through chat conversations. These interactions may involve higher-level cognitive processes, such as analyzing, evaluating, and synthesizing, particularly when working toward a consensus and developing shared understanding. The co-construction of high-level understanding may be affected by these interactions. Therefore, future analysis could explore the relationship between the message in conversations and the similarity of students' understanding at high cognitive levels within a group. Moreover, analyzing the conversation may reveal the background of individual students within a group and the nature of their interactions, both of which may influence learning performance. For instance, when students choose their own partners, analyzing their conversation may expose the diversity of prior knowledge and how this diversity affects group interactions and learning outcomes. These future analyses might be conducted by using qualitative analysis methods. Additionally, this approach may reveal whether students are able to form relevant relationships among concepts, which may influence the accuracy of the information they retain and comprehend, thereby ensuring overall educational effectiveness.

Considering the context-dependent nature of concept maps, it is valuable to discuss the improvement of learning performance from the perspective of constructing the contextual information and how the cognitive processes occur through group interaction within this context in future research.

Previous research of KBCM demonstrated that using the concept mapping activities with the recomposing method before asynchronous online discussion could enhance students' basic conceptual understanding and increase the cognitive presence of the Community of

Inquiry (CoI) framework in their discussion (Hasani et al., 2023). Therefore, it is an interesting area for future study to investigate the impact of CKB activity on students' HOT and discussion quality in online and asynchronous settings. This includes examining how the three presences of the CoI framework, i.e., cognitive, social, and teaching, relate to students' learning performances.

Given that CKB and CSM support collaborative learning, combining the two methods might further enhance HOT performance. CKB could serve at the beginning stage, followed by CSM, or the two methods could be integrated. A previous study on individual learning showed that students were able to construct their own cognitive structures (concept map) after recomposing a concept map (Prasetya et al., 2022), suggesting the feasibility of combining both methods. Thus, this combination offers an interesting topic for future research.

Conclusion

This study investigated the effectiveness of CKB in promoting students' HOT. Pre- and post-tests, consisting of questions categorized as LOT and HOT based on the cognitive level of the revised Bloom's Taxonomy, were used to evaluate the students' learning performances. A comparison with CSM was performed to evaluate the effectiveness of the CKB method. Results showed that the students who learned using CKB improved their ability to solve the HOT questions, and the improvement was significantly better than the students who learned using CSM. In addition, students who engaged in the CKB activity showed improvement in LOT, with their performance significantly better than that of the students who carried out the CSM activity. These results demonstrated that by applying CKB in collaborative learning, students' understanding, including remembering and understanding knowledge, could reach higher levels, such as applying and analyzing domain-specific knowledge. Concerning overall learning performance when answering all questions, the students who applied CKB in their learning showed significant improvement and were significantly better than those who employed CSM. Thus, these findings highlight the potential of KBCM to support collaborative learning by utilizing concept map recomposition.

Abbreviations

CKB: Online Collaborative Kit-Build Concept Mapping; CoI: Community of Inquiry; CSM: Online Collaborative Scratch-Build Concept Mapping; EFL: English as a Foreign Language; HOT: Higher-Order Thinking; KBCM: Kit-Build Concept Map; LOT: Lower-Order Thinking; MCQ: Multiple-Choice Question; SG: Shared Goal.

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Authors' contributions

N managed the experiments, analyzed the data, and wrote the manuscript. AP designed and developed the system and managed the experiments. YH discussed and reviewed the analysis results. TH reviewed the experiment design, the analysis results, and the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

Data and materials may be accessed upon reasonable request.

Declarations

Competing interests

The authors declare that they have no competing interests.

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