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Exploring the differences in response characteristics to teacher scaffolding between the high- and low-performing groups during collaborative problem solving

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ABSTRACT

Studies have highlighted the crucial role of student response to teacher scaffolding in achieving effective instructional intervention. This response, encompassing what students have said and done after receiving teacher scaffolding, can be categorized as either immediate uptake or delayed use according to the length of responding time. However, the empirical exploration of this statement in collaborative problem solving (CPS) context remains scarce, with few in-depth research investigating the specific differences in student response to teacher scaffolding within the context of CPS, especially in terms of immediate uptake and delayed use. This study aims to investigate student response to teacher scaffolding in a comprehensive perspective by comparing the immediate uptake and delayed use between high- and low-performing groups in CPS. Specifically, the distinction between high- and low-performing groups is based on the academic outcomes of their completed collaborative problem solving tasks. Employing an integrated method combining content analysis and sequential analysis, videos and discourse data were collected and analyzed to reveal the response characteristics of selected groups to teacher scaffolding throughout the activity. The results indicated that: (1) For immediate uptake, the high-performing groups were more likely to repeat, ask questions, and apply the teacher scaffolding, whereas the low-performing groups tended to respond, ignored or kept silent to the teacher scaffolding; (2) For delayed use, the low-performing groups exhibited less delayed use to teacher scaffolding compared to the high-performing groups, and the high-performing groups had a higher proportion of delayed uses in repeating and applying. (3) For response sequence from immediate uptake to delayed use, the high-performing groups tend to consistently use teacher scaffolding, whereas low-performing groups prefer to use it after responding or repeating the content of teacher scaffolding. Drawing upon these findings, this study proposed implications for educators on the use of teacher scaffolding in CPS, which will aid learners in more effectively engaging in collaborative problem solving tasks.

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1. Introduction

As a productive form of collaborative learning, plentiful studies have demonstrated the benefits of collaborative problem solving activities (CPS), such as consolidating conceptual understanding Kwon et al. (2019); (Meng-Tzu et al., 2014), enhancing deep learning (Dolmans et al., 2016), cultivating critical thinking ability (Choi et al., 2014) and career interests (Corwin et al., 2018). However, this type of learning activity is not inherently successful, students may encounter various cognitive (Papadakis, 2018), metacognitive (Hadwin et al., 2018), and socio-emotional challenges (Demir & Seferoglu, 2021). Studies have shown that providing teacher scaffolding during the process of collaborative problem solving can greatly help students address these challenges and achieve high quality of collaboration (Ouyang & Xu, 2022; Zheng et al., 2022).

In order to provide more effective teacher scaffolding in CPS, researchers have conducted numerous studies, most of which have centered on the functional design of teacher scaffolding and its influence on learning process and performance (Ouyang, et al., 2022; Ouyang & Xu, 2022; Zheng et al., 2022). Nevertheless, some researchers also emphasized the critical role of student response in achieving effective teacher scaffolding (van de Pol et al., 2012; Wittwer & Renkl, 2008). As a key factor affecting interaction with peers and teachers, resulting in varied collaborative performance (Gillies, 2011; Jadallah et al., 2011), student response can be observed through students' actions and statements following scaffolding provision (Nystrand et al., 2003; van de Pol et al., 2014) and be divided into immediate uptake and delayed use based on the length of responding time (Ouyang, Dai, & Chen, 2022; van de Pol et al., 2019).

Previous studies have provided evidence that students in high- and low-performing groups may respond differently to teacher scaffoldings respectively in terms of immediate uptake and delayed use (Gillies & Khan, 2008; van de Pol et al., 2019). However, few studies have holistically combined these two aspects of student response (immediate uptake and delayed use) in a comprehensive perspective to explore the response characteristics of high- and low-performing groups to teacher scaffoldings. Such an exploration can offer valuable insights for teachers to diagnose student comprehension and support students in navigating challenges within CPS more efficiently, thereby enhancing the quality of CPS (Ouyang, Dai, & Chen, 2022; Wittwer et al., 2010).

To fill the gap, this study compared the differences in the immediate uptake and delayed use to teacher scaffolding between the high- and low-performing groups. From that, this study aims to reveal the response characteristics to teacher scaffolding between the groups and provide an insight of this process to bring inspiration for teacher designing scaffoldings in CPS.

2. Literature review

2.1. Collaborative problem solving activity

Collaborative problem solving activity (CPS) is a productive form of collaborative learning, it refers to a joint process where dyads or small groups pool their diversified knowledge, skills, and effort to establish a mutual understanding of the problem and propose a final solution to the problem through the process(Gao et al., 2022; Hesse et al., 2014). During this process, students are required to gain a profound understanding of the knowledge acquired, explore the essence of problems through effective communication and negotiation (Griffin & Care, 2015; Ouyang et al., 2021), which significantly facilitates their comprehension and construction of knowledge, thereby rendering it an indispensable aspect of contemporary teaching practices (Hmelo-Silver et al., 2010; Lin et al., 2013). Studies have indicated the advantages of collaborative problem solving activity, such as consolidating conceptual understanding (Care & Griffin, 2022; Kwon et al., 2019), strengthening deep learning (Dolmans et al., 2016), establishing critical thinking skills (Gauvain, 2018), and gaining in long-term retention (Yew & Goh, 2016).

Despite the various advantages of CPS, its achievement can't be guaranteed. CPS typically involves group members in solving real-world and ill-structured problem situations, encouraging them to integrate multiple perspectives, create mutual knowledge, and develop effective solutions through group interaction and reflection (Dillenbourg & Traum, 2006). These problems usually exceed students' existing knowledge and abilities (Kapur, 2008; Scardamalia & Bereiter, 2005), resulting in cognitive (Papadakis, 2018), metacognitive (Hadwin et al., 2018), and social-emotional challenges (Demir & Seferoglu, 2021). For example, in CPS, groups need to establish common goals and maintain an equal level of motivation, which requires them to have sufficient drive to stay focused and enthusiastic about the objectives (A. Tawfik et al., 2014). During collaboration, groups must identify potential shortcomings in a timely manner and adjust their collaborative direction flexibly to ensure the successful completion of tasks. This requires them to possess monitoring and reflective abilities regarding the collaboration process (Hadwin et al., 2018; Järvelä et al., 2016). Additionally, groups also need to engage in continuous knowledge creation to solve problems and sustain high-level knowledge construction. This necessitates students to continuously share, explore, and create new knowledge (Veerasamy et al., 2019), offering new insights and solutions. Without additional prompts or assistance, this can be particularly challenging for most students (Radkowitsch et al., 2020). Research has shown that providing appropriate teacher scaffolding in CPS can significantly help students overcome these challenges and achieve high-quality collaboration (Ouyang, et al., 2022; Ouyang & Xu, 2022). Therefore, it is essential to provide teacher scaffolding to facilitate productive engagement in CPS (Zheng et al., 2022).

2.2. Teacher scaffolding in collaborative problem solving

As mentioned above, in CPS, students need to jointly construct their understanding of knowledge (A. Tawfik et al., 2014; Kwon et al., 2019) and come up with solutions to the problem through interaction with peers and teachers (Haataja et al., 2019). In this interactive process, teachers often need to provide additional support in the students' proximal development zone to help students complete tasks that they cannot currently accomplish independently (Stone, 1998; Wood et al., 1976). This kind of support is known as teacher scaffolding, which serves as an essential assistance for collaborative problem solving (Ouyang & Xu, 2022).

According to previous studies, teacher scaffolding can be divided into three categories based on its role in instruction: cognitive scaffolding (Hou & Keng, 2021; Zheng, 2021), metacognitive scaffolding (Kim et al., 2022; Zheng et al., 2019), and social scaffolding (Ouyang, Dai, & Chen, 2022; Ouyang & Xu, 2022). Among them, cognitive scaffolding refers to providing additional explanations for problems that the groups need to solve, with the aim of promoting knowledge construction or problem solving (Ouyang et al., 2021). Metacognitive scaffolding refers to providing relevant strategies or tips to improve group metacognitive behaviors, with the aim of encouraging groups to plan, monitor, evaluate, and reflect on their process of problem solving (Zheng, 2021). Social scaffolding refers to providing emotionally supportive assistance to foster team awareness and cultivate a collaborative atmosphere, aiming to facilitate group interaction and sustain positive social emotions in CPS (Belland et al., 2017; Ouyang & Xu, 2022; Zheng et al., 2022).

So far, researchers have conducted a series of explorations to provide more effective teacher scaffolding in the context of CPS, and most of the existing empirical studies have focused on the functional design of teacher scaffolding and its impact on learning process and performance (Ouyang, et al., 2022; Ouyang & Xu, 2022; Zheng et al., 2022). For example, Ouyang and Xu (2022) designed cognitive scaffolding, metacognitive scaffolding, and social scaffolding in the process of group collaborative concept mapping. They found that the groups providing with cognitive scaffolding performed best in concept mapping, but had the lowest levels of social interaction and metacognition. Ouyang et al. (2022) designed three types of group metacognitive scaffoldings: general scaffolding, task-oriented scaffolding, and idea-oriented scaffolding, and explored the impact of these three types of group metacognitive scaffolding on the knowledge construction process and collaborative performance of groups. The research results showed that idea-oriented scaffolding had the best effect in promoting problem stimulation and idea presentation, and had a greater role in improving domain specific understanding.

It is worth noting that, previous studies have indicated that student response to teacher scaffolding is crucial for achieving effective instructional intervention, as it furnish critical diagnostic information to teachers (van de Pol et al., 2011; van de Pol et al., 2014; Wittwer et al., 2010). By observing students' responses, teachers can assess students' current understanding of the scaffolding and evaluate their ability to effectively apply it in collaborative learning process (Martin et al., 2019; Puntambekar, 2022). Specifically, when students exhibit confusion regarding the concepts, methods, or strategies within the scaffolding, teachers should adaptively adjust the content and delivery of scaffolding to more precisely meet students' learning needs (Stone, 1998; van de Pol et al., 2012). Conversely, when students demonstrate understanding and application of the scaffolding, teachers should gradually reduce intervention and transfer responsibility back to students (Forman et al., 2017; Tabak & Baumgartner, 2004), thereby achieving effective teacher scaffolding. Although prior research has highlighted the significance of student response to achieve effective teacher scaffolding in collaborative learning (van de Pol et al., 2010, 2012), there remains a dearth of exploration within collaborative problem solving contexts, and further research is needed to reveal more details of student response to teacher scaffolding in CPS for enhancing the quality of CPS (Ouyang, Dai, & Chen, 2022).

2.3. Student response to teacher scaffolding

Student response to teacher scaffolding refers to the behaviors they exhibit after receiving a guidance and support from the teacher (Barron, 2003; van de Pol et al., 2012), which can be reflected by what students have said and done after the provision of scaffolding (Nystrand et al., 2003; van de Pol et al., 2014). Based on the length of responding time, researchers divided student response into immediate uptake and delayed use (Ouyang, Dai, & Chen, 2022; van de Pol et al., 2019). The immediate uptake of the student to scaffolding refers to the response of the student to the scaffolding immediately after its provision, such as repeating, applying, etc. (Barron, 2003; van de Pol et al., 2010). The delayed use of the student to scaffolding is reflected in whether student can integrate and apply the information from the scaffolding to address subsequent problems encountered during collaboration. (van de Pol et al., 2019; Wittwer & Renkl, 2008).

As indicated by existing studies, the student responses to teacher scaffolding can affect their communication and interaction with peers and teachers (Graesser et al., 2018; Webb & Gibson, 2015), resulting in different collaborative performance(Gillies, 2011; Jadallah et al., 2011), which typically refers to the score assigned to the solution outcome of a group's collaborative task (Zheng et al., 2023). That is, if students can actively utilize the scaffolding provided by teacher, they will be more willing to share their ideas, opinions, and knowledge in the collaborative process, promoting communication and learning within the team (Lin et al., 2015; Zhu & Lin, 2023). On the contrary, if students keep silent or react negatively to the teacher scaffolding, it may lead to poor communication within the team and thus have a negative impact on collaborative performance (Ouyang, Dai, & Chen, 2022; Webb et al., 2006).

In order to reveal the relationship between student response to teacher scaffolding and collaborative performance, researchers attempted to obtain clues from the differences in student response between high- and low-performing groups (Barron, 2003; Webb et al., 2006), as the high-performing groups are identified as those whose solution outcomes rank among the top, while the low-performing groups are those that rank lower in terms of scores (Gao et al., 2023; Li et al., 2023). From the perspective of immediate uptake of teacher scaffolding, Barron (2003) revealed, after receiving the teacher's correct proposal regarding the problem solving solution, the high-performing groups were more verbally engaged and more effective in applying the suggested proposal than the low-performing groups. Webb et al. (2006) found, in the process of teachers using questioning strategies to assist students in solving immediate challenges, students' varied responses to this support directly influenced the collaboration process, leading to differentiated collaborative performance. Specifically, when students imitated higher-level helping behaviors from teachers, their group members experienced less confusion, deeper communication, and higher performance. From the perspective of delayed use of teacher scaffolding, van de Pol et al. (2019) indicated, after teachers provided varying levels of scaffolding, ranging from open-ended questions to direct answers, high-performing groups tend to apply the information of teacher scaffolding in subsequent collaboration and develop more accurate answers while low-performing groups ignored them. Lin et al. (2015) found the groups which were able to discover their misunderstandings, sort out complex concepts, and explicate ideas following the teacher's prompts and praise achieved higher performance than those who did not exhibit these behaviors.

Previous studies have provided evidence that students in high- and low-performing groups may have differentiated responses to teacher scaffolding from the perspectives of immediate uptake and delayed use respectively (Gillies & Khan, 2008; van de Pol et al., 2019). However, few studies have combined these two aspects (immediate uptake and delayed use) in a comprehensive perspective to analyze the response characteristics of high- and low-performing groups to teacher scaffolding. Further research is needed to reveal the specific differences in the context of CPS for providing more useful information for teachers to diagnose student comprehension and guiding future instructional interventions. Moreover, current research predominantly focuses on student responses to cognitive scaffolding provided by teachers, such as questioning, prompts, and cues (Lin et al., 2015; van de Pol et al., 2019). However, in authentic teaching contexts, the teacher's role is more multifaceted, extending beyond cognitive support to include metacognitive guidance and social assistance, among other forms of scaffolding (Ouyang & Xu, 2022; Zheng, 2021). Consequently, student's response on these diverse scaffolding forms exhibits both immediate and delayed, complex characteristics. Unfortunately, there is a lack of empirical evidence addressing the specific manifestations of these multidimensional and temporally varied responses in CPS.

Hence, this study aims to compare the differences between high- and low-performing groups in terms of (a) immediate uptake and (b) delayed use to the three types of teacher scaffolding (cognitive, metacognitive, and social scaffolding) during CPS. Therefore, this study attempted to identify the response characteristics of high- and low-performing groups and provide some suggestions for teachers to more precisely support collaborative problem-solving processes, thereby improving both the efficiency and quality of collaboration.

The following three research questions lead this investigation:

RQ1: What are the differences in immediate uptake to teacher scaffolding between the high- and low- performing groups in CPS?

RQ2: What are the differences in delayed use to teacher scaffolding between the high- and low- performing groups in CPS?

RQ3: What are the differences in the response sequence from the immediate uptake to delayed use to teacher scaffolding between the high- and low- performing groups in CPS?

3. Methods

3.1. Participants

This study involved 39 graduates and undergraduates with diverse majors (mean age=21.1years) from a university in Beijing, China, and the demographic data of all students is presented in Table 1. Students were recruited through voluntary registration, and before official participation, all students were informed of the purpose, confidentiality, and their right to withdraw at any time. After fully understanding the nature of the study and agreeing to participate, students were tasked with completing a pre-test questionnaire, aiming to gain a clearer understanding of the students' backgrounds and their knowledge and skill levels. This questionnaire is divided into two sections: The first section gathers personal information, including the student's gender, major, and academic year. The second section is a self-report, consisting of five key items that assess students' understanding of population migration, mathematical modeling, and their familiarity with tools such as Matlab, SPSS, and Python. These questions were presented on a five-point Likert scale to gauge students' knowledge base and relevant problem-solving experience, which served as a reference for the subsequent group formation.

After collecting the information from the pre-test questionnaire, the researchers carefully assessed each student's academic background and self-reported result to create a diverse group composition, ensuring that students from different majors were included in each group. Additionally, this study evenly assigned the 39 students to 13 groups, aiming to maintain a balance in knowledge and skill levels across the groups to facilitate effective collaboration and efficient problem solving within the groups.

3.2. The CPS activity

The CPS activity lasted around 2 hours for each group (Fig. 1). This activity required groups to utilize the provided materials and integrate knowledge from various disciplines, such as mathematical modeling, political science, geography, and economics, to accurately predict and analyse population trends in a specific Chinese city. Groups are also expected to identify potential factors

Table 1
The demographic data.

Category	Number of students
Gender	
Male	4
Female	35
Major	
science and engineering	17
humanities and social fields	22
Degree	
Undergraduate student	23
Graduate student	16

Fig. 1. The CPS activity.

influencing population shifts and propose practical strategies to attract young people to settle in the area. Ultimately, each group must develop a feasible solution to address these issues.

Before the activity, descriptions for activity, task requirements, and testing for software were given, ensuring seamless participation of all members. Subsequently, group members engaged in a 15 minutes independent thinking to familiarize themselves with the materials and develop individual problem solving ideas. Following the independent thinking phase, groups collaborated for the next 105 minutes to jointly analyze the population data, identify trends in population change, explore underlying causes for the trends, and propose strategies to attract young populations. After the activity, each group is required to submit a solution to the aforementioned issues (Fig. 2).

During the CPS activity, three students in the same group were located in different physical locations, engaging in online communication and collaboration via the "Tencent Meeting" software. Additionally, a teacher, who possessed a comprehensive understanding of the diverse facets and interconnectedness of knowledge related to this activity, and had a good understanding of different types of scaffolding in CPS, participated synchronously in the CPS activities for all groups. The teacher monitored students' learning status and collaborative progress in real-time and provided scaffolding when necessary.

3.3. The selection of high- and low-performing groups

The assessment criteria for group problem solving solutions (see Appendix A) are adapted from the study by Docktor et al. (2016) and have five dimensions: description accuracy, method appropriateness, result correctness, application rationality and logical coherence. The highest score for each dimension is 5, with a maximum score of 25. Based on this scoring standard, two experienced researchers independently rated each group's solution. Both raters received systematic training on the scoring rubric. After the rating process, the average of the scores was used as each group's solution score, with groups ranked from highest to lowest based on these scores. Considering that the scores of the 13 groups following a normal distribution, based on previous studies (Gao et al., 2023; Li et al., 2023; Liu et al., 2023), this study ultimately selected four high performing groups (HP) from the top 27 % and four low performing groups (LP) from the bottom 27 % for subsequent data analysis.

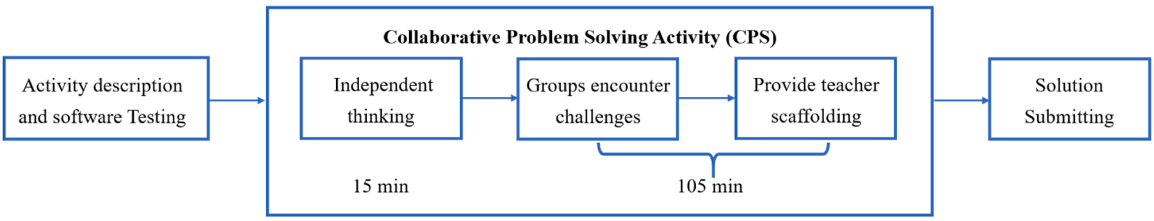

Fig. 2. The experimental process.

3.4. Data collection and analysis

Phase1 data collection

The data collected in this study consist of two components: (1) video recordings (N=8, around 20 h, mean=2.5h, SD=11.5min) documenting the collaborative problem solving processes of each group, including the process of the teacher scaffolding in the activity and the immediate uptake and delayed use by each group member. (2) Screen recordings (N=24, around 50 h, mean=2.1h, SD=10.9min) documenting the computer operations of each group member during collaboration.

Phase2 data processing

Firstly, for the video recordings, dialogue content was automatically transcribed into Excel files in time order thus creating dialogue data. During transcription, differentiation was made based on individual speakers, and the data were organized chronologically to ensure integrity and accuracy. Ultimately, 8 Excel files were obtained, comprising a total of 3913 rows of dialogue data, documenting the specific communication content between group members and teacher during CPS activities.

Secondly, to ensure data accuracy, an experienced researcher conducted detailed verification of the automatically transcribed dialogue data. Additionally, the researcher meticulously organized and time-corrected all collected screen recordings of the group members, aligning them accurately with the dialogue data timestamps. This ensured subsequent pinpointing of specific computer operation behaviors of corresponding group member based on the occurrence time of dialogue data.

Phase3 coding

Before commencing formal coding, it is essential to define the time range for immediate uptake and delayed use to divide conversational discourses in dialogue data. Given the complexity of the CPS activity and the requisite response time for provided scaffoldings by the researcher, this study made a few adjustments based on the research of Ouyang, Dai and Chen (2022), dividing conversational discourses at 30s intervals: (1) immediate uptake: refers to the student's response to teacher scaffolding within 30s of its provision; and (2) delayed use: refers to the student's response to the scaffolding from 30s after immediate uptake until the end of the activity. In this study, we selected a 30-second interval to segment the discourse data, following previous research. Studies have shown that 30 seconds provides a balanced duration—neither too short nor too long—allowing students to develop relatively complete thoughts and express themselves in coherent sentences, and ensuring data consistency (Gao et al., 2023; Li et al., 2024).

After definition, the two coders used the coding frameworks of the teacher scaffolding (Table 2) and the student response (Table 3,4) to code the scaffolding provided by the researcher during the CPS process, along with the immediate uptake and delayed use of the students to the scaffoldings. During the coding process, two considerations were taken into account: firstly, in coding student responses to teacher scaffolding, each team member's response is considered individually. For example, if all three students in a group ignore the scaffolding, the response that ignoring the scaffolding was recorded three times. Secondly, if the group member was engaged in discussions and the teacher provided scaffolding. After receiving it, the member neither mentioned nor utilized it and continued to solve problems independently while group discussions progress, then the member's response was coded as ignoring scaffolding. If none

Table 2
The coding framework of teacher scaffoldings.

Types	Condition	Sub-types	Descriptions	Examples
Cognitive scaffolding (CS)	when groups encounter intellectual problems cannot be solved independently	Low-control cognitive scaffolding	Guide the group's problem-solving process by asking open-ended questions that encourage deeper reflection and exploration of potential solutions.	"Please take a moment to consider whether there is a more scientific approach."
		Medium-control cognitive scaffolding	Provide groups with relevant information, tips, or clues to solve the problem.	"It seems you're unsure how to interpret the model. Try searching for how to explain a multiple regression equation."
		High-control cognitive scaffolding	Offer the group direct solutions to relevant questions or provide demonstrations of how to perform specific tasks.	"Although the first question asks about the trend, you still need to calculate the data for each year to understand the specific changes."
Metacognitive scaffolding (MS)	when groups encounter problems related to the coordination of the collaborative process	Strategy formulation scaffolding	Provide effective methods for coordinating current processes, solving current problems, and achieving goals for the groups.	"How about collaborating to build the model together?"
		Time management scaffolding	Remind groups of the remaining time.	"There are still about 40 minutes left in the activity."
		Process monitoring scaffolding	Make groups confirm their progress by reviewing and sharing completed work, and focus on task completing.	"You're behind schedule. Everyone should begin the practical tasks now. Please pick up the pace."
Social scaffolding (SS)	when groups encounter problems related to regulation of the collaborative climate	Emotional regulation scaffolding	Encourage group members or ease the group atmosphere through comfort, persuasion, motivation, encouragement, praise, and other means.	"Great job, everyone! Keep up the good work!"
		Team awareness scaffolding	Encourage group members to share personal issues or cooperative feelings, form team awareness, and promote group interaction.	"What are the perspectives of the other two students regarding Yang's sharing? Each of you is encouraged to engage in discussion and share your viewpoints."

Table 3
The coding framework of student's immediate uptake of teacher scaffolding.

Classification	Category	Description	Examples
low cognitive immediate uptake	Keeping silent to scaffolding (KPS)	The student remained silent, neither engaging in group discussions nor acting on the scaffolding provided.	
	Ignoring scaffolding (IGN)	The student did not mention or use the content of scaffolding, and continued to solve the problem through discussion.	
high cognitive immediate uptake	Responding to scaffolding (RES)	The student responded to the content of the scaffolding, such as answering the researcher's prompt with "okay".	• Teacher scaffolding: "Please take a moment to consider whether there is a more scientific approach." • Student's response: "OK."
	Repeating or copying scaffolding (REC)	The student repeat or directly use the content of scaffolding.	• Teacher scaffolding: "You can start with a simple linear regression using the existing data, where the year serves as the independent variable." • Student's response: "Exactly. Let's use this to predict the dependent variable and estimate the population size."
	Asking questions about scaffolding (ASQ)	The student did not understand the content of the scaffolding and asked questions related to the scaffolding.	• Teacher scaffolding: "VIF is a key coefficient for testing multicollinearity among independent variables. Ideally, this value should not exceed 10 to ensure model accuracy; values greater than 10 indicate reduced precision." • Student's response: "What does this accuracy refer to?"
	Understanding or applying scaffolding (UAS)	The student explained the content of the scaffolding in their own words, or applied the content of scaffolding to solve the problem.	• Teacher scaffolding: "Consider what data you need to obtain. The variables must be correct for prediction. So, what should the independent variable be?" • Student's response: "I'll calculate the data now. We need the birth rate, which I've just computed based on the guidelines. I also need to calculate data related to health institutions."

Note: There are a total of 6 immediate uptakes, arranged in ascending order of student's cognitive level.

Table 4
The coding framework of student's delayed use of teacher scaffolding.

Classification	Category	Description
No delayed use	Not used the scaffolding anymore (NUD)	The student exhibited no delayed use in interaction or utilization of scaffolding. For instance, once scaffolding was provided, group members did not retell or utilize it again.
delayed use	Repeating or copying scaffolding (REC)	The student repeated or directly used the content of scaffolding.
	Asking questions about scaffolding (ASQ)	The student did not understand the content of the scaffolding and asked questions related to the scaffolding.
	Understanding or applying scaffolding (UAS)	The student explained the content of the scaffolding in their own words, or applied the content of scaffolding to solve the problem.

Note: There are a total of 4 delayed uses, arranged in ascending order of students' cognitive level.

of the group members were discussing and seem to be stuck in a problem and the teacher provided scaffolding, the member didn't act on or discuss the content of the scaffolding at all, maintaining complete silence, then the member's response was coded as keeping silent to scaffolding.

After all data coding is completed, the two coders checked the coding results, discussed all of the inconsistencies, and ultimately reached a consensus. The Kappa coefficient of the two coders coding was 0.833, indicating a high consistency. After completing the coding verification, this study aggregated the responses from all team members to obtain the total count of immediate uptakes and delayed uses to teacher scaffolding for each group.

Phase4 data analysis

Based on the preliminary coding, a combination of qualitative and quantitative analysis was used to delve into the response characteristics of high and low-performing groups to teacher scaffolding. The main methods include Chi-square analysis, lag sequential analysis, and qualitative micro-level analysis. The specific data analysis procedures are outlined as follows.

Firstly, for RQ1, (1) Chi-square analysis of independence was used to examine whether there were significant differences in the overall frequency of immediate uptake to teacher scaffoldings between the groups; (2) Lag sequential analysis was used to explore the specific difference in immediate uptake between the groups after receiving different types of teacher scaffolding. The codes (immediate uptake and types of teacher scaffolding) of HP and LP groups were imported into GSEQ 5.1 to perform the sequential analysis. We analyzed the transition matrices for behavior frequencies, conditional probabilities, and expected values, and derived the adjusted residuals (Z-scores). If the Z-score for a particular sequence was greater than 1.96, it was considered statistically significant ($p < 0.05$) (Hou, 2015). Since this study aimed to reveal differences in immediate uptake sequences between high and low-performing groups following different types of teacher scaffolding, the focus was on sequences where teacher scaffolding preceded student's immediate uptake.

For RQ2, Chi-square analysis of independence was used to examine whether there were significant differences in the overall frequency of delayed use to teacher scaffoldings between the groups.

For RQ3, qualitative micro-level analysis was conducted to statistically analyze and summarize the overall response sequence to teacher scaffolding (from immediate uptake to delayed use) between the groups. In the qualitative micro-level analysis, all the scaffoldings that groups had delayed use were selected, and three members from the same group were considered collectively to calculate the frequency of both immediate uptake and delayed use of these scaffoldings. In cases where group members exhibited multiple immediate uptakes of a scaffolding, the one with the highest cognitive level was selected as the group's immediate uptake, and the determination of delayed use did the same. Additionally, qualitative fragments were selected to illustrate disparities in the overall response sequence to teacher scaffolding between the groups. These fragments adhered to the requirements of the Jefferson system of transcription notation (see Appendix B), encompassing both the group's speech content and accompanying nonverbal cues (such as gaze, nod, etc.) during CPS (Isohätälä et al., 2018).

4. Results

4.1. Differences in immediate uptake to teacher scaffolding between the HP and LP groups

4.1.1. The overall differences

The frequency and percentage of the HP and LP groups' immediate uptakes to teacher scaffolding was calculated and compared, as shown in Table 5. The results in Table 5 indicate that the HP groups demonstrated a greater proportion of high cognitive immediate uptakes overall (HP=51.2 %, LP=42.2 %). It is noteworthy that approximately half of the students in both the HP(45 %) and LP(50 %) groups kept silent after receiving teacher scaffolding. This finding underscores the tendency of students to engage in independent thinking and information integration, rather than immediately externalizing their reactions or perspectives with others, even in the presence of explicit learning support. And the further Chi-square analysis indicates a significant difference in the distribution of the high cognitive immediate uptakes between the HP and LP groups (χ^2=16.349, df=3, p=0.001). Specifically, the proportion of HP groups in repeating, asking questions, and understanding or applying scaffolding were relatively higher than LP groups. This indicates that, after receiving teacher scaffolding, the HP groups are more inclined to repeat, ask questions, and apply the scaffolding, whereas the LP groups tended to respond, ignored or kept silent to the scaffolding.

4.1.2. The sequential differences

To further explore the difference in immediate uptakes after receiving three types of teacher scaffolding between the HP and LP groups, lag sequential analysis was employed to examine the behavioral patterns across the groups, the adjusted residuals table can be found in Appendix B. The behavioral transition diagrams were drawn to facilitate visual observation of the significant behavioral sequences. All the sequences that reached statistical significance (Z-scores>1.96, p<0.05) were noted in Fig. 3, indicating distinctive differences in the behavior patterns of immediate uptakes after receiving different teacher scaffoldings between the HP and LP groups, with CS referring to cognitive scaffolding, MS to metacognitive scaffolding, and SS to social scaffolding.

Firstly, the HP groups showed a more significant behavior path on CS→UAS (z=5.06, p<0.05) than the LP groups (z=4.09, p<0.05), indicating that after receiving cognitive scaffolding, the HP groups were more capable of comprehending and processing the content of cognitive scaffoldings. Secondly, the HP groups exhibited a more significant behavioral path on MS→REC (z=5.44, p<0.05) compared to the LP groups (z=3.67, p<0.05), indicating that the HP groups were more inclined to repeat or directly use the content of metacognitive scaffoldings.

Thirdly, the LP groups showed a significant behavioral path on CS→REC (z=4.1, p<0.05), indicating that the LP groups primarily repeated or directly used the content of cognitive scaffoldings rather than engaging in processing and internalization. Fourthly, the LP groups showed significant behavioral paths on MS→IGN (z=3.98, p<0.05) and MS→RES (z=3.67, p<0.05), which were not observed in the high-performing group, indicating that the LP group was more inclined to ignore or respond superficially to the metacognitive scaffoldings, and had less attention to the issues that reminded by metacognitive scaffoldings, such as collaborative process regulation and time management. Additionally, the transition SS→RES in the LP groups(z=6.28, p<0.05) was far more significant than that of the HP groups(z=4.97, p<0.05), indicating that the LP groups were more inclined to respond superficially to social scaffoldings, and they

Table 5
Frequency and percentage of immediate uptakes to scaffolding from HP and LP groups.

Category of immediate uptake	HP groups(N=4)		LP groups(N=4)		χ2	*p*
	F	%	F	%		
Low cognitive immediate uptakes	**119**	**48.8 %**	**311**	**57.8 %**	**2.15**	**0.143**
Keeping silent to scaffolding	110	45.1 %	272	50.6 %		
Ignoring scaffolding	9	3.7 %	39	7.2 %		
High cognitive immediate uptakes	**125**	**51.2 %**	**227**	**42.2 %**	**16.349**	**0.001***
Responding to scaffolding	24	9.8 %	89	16.5 %		
Repeating or copying scaffolding	57	23.4 %	70	13.0 %		
Asking questions about scaffolding	25	10.2 %	44	8.2 %		
Understanding or applying scaffolding	19	7.8 %	24	4.5 %		

*p<0.05.

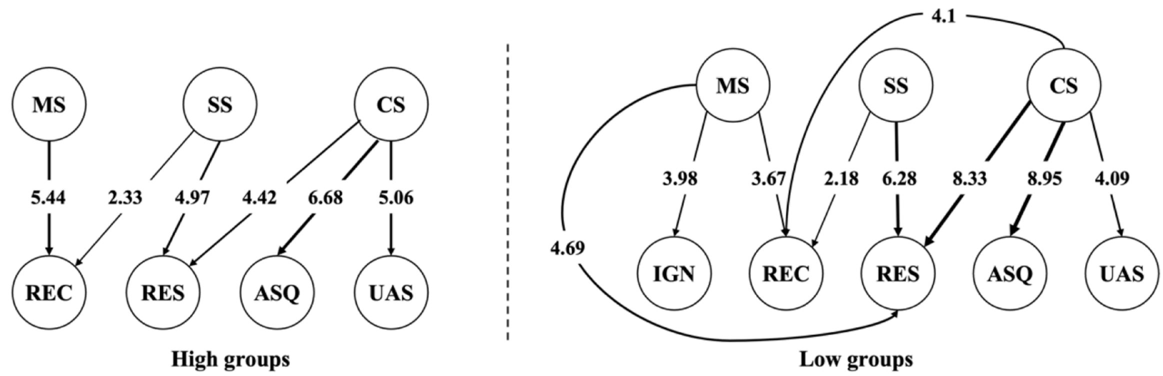

Fig. 3. Behavioral sequence of immediate uptake after receiving different scaffolding.

paid less attention to fostering a cooperative atmosphere within the group.

Note: CS=cognitive scaffolding, MS=metacognitive scaffolding, SS= social scaffolding

4.2. Differences in delayed use to teacher scaffolding between the HP and LP groups

The frequency and percentage of the HP and LP groups' delayed uses to teacher scaffolding was calculated and compared, the results are presented in Table 6. As most teacher scaffolding elicited no response from students, in cases where delayed use to teacher scaffolding occurred, the HP groups demonstrated relatively higher proportions in the dimensions of repeating or copying scaffolding (HP=7.3 %, LP=4.9 %) and understanding or applying scaffolding (HP=10.8 %, LP=3.8 %). Furthermore, results from the Chi-square analysis indicate a significant difference between HP and LP groups regarding the frequency of delayed use to teacher scaffolding (χ^2=8.86, df=3, P=0.031). This result suggested that after receiving teacher scaffolding, the HP groups were more inclined to repeat, question, or apply the content of scaffolding in subsequent collaborative process compared to the LP groups.

Additionally, the study also calculated the frequency and proportion of groups' delayed uses to different types of teacher scaffolding, as shown in Table 7. The results indicate that both the high-performing and low-performing groups primarily exhibited delayed uses to cognitive scaffolding (82.4 %, 81 %), while delayed uses to metacognitive scaffolding (17.6 %, 14.2 %) and social scaffolding (0 %, 4.8 %) were less frequent. This suggests that students in all groups tended to rely on cognitive scaffolding, which is directly related to the task, and over time, they showed almost no delayed uses to metacognitive and social scaffolding.

4.3. Differences in response sequence to teacher scaffolding between the HP and LP groups

The specific differences in the overall response sequence from immediate uptake to delayed use of teacher scaffolding between the HP and LP groups were also included to reveal response characteristics. Since delayed uses commonly involve features of application, the classification of overall response sequences is primarily determined by the types of immediate uptakes. Considering that both asking questions about scaffolding (ASQ) and responding to scaffolding (RES) exhibit characteristics of responding, this study merged segments of immediate uptakes from these two types into a single category, labeled "responding", and are presented in the first and second rows of Table 8. The final categorized overall response sequences were shown in Table 8.

As shown in Table 8, the overall response sequence of 8 groups can be categorized into three cognitive levels, ranging from low to high. These categories include: (1) use after simple responding, indicating that after receiving scaffolding, the group initially responded it with phrases like "okay,", and subsequently repeated or directly used the content of scaffolding in later collaboration; (2) use after repeating, indicating that after receiving the scaffolding, the group first repeated the content of scaffolding, and later retold or directly used it in subsequent collaboration; (3) keep using, indicating that after receiving the scaffolding, the group constantly used the content of the scaffolding to solve problems in both current and subsequent collaboration.

After summarizing these three response sequences mentioned above, this study further calculated the proportion of the HP and LP groups within each sequence. The result indicated that the HP groups had a higher proportion in keep using sequence (HP=54.55 %,

Table 6
Frequency and percentage of delayed uses to scaffolding from HP and LP groups.

Category of delayed use	HP groups(N=4) (F)	(%)	LP groups(N=4) (F)	(%)	χ2	*p*
Not used the scaffolding anymore (NUD)	66	79.5 %	163	88.6 %	8.860	0.031*
Repeating or copying scaffolding (REC)	6	7.3 %	9	4.9 %		
Asking questions about scaffolding (ASQ)	2	2.4 %	5	2.7 %		
Understanding or applying scaffolding (UAS)	9	10.8 %	7	3.8 %		

*$p<0.05$

Table 7
Frequency and percentage of delayed uses to different types of teacher scaffolding.

Category of teacher scaffolding	HP groups(N=4)		LP groups(N=4)	
	(F)	(%)	(F)	(%)
Cognitive scaffolding (CS)	15	82.4 %	17	81 %
Metacognitive scaffolding (MS)	3	17.6 %	3	14.2 %
Social scaffolding (SS)	0	0	1	4.8 %

Table 8
Sequences of immediate uptake and delayed use.

Category of sequence	immediate uptake	delayed use	cognitive engagement level
use after simple responding	ASQ, RES	REC	Low
	ASQ, RES	UAS	
use after repeating	REC	REC	Medium
	REC	UAS	
keep using	UAS	UAS	High

Note: ASQ= Asking questions about scaffolding, RES=Responding to scaffolding, REC=Repeating or copying scaffolding, UAS=Understanding or applying scaffolding.

LP=16.67 %), while the LP groups had a higher proportion in use after repeating (HP=25 %, LP=9.09 %) and use after simple responding sequences (HP=58.33 %, LP=36.36 %). This indicated that after receiving the scaffolding, the HP groups quickly understood and used it in their collaboration, whereas LP groups tended to initially respond or repeat the scaffolding. They gradually developed an understanding of how to apply it as collaboration progressed.

To provide a more explicit depiction of the overall response sequences to teacher scaffolding for HP and LP groups, this study selected three qualitative exemplified fragments for in-depth analysis. These fragments include the keep using sequence from the HP groups (Table 9), the use after simple responding sequence (Table 10) and the use after repeating (Table 11) sequence from the LP groups.

(1) The exemplified fragment of the HP group's keep using sequence

The exemplified fragment of Group 11 illustrated the HP group's keep using sequence. In this fragment, the teacher provided

Table 9
The exemplified fragment of the HP group's keep using sequence.

Line	Time	Participant	Content	Code
1	01:42:58	Teacher	You can think about how to attract young people from a broader perspective.	Teacher scaffolding-CS
2	01:43:03	S1 (Geography)	Well, okay ((places hand on lips and looks thoughtfully at the population data results displayed on the computer screen))	RES (immediate uptake)
3	01:43:11	S2 (Economics)	Oh, let's mo(h)ve on. ((laughs and looks at the group's online document)) Ah (.)from a broader perspective (0.8) and ⟨attract young people⟩ (1) first, we need to attract them, and then >we need to encourage them to have children. < ((smiles at S1 and S3)) (5) is:: that [right?]	UAS (immediate uptake)
4	01:43:20	S3 (Psychology)	[How] to attract young people? ((hand moves from forehead to chin, eyebrows slightly furrow))	ASQ(immediate uptake)
5	01:43:26	S2 (Economics)	Give them a house? ((looks at the group's online documents))	ASQ(immediate uptake)
The group members continued to search for information to complete the task...				
6	01:43:56	S1 (Geography)	Emm (.) in the previous question, we analyzed the ⟨advantages of large-population cities⟩ so, we can expand those advan(h)tages and °attract them to come° (smiles at S2, S3)	UAS (delayed use)
7	01:44:05	S3 (Psychology)	((holds face with hand)) Ye(h)s, we can.	NUD (delayed use)
8	01:44:12	S2 (Economics)	According to the third point, (.) We can know that young people are under a lot of pressure when they first come out of work, and their consumption level cannot keep up with housing prices, so we should concern about this ((holds glasses and looks up)) what are currently recruiting for "The introduction of talents" (.) or ((covers her mouth)) "labor force", there may also be considerations for providing (0.5) certain incentives in terms of [consumption and housing prices].	UAS (delayed use)
9	01:44:33	S1 (Geography)	[Yeah]((nods)).	NUD (delayed use)
10	01:44:35	S2 (Economics)	Well... (0.8) That's all for this. If they (0.5) don't come to this place, it means they can't afford to eat or live. (1) [Consumption] (unclear) Well, what do you say? (gazes at S3)	NUD (delayed use)
11	01:44:43	S3 (Psychology)	[Another point] is that the medical infrastructure is outdated, as mentioned in the material.	UAS (delayed use)
12	01:44:51	S2 (Economics)	Oh, young people may consider this ((looks at the text in the material)), yeah ((nods)).	NUD (delayed use)

Note: S1=Student1, S2=Student2, S3=Student3, and the field of study indicated in parentheses represents the student's major.

Table 10
The exemplified fragment of the LP group's use after simple responding sequence.

Line	Time	Participant	Content	Code
1	01:33:45	Teacher	You can put the model problem aside and do a linear regression first. It's not difficult, just use the existing data and establish the regression equations.	Teacher scaffolding-CS
2	01:33:56	S4(Computer Science)	Well (.) let me take a look at the data analysis results first ((swipes the mouse to view data analysis results)).	RES (immediate uptake)
3	01:34:02	S5(Geography), S6 (Linguistics)	((Without expression, swipes the mouse and looks the results)).	KPS (immediate uptake)
The group members employed SPSS for data analysis...				
4	01:34:58	S4(Computer Science)	Emm (.) Is this the value? (0.8) Can you see my shared screen? I have come up with some results, which should be [the values].	UAS (delayed use)
5	01:35:22	S5(Geography)	[We can see that].	NUD (delayed use)
6	01:35:25	S6(Linguistics)	[It looks] quite (.) reliable.	NUD (delayed use)
7	01:35:30	S5(Geography)	Yes, then we can directly use this (0.5) to calculate the (0.8) population size.	UAS (delayed use)
8	01:35:34	S4(Computer Science)	Well >then it should be possible< to calculate directly (2) this should be the population from 2022 to 2028 ((holds glasses)).	UAS (delayed use)

Note: S4=Student4, S5=Student5, S6=Student6, and the field of study indicated in parentheses represents the student's major.

Table 11
The exemplified fragment of the LP group's use after repeating sequence.

Line	Time	Participant	Content	Code
1	01:42:54	Teacher	It is not scientific to predict the population by year. I suggest that you can ignore the issue of year, and focus on developing the population prediction formula first.	Teacher scaffolding-CS
2	01:43:03	S7 (Education)	Well, okay, thanks. So, let's (.) first create a formula (0.8) create a population prediction formula and then use it to make [predictions] ((gazes at data analysis software))	REC (immediate uptake)
3	01:43:10	S8(Law)	[For formula] (0.8) we can just look at the table of coefficient ((places hand around neck and slides the mouse to analyze the data))	REC (immediate uptake)
4	01:43:20	S9 (Geography)	((Keeps silent, furrows brows))	KPS(immediate uptake)
The group members independently conducted research to gather relevant materials…				
5	01:48:30	S7 (Education)	That's it ((nods))	NUD (delayed use)
6	01:48:43	S8(Law)	I think (.) we should use all of these data, as they all seem to (.) fit well. ((places hand around neck and points the mouse to the key data))	NUD (delayed use)
7	01:49:03	S7 (Education)	Let's (.) work out this formula and then see if we can predict the population based on the formula ((holds her face with hand)) what is the (.)coefficient? ((looks at the data analysis results))	NUD (delayed use)
8	01:49:08	S8(Law)	Emm (.) the birth rate is 6.245	NUD (delayed use)
9	01:49:10	S7 (Education)	That's (0.8) 6.245, then (0.5) 0.001, then (0.5) 0.046 ((pushes glasses upwards)) ah (.)How about S8 writing down this formula? ((gazes at Ming)) Then (.) take a screenshot of this and post it in the chat group for S9 to organize.	NUD (delayed use)
10	01:49:38	S9 (Geography)	I (.) have another question, did you exclude (0.5) year ⟨as the independent variable⟩ just now ((looks at the results))?	NUD (delayed use)
11	01:45:38	S7 (Education)	Yes (0.5) this is an unscie(h)ntific idea, which is that it is not possible to predict the annual population only using years ((gazes at S9))	REC (delayed use)
12	01:45:50	S9 (Geography)	Okay, got it.	NUD (delayed use)

Note: S7=Student7, S8=Student8, S9=Student9, and the field of study indicated in parentheses represents the student's major.

cognitive scaffolding, prompting them to consider strategies from a broader perspective. After receiving the prompt, group members swiftly generated fresh ideas, effectively stimulating in-depth discussions within the group.

(2) The exemplified fragment of the LP group's use after simple responding sequence

The exemplified fragment of Group 9 illustrated the LP group's use after simple responding sequence. In this fragment, the teacher provided cognitive scaffolding by advising the utilization of linear regression analysis. After receiving this scaffolding, one member of Group 9 quickly responded to the prompt, while the other two members chose to keep silent. Initially, there was minimal interaction within the group. However, as one member derived specific results based on the scaffolding and actively sought input and feedback from others, discussions within the group gradually became vigorously.

(3) The exemplified fragment of the LP group's use after repeating sequence

The exemplified fragments of Group 7 illustrated the LP group's use after repeating sequence. In this fragment, the teacher provided cognitive scaffolding to the LP group by suggesting they exclude the consideration of years when formulating equations. Faced with this scaffolding, two members of the group promptly responded, not only repeating the content of scaffolding but also engaging in-depth discussion and negotiation based on it, jointly advancing the collaboration. However, one member remained consistently confused and silent throughout the discussion. When the group reached a definitive conclusion, this previously silent member expressed her doubts and sought clarification from other group members.

5. Discussion

The purpose of the present study was to investigate the differences between the high-performing and low-performing groups in terms of the immediate uptake and the delayed use of different teacher scaffolding in CPS. From that, the study aimed to reveal the response characteristics to teacher scaffolding between the groups and offer insights to inform the design and provision of scaffolding in CPS. To accomplish this, the study constructed four phases of data analysis, attempting to provide specific evidence of the different response characteristics exhibiting in CPS.

Firstly, for the overall differences in immediate uptake of teacher scaffolding, this study found the high-performing groups had a relatively higher proportion of high cognitive level immediate uptake, such as repeating, questioning, and applying. Consistent with Barron (2003), the more successful groups understood and applied the scaffolding prompts more often after its provision, and they ignored and kept silent about the scaffolding prompts less. This response characteristic of the high-performing groups enables them to strengthen communication during interacting, negotiating and establishing and maintaining a shared understanding (Graesser et al., 2018; Webb & Gibson, 2015), and thus make progress on the CPS process. On the contrary, the ignorance or silence characteristics exhibited by the low-performing groups towards scaffolding may cause the omission of correct information, resulting in the incorrect attention to low-quality information (Zheng et al., 2023).

Secondly, the sequential differences between groups in immediate uptake after receiving three types of scaffolding were also compared. Specifically, the high-performing groups were more able to understand and process the content of cognitive scaffolding, while the low-performing groups were more inclined to repeat or directly use cognitive scaffolding. This result was in accordance with previous findings, sometimes the teacher's explanation can only play a minor role (Webb, 2009; Wittwer & Renkl, 2008). If students only receive surface explanations of the problems, they may not be able to deeply understand the concepts (Wittwer & Renkl, 2008). The high-performing groups performs better because they are able to form high-level thinking and complex learning processes based on teacher scaffolding (Gillies, 2011), which helps them integrate new skills with existing diagrams to internalize knowledge. Once internalization has occurred, these skills can be used in future learning (Jadallah et al., 2011). Besides, the result also indicated that the high-performing groups were more receptive to the regulative strategies or time manage cues given by metacognitive scaffolding compared with the low-performing groups, which was beneficial for the collaboration of CPS (J. J. Zheng et al., 2019). In CPS, it is crucial to make timely adjustments according to the collaborative process. If there is a lack of timely attention and appropriate adjustments to the group process, collaborative strategy, time management, etc., the collaborative performance of the group will be constrained (Lin et al., 2015; Zhu & Lin, 2023). Additionally, compared with the high-performing groups, the low-performing groups paid less attention to the collaboration atmosphere and the feelings of group members. As previous studies have revealed, collaboration atmosphere and team members' feelings were important factors affecting group processes (Ouyang & Xu, 2022). If the collaboration atmosphere of the group was not good, or some members in the group were obviously ignored, it would be difficult for the group to maintain an efficient collaboration process.

Thirdly, in terms of the differences in delayed use of teacher scaffolding, same with immediate uptake, the HP groups demonstrated relatively higher proportions in repeating and applying scaffolding, and the Chi-square analysis confirms the statistical significance of this difference. It is worth noting that despite the delayed use of cognitive scaffolding occurred in low-performing groups, their performances remained low. One possible explanation for this is that when students encounter difficulties understanding the teacher's scaffolding, they may still respond to the scaffolding due to the social pressure to avoid appearing impolite (van de Pol et al., 2010, 2012). Another possibility is that students struggle to adapt their explanations to meet the needs of their peers, resulting in one student understanding the scaffolding while the rest remain confused, this also limits the effectiveness of the scaffolding (Wittwer & Renkl, 2008).

Fourthly, by summarizing the sequences of immediate uptake and delayed use of the 8 groups, this study found that, after receiving teacher scaffolding, the high-performing groups were able to produce an immediate uptake to the scaffolding with a high level of cognitive engagement and sustained high-quality use of the scaffolding, while the low-performing groups initially simply responded or repeated the content of the scaffolding, and it was only during the subsequent collaborative processes that they began to comprehend and utilize the scaffolding. These characteristics exhibited by the high- and low-performing groups on the three response sequences echo previous findings that students responding to scaffolding does not guarantee ideal performance (Ouyang, Dai, & Chen, 2022; van de Pol et al., 2019). In order to achieve higher performance, students' active engagement alone is not enough to expand the understanding of specific concepts, and the combination of students' self-explanation and teaching prompts can contribute to knowledge understanding and transfer.

6. Pedagogical implications

Based on the aforementioned research findings and discussions, the present study offers the following suggestions for educators to employ teacher scaffolding more effectively in collaborative problem solving activities, serving as a practical reference for educational instruction.

6.1. Providing concrete examples to help students understand cognitive scaffolding

Research suggests that the cognitive scaffolding provided by teachers may lead to cognitive overload, causing students to remain silent rather than respond actively (Ouyang, Dai, & Chen, 2022). To address this issue, it is recommended that educators use concrete examples to explain the scaffolding content, helping students gain a deeper understanding of the knowledge and encouraging them to apply the scaffolding more effectively to solve problems.

6.2. Ensuring students' accurate understanding of cognitive scaffolding

In cases where students remain silent or provide only minimal responses due to confusion or social etiquette, educators should ensure that students fully grasp the cognitive scaffolding in the early stages of its introduction. Educators should also guide students in applying the scaffolding to similar problems and support the internalization of knowledge through continued practice, enabling students to independently apply these scaffolding in future learning.

6.3. Flexibly adjusting the level of cognitive scaffolding interventions

When groups show silence or neglect toward cognitive scaffolding, educators should intervene to assess their understanding of the scaffolding content. If the group has understood the content, educators can reduce subsequent interventions. If not, further explanation is needed to assist their understanding (van de Pol et al., 2019).

When groups demonstrate understanding or application of cognitive scaffolding, educators should scale back further scaffolding and encourage students to deepen their knowledge through group discussion and negotiation. If there is a lack of in-depth discussion, educators may introduce new cognitive scaffolding to stimulate exchange and collaboration among group members.

6.4. Emphasizing key Task- or Process-Related elements in metacognitive scaffolding

The findings indicate that students rarely exhibit delayed uses to metacognitive or social scaffolding. Therefore, educators should emphasize key elements in the metacognitive scaffolding that are closely tied to the collaborative tasks and processes, and encourage students to continuously apply these elements during collaboration. This helps prevent negative impacts on the collaboration process due to the omission of critical information.

6.5. Introducing role scripts in social scaffolding to facilitate collaboration

This study found that peer attitudes and behaviors within collaborative teams significantly influence students' responses to teacher scaffolding, with students often mimicking the behaviors of their peers (Jadallah et al., 2011). As such, when group members remain silent, this silence is likely to spread within the group. To address this, educators can introduce role scripts within social scaffolding, assigning specific responsibilities to group members to ensure that each member is aware of their tasks. Particularly when silence persists, designating a speaker role can encourage certain students to take the initiative in guiding group discussions. This role assignment helps break the silence, promoting deeper collaboration and problem solving.

7. Conclusion

By comparing the high- and low- performing groups, the present study revealed differences in response characteristics to three types of teacher scaffolding across groups and unpacked the reasons that may affect the performance of the groups in CPS. The results indicate that in terms of immediate uptake to teacher scaffolding, after receiving cognitive scaffolding, high-performing groups quickly understood and internalized the scaffolding content, applying it effectively throughout the collaboration process. In contrast, low-performing groups tended to restate or directly use the cognitive scaffolding. After receiving metacognitive scaffolding, high-performing groups were more inclined to restate or directly use the scaffolding, while low-performing groups were more likely to ignore or provide brief responses. After receiving social scaffolding, high-performing groups tended to restate or directly use it, while low-performing groups gave simpler responses. Compared to high-performing groups, low-performing groups showed less concern for group dynamics and members' feelings. Regarding delayed use to teacher scaffolding, after receiving scaffolding, high-performing groups were more likely than low-performing groups to repeat, question, or apply the scaffolding again during subsequent collaboration, repeatedly testing the process-related data and results obtained through collaboration. Both high-performing and low-performing students tended to delay using cognitive scaffolding that was directly related to the task, and over time, they responded less to metacognitive and social scaffolding. Additionally, the study identified three overall response sequences to teacher scaffolding: *keep using, use after repeating*, and *use after* simple *responding*. Statistical results showed that high-performing groups had a higher proportion in *keep using* sequence, while low-performing groups were more prevalent in *use after repeating* and *use after* simple *responding* sequences. This suggested that high-performing groups quickly understood and utilized teacher scaffolding after receiving it, consistently applying it throughout the collaborative process to solve problems. In contrast, low-performing groups were more likely to initially respond or repeat the scaffolding and gradually understand and apply it as the problem-solving process progressed. The analysis of response characteristics helps educators to better understand why different responses from students to teacher scaffolding can lead to vastly performance. Therefore, educators can strategically orchestrate the usage of scaffolding based on the response characteristics of students (Maksić & Jošić, 2021).

This study still has some limitations. First, the research data were originated through recruiting participants to conduct quasi experiments, lacking the understanding of response characteristics in natural classroom environment. Future research should consider a natural classroom context to examine and verify the student response characteristics of different scaffolding. Secondly, the sample size involved in this research was small, future research could expand the sample size to further confirm the results and implications.

Thirdly, this study mainly analyzed the explicit behavioral data of the groups, and the psychological activities that students did not exhibit are worth considering in future work to supplement the behavioral data and better reveal the group's CPS process.

CRediT authorship contribution statement

Rui Wang: Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Xiaoran Li:** Writing – review & editing. **Wanqing Hu:** Writing – review & editing. **Yanyan Li:** Funding acquisition. **Jirong Tian:** Formal analysis.

Declaration of competing interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Statements on open data, ethics and conflict of interest

No conflict of interest exists in the submission of this manuscript, and the manuscript is approved by all authors for publication. I would like to declare on behalf of my co-authors that the work described was original research that has not been published previously, and is not under consideration for publication elsewhere, in whole or in part. All the authors listed have approved the manuscript that is enclosed.

Appendix A. The assessment criteria for the problem solution

Dimension/ Score	5	4	3	2	1
Description accuracy	The descriptions of this solution are useful, appropriate, and complete.	The descriptions of this solution are useful, but contain a small amount of errors or omissions.	Parts of the descriptions of this solution are useless, missing, or incorrect.	Most of the descriptions of this solution are useless, missing, or incorrect.	Almost all the descriptions of this solution are useless, missing, or incorrect.
Method appropriateness	The data analysis method used in this solution is appropriate and complete.	The data analysis method used in this solution contains minor omissions or errors.	Some concepts and principles of the data analysis method used in this solution are missing or inappropriate.	Most of the concepts and principles of the data analysis methods used in this solution are missing or inappropriate.	Almost all of the concepts and principles of the data analysis methods used in this solution are missing or inappropriate.
Result correctness	The data results obtained by this solution are appropriate and complete.	The data results obtained by this solution contain minor omissions or errors.	The data results obtained by this solution are partly missing or incorrect.	The data results obtained by this solution are mostly missing or incorrect.	The data results obtained by this solution are almost all missing or incorrect.
Application rationality	The resulting applications of this solution are reasonable and complete.	The resulting applications of this solution contain minor omissions or errors.	The resulting applications of this solution are partly unsuitable.	The resulting applications of this solution are mostly unsuitable.	The resulting applications of this solution are almost unsuitable.
Logical coherence	The solution to the entire problem is clear, focused, and logically consistent.	The solution to the entire problem is relatively clear and focused, with slight inconsistencies.	The solution to the entire problem is partly unclear, lacks focus, or inconsistent.	The solution to the entire problem is mostly unclear, lacks focus, or inconsistent.	The solution to the entire problem is almost all unclear, lacks focus, or inconsistent.

Appendix B. The adjusted residuals table (Z-scores) of the HP and LP groups

	HP groups									LP groups								
	CS	MS	SS	KPS	IGN	RES	REC	ASQ	UAS	CS	MS	SS	KPS	IGN	RES	REC	ASQ	UAS
CS	-3.04	-1.86	-1.19	-5.39	-0.3	**4.42***	0.62	**6.68***	**5.06***	-5.03	-2.83	-1.92	-8.32	-0.09	**8.33***	**4.1***	**8.95***	**4.09***
MS	-2.06	-1.26	-0.81	-3.2	0.44	1.27	**5.44***	1.74	-1.23	-2.9	-1.63	-1.11	-4.3	**3.98***	**4.69***	**3.67***	1.59	-1.25
SS	-1.19	-0.73	-0.46	-2.1	-0.49	**4.97***	**2.33***	-0.84	-0.71	-2.02	-1.13	-0.77	-2.77	0.83	**6.28***	**2.18***	-1.19	-0.87
KPS	7.52	4.26	3.99	1.38	-0.76	-3.41	-6.06	-3.31	-3.14	13.56	6.32	4.22	1.29	-5.02	-7.88	-6.63	-5.35	-3.9
IGN	1.61	-0.77	-0.49	2.02	-0.52	-0.81	-1.45	-0.9	-0.75	-2.34	-0.14	-0.04	1.35	9.31	-2.43	-1.57	-1.65	-1.2
RES	-1.97	-1.2	-0.77	2.67	0.54	1.44	-1.68	0.27	-0.2	-3.45	-2.46	-1.67	5.53	-1.43	1.67	-1.43	-1.65	0

(*continued on next page*)

(*continued*)

	HP groups									LP groups								
	CS	MS	SS	KPS	IGN	RES	REC	ASQ	UAS	CS	MS	SS	KPS	IGN	RES	REC	ASQ	UAS
REC	-2.67	0.3	-1.36	-0.1	2.04	-2.26	5.73	-1.94	-1.45	-3.14	0.04	-0.68	2.34	0.09	-2.57	4.28	-1.22	-0.25
ASQ	-0.91	-1.29	-0.82	3.83	-0.88	-1.36	-2.43	-0.71	2.4	-2.97	-1.67	-1.13	3.22	-0.96	-1.18	0.35	1.47	1.31
UAS	-1.12	-1.11	-0.71	1.88	-0.75	-0.2	-0.2	-0.39	1.01	-2.16	-1.22	0.46	1.61	-0.29	-1.88	-0.25	0.45	4.82

CS cognitive scaffolding, MS metacognitive scaffolding, SS social scaffolding, KPS keeping silent to scaffoldings, IGN ignoring scaffoldings, RES responding to scaffoldings, REC repeating or copying scaffoldings, ASQ asking questions about scaffoldings, UAS understanding or applying scaffoldings, $*p<0.05$.

Appendix C. Used transcription notations based on Jefferson system of transcription

Symbol	Meaning
(.)	a short but noticeable pause
(time)	a timed pause (≥0.5 s)
[…]	overlapping speech
> <	the pace of the speech has quickened
< >	the pace of the speech has slowed down
()	unclear speech
(())	contextual information, e.g. gazes and gestures.
word	a raise in volume or emphasis
°word°	quiet voice
wo(h)rd	laughter within the talk
::	elongated speech, a stretched sound

Data availability

The authors do not have permission to share data.

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