

# Examining Coordinated Computer-Based Fixed and Adaptive Scaffolds in Collaborative Problem-Solving Game Environments

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**Abstract:** The study aims to examine the effectiveness of the coordinated computer-based scaffolds mediating students' collaborative problem-solving (CPS) practices and science learning. 24 students in six groups participated in CPS activities related to middle school life science, conducted in a scaffolded collaborative game. We analyzed their CPS practices during 31 collaborative periods across three quests using latent profile analysis, chi-square tests, and interaction analysis. We found certain clusters associated with higher-performing groups and patterns of their CPS engagement. Furthermore, we found that these CPS engagement patterns linked to higher performance were synergistically mediated by the coordination of fixed and adaptive scaffolds. The study also discusses implications and outlines future research directions.

## Introduction

Collaborative game-based inquiry environments are contexts for Computer-Supported Collaborative Learning (CSCL) and enable students to learn as they collaboratively engage with complex problems (Jeong et al., 2019). However, in such environments, students can face multiple challenges such as navigating a complicated problem-solving process (Savery, 2015). Successful learning in such circumstances largely hinges on skills in collaborative problem solving (CPS). Individuals with well-developed CPS are able to solve a shared problem by effectively sharing and negotiating ideas and experiences, jointly coordinating behaviors, and learning activities, and applying social strategies to sustain positive communication (Liu et al., 2016). As such, success at addressing authentic ill-structured problems in CSCL settings could be achieved if the students are provided with appropriate scaffolding to extend and enhance such capabilities as they engage with the target problems (Belland, 2017).

In CSCL environments, beyond support from teachers and peers, diverse forms and types of computer-based scaffolds have been embedded (Puntambekar, 2022). Two forms of computer-based scaffolds, fixed and adaptive scaffolds, have varying functions and play different roles in the learning process (Puntambekar, 2022). Computer-based adaptive scaffolds are supports that are offered contingent on students' previous learning performance or actions. In contrast, fixed scaffolds provide support that helps learners deal with problem complexity regardless of learner actions (Reiser, 2004). Previous studies suggest that it is necessary to seamlessly integrate the two different scaffolds in a scaffolding system to successfully design CSCL environments (Puntambekar, 2022). Such well-coordinated scaffolding is effective in synergistically addressing student's learning needs (Tabak, 2004). Despite some research studies examining coordinated scaffolds (e.g., Martin et al., 2019; Saleh et al., 2020), there is limited research that addresses how to coordinate fixed scaffolds with adaptive scaffolds in CSCL. Furthermore, little is known about how effectively coordinated computer-based scaffolds may or may not be taken up by students, thereby contributing to students' practices in CPS and disciplinary learning in science. As such, this study aims to understand how computer-based fixed and adaptive scaffolding may or may not effectively mediate student disciplinary learning in life science and CPS within a scaffolded game-based science learning environment. Specifically, the current study seeks to answer the following research questions within the context of collaborative problem-solving activities:

- RQ1: What CPS patterns do students who received both computer-based fixed and adaptive scaffolds show, compared to those who received fixed-only scaffolds?
- RQ2: What CPS patterns are related to higher and lower performance in science inquiry?
- RQ3: How do the coordinated scaffolds mediate learners' CPS practices in ways that may be associated with learning performance, if at all?

Throughout the paper, scaffolding is defined as the process of providing support, whereas scaffolds are the tools and artifacts that actually provide the support (Puntambekar, 2022). Adaptive scaffolds refer to a form of support that is only delivered to certain groups or students based on their prior gameplay actions or responses

to student actions. Fixed scaffolds refer to a form of support that is provided to all students regardless of their previous performances once they complete an activity or reach a certain point.

## Literature review: Scaffolding collaborative problem solving (CPS)

Collaborative problem solving (CPS) is described as a complex process in which two or more individuals attempt to solve a problem by sharing and jointly consolidating their knowledge, skills, and endeavors to reach a desired solution (Grasser et al., 2018; OECD, 2017). CPS encompasses both cognitive and social dimensions, which are closely intertwined with each other (Sun et al., 2022). Practices in CPS can be observed in discursive settings such as face-to-face conversation and text-mediated communications. Specifically, Liu et al. (2015) proposed a CPS framework focusing on the practices from a discursive perspective that consists of four major categories: (a) sharing ideas, (b) negotiating ideas, (c) regulating problem solving, and (d) maintaining communication. Under each category, they specified observable discursive practices. However, in problem-based learning (PBL) settings, CPS demands students engage in these discursive practices to understand a problem but also regulate their actions to solve it. Therefore, scaffolding is necessary to support students to overcome the challenges, productively engage in CPS and disciplinary learning, and ultimately, to be successful in PBL.

Computer-based scaffolding refers to support by a computer system that promotes student engagement with content and performance that are beyond their independent capacities (Belland et al., 2017). In CSCL classrooms, two types of computer-based scaffolds, fixed and adaptive scaffolds, can be offered to support students' CPS and content learning. The pedagogical framework itself (e.g., PBL cycle and inquiry process) also can be embedded as a fixed scaffold in CSCL environments (Martin et al., 2019). Both types of scaffolds benefit students by posing challenges to engage students with problems, decomposing a complex task to make it more manageable, and maintaining a forward direction (Reiser & Tabak, 2014). Indeed, computer-based scaffolding demonstrates substantial positive effects, as compared to comparison conditions (Belland et al., 2017).

Multiple forms of support are necessary to afford opportunities to engage students in learning activities and perform successfully (Reiser & Tabak, 2014). Tabak (2004) proposed the notion of *Synergistic scaffolds* as one of the patterns of how different types of scaffolds can support learners. The pattern involves multiple supports targeting the same needs such that the various supports complement the effects of other scaffolds that might not be sufficient alone. However, previous studies raised questions concerning the effectiveness of combining multiple forms of scaffolds, as varying features, functions, and goals of scaffolds can be dissonant and even conflicting in supporting students' learning (Zydney, 2010). Furthermore, one of the forms of scaffolds can be ignored, and their effects become diminished (Tchounikine, 2017). Although some previous studies examined how to distribute scaffolds across people and computer systems (Martin et al., 2019; Puntambekar, 2022), how (or if) students take up and use computer-based adaptive and fixed scaffolds as intended in CSCL settings remains unclear. Furthermore, if the coordinated scaffolds have been taken up, few have examined the synergistic effects of the coordinated scaffolding on students' CPS and how it contributes to disciplinary learning in science. As such, this study aims to examine how coordinated computer-based scaffolds mediate students' practices in CPS and science learning in collaborative game-based science learning environments compared to fixed-only scaffolding.

## Methods and analysis

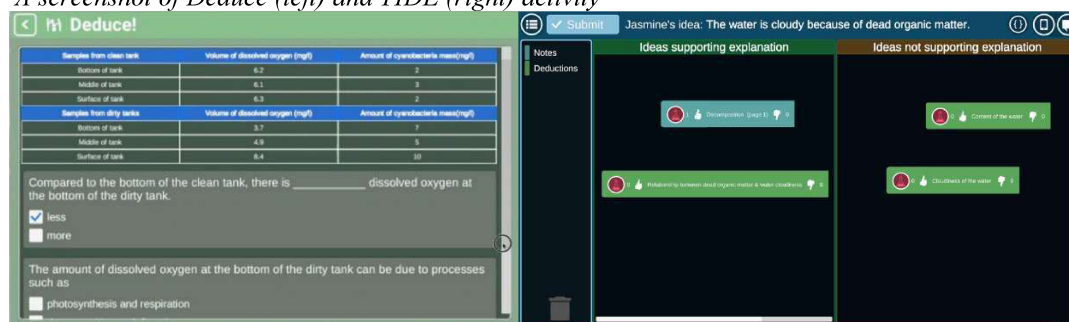
### Scaffolded game environment

CRYSTAL ISLAND: ECOJOURNEYS is a scaffolded collaborative game-based learning environment designed to support disciplinary learning in middle school life science concepts and CPS practices. Three to four students within a group collaboratively investigate why the tilapia fish at a farm are sick. The game contains a tutorial followed by three quests. In each quest, students individually collect data related to the fish ecosystems by collecting notes, talking to non-player characters (NPCs), and measuring water quality. Subsequently, students engage in CPS activities called Deduce and TIDE (*Talk, Investigate, Deduce, and Explain*), using what they have learned previously. In Deduce activities (see Figure 1 left), students as a group are required to answer aquatic ecosystem multiple-choice questions. In TIDE activities, they need to determine if the information collected (i.e., a note) supports a given claim or not, using the "TIDE board" (see Figure 1 right), which is a real-time collaborative whiteboard. They share their arguments on the claim by placing relevant notes as evidence into one of the columns on the board. During the activities, they discuss through in-game chat and in-person conversation. In this study, we only focus on the Deduce and TIDE activities, where students have to engage in CPS practices.

Fixed and adaptive scaffolds are embedded to support students' disciplinary learning in life science and CPS. Fixed scaffolds take the form of the Deduce App and the TIDE board. After entering answers for each question in Deduce, students in a group receive an update on their agreement status as a group for the answer choice. The TIDE board represents a fixed scaffold that models the collaborative inquiry processes by making

students' thinking visible and structuring their inquiry activity (Reiser & Tabak, 2014). They can justify their ideas with evidence by placing relevant data (i.e., a note) they have collected on one of the columns on the board. Students then read each note and express their opinions on its placement through voting, which facilitates them in negotiating ideas and reaching an agreement. During the discussion, they can use sentence starters based on the *Accountable Talk* framework, modeling quality collaborative discourse that helps students stay accountable for knowledge (e.g., "As I was playing, I learned that ..."), to reasoning (e.g., "My reason is ..."), and community (e.g., "Does anyone agree with my idea that ...") (Resnick et al., 2018). Following each group's submission in Deduce and TIDE activities, the game system also provides feedback on the accuracy of the answer to the group.

**Figure 1**  
*A screenshot of Deduce (left) and TIDE (right) activity*



Adaptive scaffolds are also included during the Deduce and TIDE activities. For example, in response to a group's prior chat contribution, an NPC delivers a message to the group at the start of either Deduce or TIDE (e.g., "Don't forget to use the group chat to talk out ideas together! Consider using sentence starters if you are stuck."). The group also receives a scaffold contingent on their level of satisfaction with prior collaboration and their identified CPS aspect that needs improvement, determined through a survey at the end of each quest. During the activity, the system also displays a prompt in the group chat that is adaptive to the group's condition (e.g., "[Player], can you share your thoughts about this question?" and "Have we heard from during Deduce? If not, let's make sure we hear from them.").

## Participants

Participants were 24 middle school students in six groups across three science classes. Before the gameplay, groups were randomly assigned to one of the two groups: fixed-only ( $n = 3$ , Fixed 1, 2, and 3) or fixed and adaptive ( $n = 3$ , Adaptive 1, 2, and 3). Each focal group consisted of four students, all of whom used individual laptops but played the game together. The unit of analysis is a collaborative activity period across three quests per group except for the tutorial. Excluding missing data, we used the 31 periods of Deduce and TIDE activities across the six focal groups.

## Data sources and analysis

For RQ1, we analyzed each group's in-game chat data and video data of in-person conversations to examine how the groups engaged in the collaborative activities (i.e., Deduce and TIDE) in each quest. After transcribing the in-person discussions, we collected a total of 3,455 utterances including the data from both videos (58%) and in-game chat (42% including 8% of spamming) across the 31 periods of the collaborative activities. In this analysis, each sentence is considered as one utterance. To classify higher and lower performing groups related to RQ2, we used individuals' final solutions, regarding the issues in the local aquatic ecosystem and the reasons for the tilapia fish becoming sick. For RQ3, we utilized the video data capturing focal group interactions during the 31 periods of the collaborative inquiry activities across the three quests. The length of the entire video corpus is approximately 372 minutes.

To analyze RQ1, two coders adapted the coding scheme by Liu et al. (2016) for our learning environments. Using the adjusted CPS coding scheme (see Table 1), they independently coded 691 utterances (about 20% of all utterances). This process yielded an inter-rater reliability of Cohen's  $\kappa = 0.81$ . Subsequently, one coder coded the remaining utterances. Following that, we summed the number of each code for each activity per group (i.e., the unit of analysis). As a result, excluding utterances coded as 'other', which were unrelated to CPS performance, we obtained the aggregate number of each CPS code for each activity per group (e.g., Group 3 in Quest 1 TIDE). We then converted the values of each CPS code to the z-standardized mean scale values for comparison and interpretation of indicator values and performed latent profile analysis (Spurk et al., 2020) to

cluster patterns of CPS. The number of profiles (i.e., clusters) was determined based on values of the Bayesian information criterion (BIC, Spurk et al., 2020), and the CPS clusters were extracted. Despite being aware of the small sample size, we performed a chi-square to determine if there was a significant difference in CPS patterns between the conditions.

**Table 1**  
*The Adjusted CPS Coding Scheme*

| Code          | CPS category                       | Description                                                                                                                                                            |
|---------------|------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sharing       | Sharing information and ideas      | Share or ask to share ideas, knowledge, resources, and information regarding ongoing tasks or game-related functions                                                   |
| Negotiating   | Negotiating ideas                  | (Asks to) Express one's opinion on ideas suggested by others or provide additional information or details to clarify, correct, or elaborate one's or teammate's ideas. |
| Regulating    | Regulating problem solving         | Identify goals and problems to work on, monitor and evaluate team's performance, and manage frustration and challenges during the activity                             |
| Maintaining   | Maintaining positive communication | Respectfully communicate with others, maintain lively conversations, or encourage and support each other during the activity                                           |
| Out of domain | Out of domain                      | Talk or work on something unrelated to the task                                                                                                                        |
| Other         | Other                              | (Fixing) Typos, inaudible and incomprehensible utterances, self-talk, mumbling, words including gibberish words such as ah, uh, bdse, etc.                             |

To identify CPS patterns associated with higher performance for RQ2, we classified the focal groups as either higher or lower performing based on their final solutions. Groups that explicitly connected the fish kill to aquatic ecosystem components and their relationships (e.g., “High levels of dead organic matter, which provides nutrients to cyanobacteria, and cyanobacteria reduces the availability of dissolved oxygen for fish, causing the fish to become sick.”) was assigned to higher-performing groups. Groups that provided a superficial description (e.g., “I think the cyanobacteria are impacting the tilapia”) or explanation that was not covered in the game (e.g., “cyanobacteria enter the fish gills and triggers an immune response making them sick”, etc.) were identified as lower-performing groups. The two coders reached a 100 percent agreement. Moreover, we probed the extent of each cluster's contribution to either higher or lower performance, computing Pearson residuals. Based on the results, we qualitatively examined student CPS practices in each category associated with either higher or lower performance. For RQ3, through interaction analysis (Hall & Stevens, 2015), we investigated how or if the coordinated scaffolds contributed to CPS practices associated with higher performance by comparing CPS practices of higher- and lower-performing groups in the adaptive condition. We selected and analyzed video segments that showed the contrasting patterns relevant to the scaffolds to identify possible scenarios of students taking up the scaffolds and engaging in productive CPS practices.

## Results

### RQ1: Collaborative problem-solving clusters

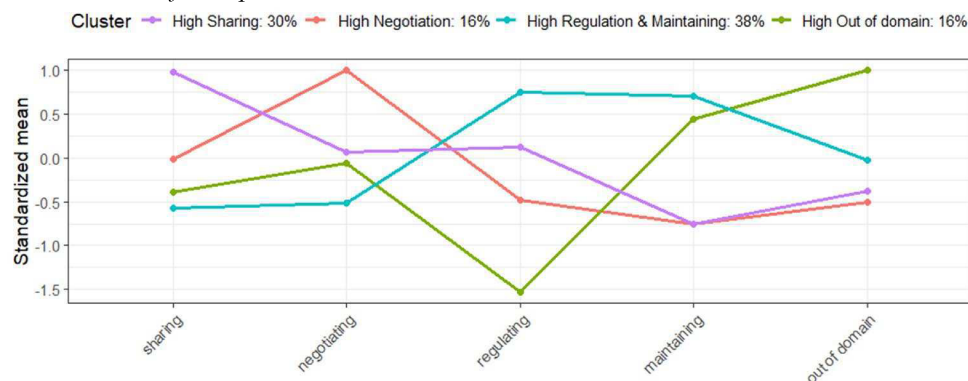
We identified four clusters (i.e., patterns) of student CPS patterns, selecting those with the lowest BIC values through the latent profile analysis (Figure 2). The first cluster was of medium size ( $n = 9$ , 30%) and showed a high level of sharing ideas and information, along with average levels of negotiation and regulation. This cluster can be characterized as the *high-sharing* (high shr) group. The second cluster was small ( $n = 5$ , 16%) and showed a high value in negotiating ideas and an average level of sharing. We labeled this cluster as the *high negotiating* (high ngt). The third cluster was of medium size ( $n = 12$ , 38%) and was characterized by above-average levels of regulating problem solving and maintaining positive communication. We named this the *high regulating and maintaining* (high rgl&mnt) group. The fourth cluster, *high out-of-domain* (high out), was small ( $n = 5$ , 16%) and showed high levels of maintaining positive communication and out-of-domain tasks. Throughout the 31 periods of the collaborative activities, groups across the conditions most frequently exhibited the high regulating and maintaining pattern, while high negotiating and high out-of-domain patterns were the least prevalent.

Furthermore, we compared the frequency distribution of each cluster between the two conditions. In the fixed and adaptive condition, the most frequent CPS pattern was the high negotiating pattern (80%), followed by



high regulating (50%), high sharing (44%), and high out-of-domain (40%). In the fixed-only condition, the most frequent CPS pattern was high out-of-domain (60%), followed by high sharing (54%), high regulating and maintaining (50%), and high negotiating (20%). Despite the trend towards variability in the frequency distribution, the results of the chi-square test indicated that there is no significant difference in the student CPS patterns between the conditions ( $\chi^2(3, n = 31) = 2.081, p > .05$ ). In other words, the groups who received both adaptive and fixed scaffolds did not exhibit distinctive CPS patterns compared to the other groups during the collaborative inquiry activities.

**Figure 2**  
*Four clusters of CPS patterns*



## RQ2: Association between CPS patterns and learning performance

To identify CPS practices associated with higher and lower performance in science inquiry, we classified the six groups based on the final solution. Adaptive 1, 2, and Fixed 2 were classified as higher-performing groups, and Adaptive 3, Fixed 1, and 3 were categorized as lower-performing groups. We examined the two groups' distribution of the frequency of each cluster (see Table 2). During the activities across three quests, 80 percent of the high-negotiating patterns were observed in the higher-performing groups, followed by 67 percent of high-sharing and 40 percent of high out-of-domain patterns. In the lower-performing groups, 67 percent of high-regulating and maintaining patterns were shown, followed by 60 percent of high out-of-domain and 33 percent of high-sharing patterns. In addition, we conducted a chi-square test to see if there was a significant difference in CPS patterns between the higher- and lower-performing groups, but the results showed no significant difference,  $\chi^2(3, n = 31) = 4.305, p > .05$ . We further computed standardized residuals to assess the degree of contribution of each cluster to higher and lower performance. The findings indicated that high sharing (.628), and high negotiating (.884) showed moderate and high associations with higher performance, whereas high regulating and maintaining (.910) and high out-of-domain (.373), showed large and small contributions to lower performance, respectively.

**Table 2**

*Each group's frequency distribution of each cluster and performance in science inquiry*

|                    | Adaptive 1          | Adaptive 2 | Adaptive 3         | Fixed 1 | Fixed 2 | Fixed 3 |
|--------------------|---------------------|------------|--------------------|---------|---------|---------|
| Performance        | Higher <sup>1</sup> | Higher     | Lower <sup>2</sup> | Higher  | Lower   | Lower   |
| High sharing       | 0                   | 4          | 0                  | 1       | 2       | 0       |
| High ngt           | 2                   | 1          | 1                  | 0       | 1       | 0       |
| High rgl & mnt     | 2                   | 1          | 2                  | 3       | 0       | 3       |
| High out-of-domain | 1                   | 0          | 1                  | 2       | 1       | 2       |
| Missing data       | 0                   | 0          | 2                  | 0       | 2       | 1       |

<sup>1</sup>Higher indicates that the group belongs to the higher-performing group.

<sup>2</sup>Lower indicates that the group belongs to the lower-performing group.

To better understand the relationship between the clusters and performance in science inquiry, we closely examined students' actual utterances. We observed nuances between the groups in their practices in each aspect of CPS, which might be related to the group's level of performance (see Table 3). In terms of practices in sharing ideas and information, both groups similarly shared ideas on potential answers. However, higher-performing groups tended to refer to more learning resources, which was subsequently connected to sharing their answers and negotiating their ideas. The other groups merely expressed ideas or typed answers for another, which did not lead

to further discussion (Fixed 3, see Table 3). In other words, the groups that engaged in limited aspects of CPS practices were still labeled as a lower performance group, even though they showed the high-sharing pattern, which had a positive correlation with higher performance. When negotiating ideas, higher-performing groups argued with their rationales and elaborated their arguments in detail. However, the lower performing groups were more likely to simply express whether they (dis)agree on one's answer. Higher performing groups' regulation tended to be tied to sharing or negotiating ideas, while the other groups mostly used the strategy to move to the next step. For instance, a student's utterance, "Hanna, we would love it if you joined in" (Adaptive 1, see Table 3), led Hanna to express her (dis)agreement. Additionally, one of the utterances from Adaptive 2, "You have to say why", was followed by an argument shared by a student and led the student to reflect on the argument and elaborate on its reasoning. Thus, even the high regulating and maintaining cluster, which was correlated to lower performance, contributed to higher performance, if students engage in multiple CPS strategies within scientific discussion. Lastly, lower-performing groups' maintaining positive communication and out-of-domain tasks distracted their science discussion, while the other groups tended to quickly get back on task. Taken together, it can be inferred CPS practices organically connected to others, especially negotiating ideas, might have contributed to higher performance in collaborative science inquiry.

**Table 3**

*Examples of the Discourse from Higher and Lower Performance Group for Each CPS Category*

| CPS category                       | Higher performance                                                                                                                                                                                                                                                        | Lower performance                                                            |
|------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Sharing ideas and information      | "i think the answer is greenish brown and cloudy" (Adaptive1)<br>"Hey, Yeah I looked at the notes and it said nothing about them swimming at the top because the water is cloudy." (Fixed 2)                                                                              | "What should I write?" (Fixed 3)<br>"I typed the answer for you" (Fixed 3)   |
| Negotiating ideas                  | "So, there's Yes, there's less dissolved oxygen because the bottom of the clean tank is 6.2 and the bottom of the dirty tank is 3.7. A 3.7 is less." (Fixed 2)<br>"no there's less on the bottom than their swimming in the top because there's more right?" (Adaptive 2) | "No, don't try less. It's more." (Fixed 1)<br>"I think it's good." (Fixed 1) |
| Regulating problem solving         | "Hanna, we would love it if you joined in" (Adaptive 1)<br>"You have to say why." (Adaptive 2)                                                                                                                                                                            | "Hit agree agree" (Adaptive 3)<br>"What should we do?" (Fixed 1)             |
| Maintaining positive communication | "Good job, Ivanna." (Adaptive 2)<br>"you can politely disagree" (Adaptive 1)                                                                                                                                                                                              | "ola" (Fixed3 C2G4)<br>"Oh Agree. Yay." (Fixed 3)                            |

### RQ3: Coordinated scaffolds mediating student CPS

Utilizing interaction analysis, we examined how or if the coordinated scaffolds productively mediated the students' CPS associated with higher performance as delineated in RQ2. Based on the results above, we differentiated between higher-performing (Adaptive 1 and 2) and lower-performing (Adaptive 3) groups in the fixed and adaptive condition, then compared their engagement in CPS during the Deduce and TIDE activities. Several segments within the videos revealed that the students in Adaptive 1 and 2 took up the computer-based scaffolds, which in turn led to an expanded science discourse during their collaborative endeavors. However, Adaptive 3 did not use scaffolds as intended. The following presents one example of each case where the students used or did not use the adaptive scaffolds as intended.

During the first set of questions in Quest 3 Deduce, Adaptive Group 2 encountered the adaptive scaffold (e.g., "Is there anyone we haven't heard from during Deduce? If so, let's make sure we hear from them."), which actively encouraged participation from all group members. Subsequently, two students, Madelyn and Eliza, started to type potential answers for the questions in the chat (e.g., "The first one is A" [CPS code: sharing]), fostering initiation into negotiations concerning the correct answers. Additionally, as promoted by the adaptive scaffold (e.g., "Don't forget to use the group chat to talk out ideas together! Consider using sentence starters if you are stuck."), Madelyn leveraged one of the conversation starters, a fixed scaffold, by sending "Does anyone agree with my idea that ... it increases?" (i.e., negotiating). Their actions elicited other's reactions (e.g., "Yeah, the first one is A, and the second one is B." [negotiating] and "That's what I said." [negotiating]), and the group resumed their discussion. As such, the adaptive scaffold, which encouraged sharing ideas and the use of the fixed scaffold, facilitated a clear consensus on the idea and progressed to the next set of questions. This highlights the synergistic

effect of the coordinated scaffolds in promoting their CPS practices. Moreover, during the second set of questions, another adaptive scaffold (i.e., “Ivanna (one of the group members), can you share your thoughts about this question?”) encouraged Madelyn to recognize a disparity in group participation and reflect on her group’s conversation, “Oh we have to hear from everybody in the chat” (i.e., regulating). She pointed out the absence of Ivanna’s participation and invited Ivanna (i.e., “Ivanna, you have to chat something. Because we haven’t heard from you in a while” [regulating]). Initially, the group’s ideas converged to answer ‘a’ and ‘d’, but Ivanna expressed disagreement on the group’s ideas (i.e., “I thought it’s produce and photosynthesis” [negotiation]). This led to an extended negotiation to address the disagreement, during which they delved into a further discussion of the relationship between photosynthesis and dissolved oxygen to support her idea. These differing perspectives necessitated regulation and evaluation of the final decision, encompassing various aspects of CPS practices. As a result, along with the fixed scaffolds, the adaptive scaffolds played a pivotal role in enhancing the depth of their negotiation and engagement in diverse aspects of CPS practices, which are associated with higher performance.

In contrast, Adaptive 3 did not consistently adopt and employ the given scaffolds as intended, resulting in distinct patterns of their CPS from the higher-performing adaptive groups. As an illustrative example, during the Quest 1 TIDE, Sam was just looking at his screen and not participating in tasks at hand (e.g., “who’s doing it?”, “no it’s not me it’s not me” [regulating]), but only two students in the group were moving notes on the TIDE board. Although they noticed that an adaptive prompt was presented, they took no action in response to the adaptive scaffold. After all the notes were placed, they did not discuss if they agreed on each note’s placement but tried to proceed forward (e.g., “Pres, press submit” [regulating]). In this situation, students even unexpectedly used the sentence starters by leaving a blank as it is (e.g., “As I was playing, I learned that ...”) and putting irrelevant content (e.g., “Does anyone agree with my idea that Arron needs to put notes” and “Does anyone agree with my idea that whale noises[noises] help me sleep”). Although the adaptive scaffold was triggered, it did not affect their CPS engagement and redirect their focus toward the task at hand. As a result, their CPS practices were skewed to certain categories of CPS, particularly regulating and maintaining, with limited connection to other facets of CPS performance. Indeed, across activities, utterances coded as regulating are about what they are working on (e.g., “what should we do?” [regulating]), suggesting selecting another option without further discussion (e.g., “do ‘a’ do the first one” [regulating]), and fostering group members to proceed by hitting a ‘submit’ button (e.g., “Let’s go. Caitlin, Caitlin. Hit submit. Hit submit. Okay” [regulating]). Such participation limited their utilization of other available scaffolds and interaction with the learning environment and peers, potentially contributing to their learning outcomes. As such, compared to Adaptive 1 and 2, Adaptive 3, which underutilized the scaffolds, demonstrated less productive CPS practices, affording fewer opportunities for meaningful interaction with the learning materials and group members.

## Discussion

This study examined the effectiveness of coordinated computer-based scaffolds mediating students’ CPS practices and science learning in a game-based CSCL context, focusing on CPS clusters linked to student performance. The study found that although each of the four identified clusters shows a slight to moderate association with either higher or lower performance, focusing on one or two categories of CPS performance is associated with lower performance. In contrast, CPS practices characterized by interconnections with various CPS categories appear to be correlated with group performance levels, offering a potential explanation for the lack of significant difference in the frequency distribution of CPS clusters between high-performing and low-performing groups. Furthermore, the study presents scenarios wherein adaptive scaffolds collaboratively encouraged students in high-performing groups to actively engage in diverse facets of CPS practices alongside the fixed scaffolds. Considering collectively, our results suggest that the pivotal distinction in group performance levels may reside in the interconnection between different CPS performance types. Nevertheless, not all students consistently utilized the adaptive scaffolds, potentially contributing to the absence of significant differences in the frequency of each CPS cluster between the conditions. Providing group-level scaffolding presents challenges as the scaffolds may not align with various group dynamics, particularly those that hinder taking up and utilizing the scaffolds effectively. This implies that it may be imperative to implement multiple forms of computer-mediated scaffolding targeting the same needs, tailored to address distinct requirements across various contexts and audiences (Puntambekar, 2022). The findings also suggest involving human intervention in scaffolding and providing strategically distributed scaffolding across tools, peers, and teachers (Puntambekar, 2022) to deliver effective scaffolding (Tabak, 2004). Such approaches would lead to a more sophisticated and comprehensive scaffolding design.

Our findings contribute to the existing body of research on the coordination of different types of computer-based scaffolds and their interplay supporting students. In line with the previous studies, the study demonstrates that different forms of coordinated computer-based scaffolding can also produce synergistic effects on student learning outcomes. One of the ways to manifest the synergistic effects of the computer-based fixed and

adaptive scaffolds is to use adaptive scaffolds as a means of encouraging learners to employ fixed scaffolds, which subsequently leads them to further engage in productive CPS practices. This can offer insights for designing scaffolded computer-mediated learning environments that promote synergistic effects of coordinated scaffolding on student learning. Given the limited sample size and the aggregation of CPS performance categories, further study should incorporate a sequence of CPS practices to examine connectivity between different CPS categories and investigate relationships between student performance and CPS practices using a larger sample size. As a result, our study is an initial step in providing design implications for different forms of scaffolding.

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