Examine Student Resource Uses in a Game-based CSCL

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Abstract: This paper explores student resources utilization and its impact on student learning outcomes in a game-based CSCL context from a sociocultural perspective. Analysis of group-level resource utilization revealed three distinct patterns that differentiate high-performing from low-performing groups. Qualitative analysis of group problem-solving responses provided further evidence of the association between group-level resource use and subsequent group performance. The study sheds light on the association between resource utilization and learning success in collaborative learning settings, offering valuable guidance for enhancing the pedagogical design of learning resources and teacher scaffolding to promote effective resource utilization.

Introduction

Sociocultural learning theories emphasize the significance of tools and artifacts in mediating learning (Danish & Gresalfi, 2018). In game-based CSCLs, these tools and artifacts often take the form of learning resources which may include video clips, visual representations, feedback from in-game characters, and digital notebooks designed to afford student learning opportunities (Jeong & Hmelo-Silver, 2010). Learning in these contexts may rely on how well students utilize available learning resources and tools important to the learning objectives (Jeong & Hmelo-Silver, 2010; Danish et al., 2022). However, CSCL environments tend to emphasize student agency and are characterized by student-centered inquiry, which necessitates that students effectively appropriate and engage with embedded resources relevant to learning and problem-solving goals (Law et al., 2021). Furthermore, the digital interactions and multimodal learning resources can introduce extra layers of complexity and challenges, and students may fail to engage deeply with the resources to achieve a sophisticated understanding of the materials (Jeong & Hmelo-Silver, 2010). Ultimately, these complexities pose challenges when teachers hope to monitor and facilitate effective resource uses within CSCL classrooms (Furberg, 2016). This study aims to explore measures of students' interactions with learning resources and utilization patterns crucial for collective learning achievements in resource-rich CSCL environments. We propose that productive resource use correlates with learning outcomes, reflected in student performances such as final assessments and group problem-solving activities. By investigating the relationship between resource utilization and knowledge acquisition in game-based CSCL settings, this study seeks to inform the design of automated tools to aid teachers and students in fostering more effective resource utilization in CSCLs.

Tools and resources in collaborative learning

The sociocultural perspective highlights that learning is fundamentally a social process, in which individuals learn through observation, negotiation, social interactions, sense-making, and solving collective problems (Pea, 2004). Within social learning processes, tools and resources help people organize and regulate their goal-directed activities, allowing them to form new representations as a group (Danish & Gresalfi, 2018). In CSCLs, the process of knowledge co-construction involves individuals making sense of digital resources and representations and negotiating their understanding with others to collectively construct shared knowledge (Stahl & Suthers, 2014). However, due to the diversity of personal and cultural experiences learners bring to the learning contexts, their goals and approaches when engaging with various resources and tools may differ from each other and from the intentions of teachers or co-created objectives (Furberg & Ludvigsen, 2013). Therefore, researchers (e.g., Danish et al., 2022) interested in studying the affordances of resources and tools tend to ask: why a particular group of learners tend to use certain tools in certain ways. In this paper, we investigate the nature of learners' interaction with the available resources, and patterns of interactions that are crucial to both group problem-solving processes and final learning success. To these ends, the present study is guided by the following research questions (RQs): RQ1) In what ways do groups with different learning outcomes vary in their utilization of learning resources over

time? RQ2) How do different levels of resource utilization manifest in subsequent collaborative problem-solving activities?

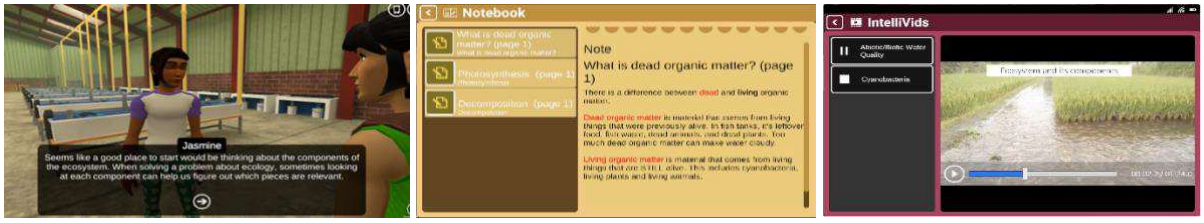
Methods

Participants and context

The study took place in a science game-based learning environment: CRYSTAL ISLAND: ECOJOURNEYS (Figure 1), designed to teach students knowledge about aquatic ecosystems. In this research, we collected data from 156 middle school students from six science classrooms in midwestern and southern US. In the game, students worked together in small groups (n=3 or 4) to solve complex problems related to sick tilapia fish at a local farm in the Philippines. The game consists of a tutorial section followed by three quests focusing on interrelated problems. Students begin with solo investigation by gathering data, receiving notes, watching learning videos, and interacting with non-player characters (NPCs). Students also engage in collaborative activities known as *Deduce* and *TIDE* (see also Hong et al., 2023). At the end of both *Deduce* and *TIDE*, students respond to the questions collectively using the notes and data collected. A pre-test and a post-test were administered before and after the game. Group learning gain refers to student's average pre- and post-test percent difference. Three types of learning resources within ECOJOURNEYS are included: informational videos offered in each quest; excerpts of key concepts presented in notebook entries collected during individual investigation; and in-game NPCs that provide key information. Figure 1 displays the screenshots of each of these resources.

Figure 1

Screenshots of In-Game Learning Resources within ECOJOURNEYS:



a b c

Note: a. In-game NPC providing information; b. Notes stored in the Tablet; c. Informational video in quest 3.

Research design, data sources, and analysis

In this paper, we utilized two data types: log data recording human-computer interactions and students' collective responses to questions at the end of *TIDE* and *Deduce*. Using log data, we identified four variables indicative of how small groups interact with learning resources in ECOJOURNEYS: group average time spent with NPC characters, group average time spent reading notes during game, whether skip a video in each quest by group, and average number of notes revisited by a group. After excluding missing data, log files of 113 students (28 groups) was utilized in the study. For RQ1, we employed log data regarding group-level resource utilization of each quest to examine the pattern of change in their interaction with the resources across the game. We centered the time_NPC and the time_note variables around the average time and number of resource usage of each quest due to the differences among each quest. To compare cases, we selected 6 high-performing groups and 6 low-performing groups from the entire dataset. The high-performing groups consisted of groups with average pre-/post-gains above the 75th percentile, while the low-performing groups are below the 25th percentile. No statistically significant difference in pretest scores between the high-performing and the low-performing groups was confirmed by an independent t-test ($p > .01$). To address RQ2, we qualitatively analyzed group responses to problem-solving questions in *Deduce* and *TIDE* from both high-performing and low-performing groups and identified and compared patterns in responses from each group.

Results

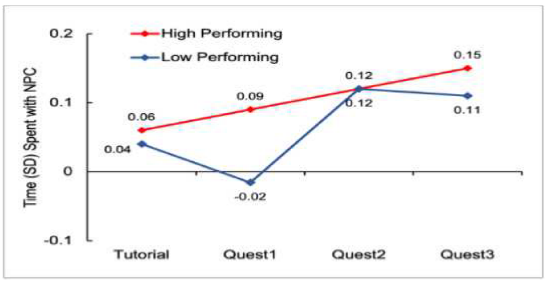
RQ1: Patterns of group resource utilization over time

We explored how group-level resource utilization evolved over time and what patterns tended to be important to group learning success. Figure 2 presents four trajectories of resource utilization over time by the high-performing and the low-performing student groups. Overall, three patterns of resource utilization were observed that differentiated the high and low performing groups. First, high-performing groups seemed to consistently utilize resources over time. For example, while both groups are seen a similar level of interaction with NPCs in tutorial,

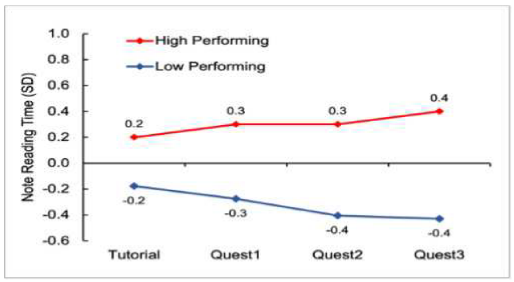
the low-performing group experienced a decline (-0.02 SD) in the time investment within quest 1, and the level of utilization went back up in the last two quests. Another pattern is that the high-performing group appeared to be more likely to complete required resources rather than skipping them or going through them quickly without completing them. For instance, while both groups have seen decline in video completion rates over time, a significant portion of the low-performing group began skipping required videos in quest one, with over half of them skipping videos in the last two quests. In comparison, the high-performing group maintained a consistently high completion rate throughout the game. The third pattern is the increased resources utilization over duration of the game in the high-performing group. For example, the high-performing group exhibited an upward trend in both the frequency of revisiting their notes (see Figure 2d) and the average time spent with the notes (see Figure 2b) as the game progressed. The increase in note revisits may be due to their growing need to reinforce knowledge as collaborative problems became more complex in later quests. They might have also become increasingly adept at navigating and locating resources as the game advanced. However, the low-performing group, despite participating in the activities in the same order, did not show a similar trend of resource utilization.

Figure 2

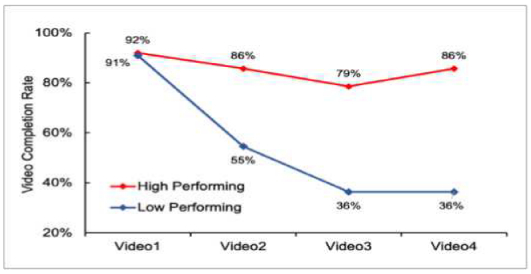
Patterns of Learning Resource Use Over Time by High-Performing and Low-Performing Groups



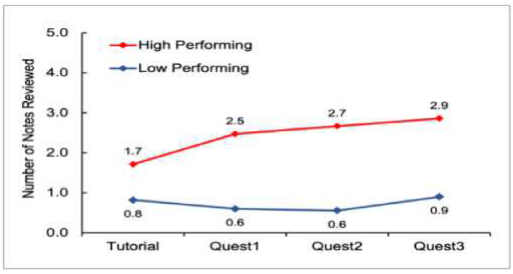
a. Time spent with NPCs by group (Standardized)



b. Time on notes in game by group (Standardized)



c. Video completion rate by group



d. Average number of notes revisited by group

RQ2: Group resource utilization in problem-solving

Next, we explored how different levels of learning resources utilization can manifest in students' problem-solving abilities. To investigate what might be the evidence of productive uses of resources, we qualitatively analyzed the constructed responses at the end of each *Deduce* and *TIDE* activities from both high-performing (HG) and low-performing groups (LG) and decided to present the sample responses in *Deduce* due to their representativeness (see Table 1). For example, when students were asked to justify the statement regarding the bacteria at the beach, we can observe how the two groups differ not only in the quality of their responses, but also how learning resources (see bold texts) were indexed in their answers. The absence of references to resources in the responses of low-performing groups is consistent with the patterns of their incomplete and inconsistent interactions with learning resources in this group, leading to their inability to use them. In addition, when asked to explain the "cloudiness" phenomenon in the water, the high-performing groups seemed to employ more essential components and related scientific concepts (see italic texts). Whereas the low-performing groups lack mentioning of scientific concepts or oversimplify the underlying mechanisms, even though the concepts and key components were covered in different learning resources (e.g., videos, notes) throughout the quest. This example provides further evidence for how different levels of interactions with learning resources would affect subsequent groups' problem-solving performances.

Table 1

Sample Responses from High- and Low-Performing Groups in Deduce

HG2: "We know this because we tested a **sample in the lab**"	LG1: "I think there's bacteria at the beach because the boats traveling back and forth could've caused the green bacteria to appear"
HG3: "We as a team think that it is bacteria because **sulu's notes** explained the effects of bacteria in water"	LG3: "They keep talking about bacteria"
HG4: "It is bacteria because it matches the shape and color of the image in the **notebook"**	LG5: "It looks like bacteria."
HG6: "The water is becoming cloudy because of the excess of *cyanobacteria* and *dead organic matter*."	LG2: "if more dead things are in the water it becomes more cloudy which make more deAd feish"
HG5: "There is bacteria and *dead organic matter* in the water making it cloudy."	LG3: "More *dead organic matter* = cloudy"
	LG6: "turbidity"

Discussion

In our study, we examined how learners utilize resources within a game-based collaborative learning environment and its impact on group learning outcomes. Drawing from sociocultural learning theories, we emphasize the significance of resource utilization in shaping learning experiences and collective knowledge building. Our analysis of group resource usage over time and problem-solving qualities suggests a link between resource engagement and group learning performance. However, there are limitations to consider, such as the lack of comprehensive understanding behind resource utilization patterns derived solely from log trace data. For instance, additional evidence is needed to elaborate on what motivated high-performing groups to increasingly revisit their notes, and what factors led low-performing groups to skip a greater number of videos.

To conclude, the findings of our study provide insights into how students use (or do not use) resources and how patterns of resource use influence their subsequent group performance in complex collaborative environments like game-based CSCL environments. Our research sheds light on the role of diverse resources in facilitating knowledge acquisition at group levels. To enhance resource utilization effectively, teacher guidance and support are crucial. Our findings can inform the development of tools for teachers to understand and improve student resource utilization. Additionally, student-facing tools can empower learners to monitor and reflect on their resource interactions during collaborative learning. Overall, this study emphasizes the importance of resource-driven factors in collaborative learning and suggests avenues for further research to optimize resource usage for better learning outcomes.

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Acknowledgments

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