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Designing Narratives in Multimodal Representations for Game-Based Math Learning and Problem Solving

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Abstract: Narratives as a game feature constantly yield mixed results for learning in the literature. In this case study, we studied the design of narratives in multimodal representations for game-based math learning and problem solving with 27 student participants. Results indicated that narratives with multimodal representations situated in the game world appeared to foster math sensemaking and reasoning. However, decontextualized math problem solving was also observed. Implications for narratives and multimodality design were discussed.

Introduction and theoretical background

Digital game-based learning (DGBL) environments have been used to provide authentic mathematical experience—exploring, formulating, and experimenting with mathematical hypotheses in the game world. Although the overall effect of DGBL for math is promising, prior research findings regarding specific design features remain controversial. The effects and design features of narratives, in particular, remain murky.

According to Bruner's (1964) learning theory, an individual's meaning making process involves three modes of representation: enactive representation (e.g., motor response or action: maneuvering in-game objects), iconic representation (e.g., images, graphics, or objects in a game), and symbolic representation (e.g., symbol systems or texts). These three modes of representations can be coordinated as *multimodal representations* that set a foundation for the design and interpretation of learning in the game space (Ainsworth, 2006; Ke & Clark, 2020).

The current case study aims to examine narratives in multimodal representations for game-based math learning. Particularly, the following research question is investigated: *What are the impacts of narratives in multimodal representation on learning in a game-based math learning environment?* In the current study, we employed a 3D architectural math learning game called *E-Rebuild* (Ke & Clark, 2020). The system of narratives in multimodal representation in *E-Rebuild* consist of (1) task narratives (i.e., explaining the task of each level for the learners), (2) contextual narratives (i.e., providing a storyline at the beginning of the task narratives), (3) math notation (i.e., a mouseover feature inscribed on the game creates), (4) concrete stimuli (i.e., tool to retrieve symbolic math information), and (5) environmental cues (i.e., popups reminding learners what went wrong). Measuring, trading, building, and allocating items in the 3D game world are major game actions designed to integrate mathematical learning actions while simulating architecture-themed problem-solving processes.

Method

To examine how the players use and interact with the narratives designed in the multimodal representation, we adopted a heuristic case study method in which each participant is a case (Merriam, 1998). As part of a longitudinal design-based research, 27 college students with variant genders, gaming experiences, and academic backgrounds were recruited as users to inform our designs in this study (Merriam, 1998). These participants played the game for one and a half hours individually, with a researcher closely observing the gameplay and providing technical support as needed. Immediately after the gameplay, a thirty-minute semi-structured interview was conducted to further collect the data on participants' gameplay experiences and perceptions. Rich data were triangulated between observations, video recordings, semi-structured interviews, and gameplay artifacts created by the learners. We performed three phases of data analyses: (1) open and descriptive coding techniques. (2) revisited the codes, revised and developed themes emerged from the data; created visuals and displays to demonstrate the relationships of the themes delineated. (3) executed queries. We wrote memos and kept reflective journals, as well as analyzed deviant cases for confirmability and credibility (Miles et al., 2020). We focus on general themes and highlight salient cases with displays in this paper.

Results

Narratives in multimodal representation supported math problem solving

In general, the narrative system in multimodal representation functioned to support math problem-solving exploration. To elaborate, all participants started their gameplay by reading the task narratives. However, it wasn't

natural for some participants to engage in math problem solving after reading the task narratives. Specifically, a random trial-and-error stage was observed, as demonstrated in the following example (See Figure 1, Right). After several rounds of trial-and-error, the narrative system prompted Participant 19 to purposefully engage in math reasoning and problem solving. He collected the task-related math information (*the height and width of the container*) from distributed task narratives (e.g., in the Task Panel and object-related tool tips). He then organized the task information while adjusting his hypothesis with the task (see *Stage 3* in Figure 1, Right). He strategically and carefully adjusted the number of families to each container. During the process, he carefully read the math notations while calculating the space needed in the 3D game world. His math reasoning process was prompted and mediated by the narrative system in multimodal representation that legitimized math-related gameplay strategies during game-based problem solving.

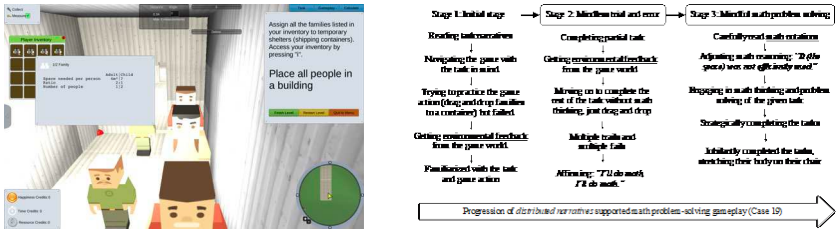

Figure 1. (Left) An example of narratives system in the game. (Right) A visual display of Participant 19's gameplay supported by distributed narratives

"Decontextualizing" math problem and the narratives

Although a body of evidence from participants supports that narratives in multimodal representation are useful in mediating math problem solving in the game world, some case analysis still indicated a deviant phenomenon. Take participant 4 for example, the multimodal narrative system did not make him cognitively flexible. In a level where he needs to process the concept of ratio in the math notation to tackle the design task, he got stuck and showed frustration. Instead of interpreting the given math notation, he used the measure tool to *measure the height* of the game object to calculate the *surface area* in square meter: "*when I do math, I feel like to measure*." He kept trying the same strategy rather than searching for alternative solutions or clues embedded in the game world. This behavior demonstrated that he was not flexible in terms of math thinking and problem solving given his consistent efforts contributed to the same solution or strategy. The case highlighted the essential role of providing a mechanism in multimodal representation to promote flexibility in experimenting with and comparing alternative problem-solving strategies.

Conclusion and implications

In this case study, distributed narratives designed in the math learning game appeared to coordinate and enhance math sensemaking and reasoning (Ainsworth, 2006). Yet, this learning process did not naturally occurred in a single form of representation (i.e., task narratives in symbolic representation). Instead, it was the narratives in multimodal representation that mediated and prompted mindful math problem solving. There are two implications for designing narratives in DGBL. First, DGBL narrative features should be intrinsically integrated into the game environments to provide a coherent system that engages learners in mindfully doing and thinking math. Second, deviant cases speak to the importance of designing narratives that stimulate cognitive flexibility. Future research should continue to explore how narratives can afford multimodal feedback for flexible math problem solving.

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