Supporting Representational Competencies in an Educational Video Game: What Does and Doesn't Work

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Abstract. To examine the effectiveness of two types of representational-competency supports in educational video games, we conducted a 2 × 2 experiment with 142 students. We found that one type of support was effective, but only for students with high prior astronomy knowledge. We discuss implications for the design of representational-competency supports for educational video game.

Keywords: Video games · Representational competencies · Instructional support

1 Introduction

Educational video games provide intuitive access to authentic scientific practices [1]. To engage in these practices, games provide interactive visual representations that students manipulate to solve domain-relevant problems [2, 3]. Visuals can enhance learning because they can make complex concepts accessible [4, 5]. However, visuals can also be confusing if students do not know how they depict information [4, 5].

To overcome these issues, research has investigated ways to support students' representational competencies: skills that enable students to use visuals to solve tasks [5]. This research has shown that students need two types of representational competencies to benefit from visuals: sense-making competencies that allow students to explain how visuals depict information [4, 5] and perceptual fluency that allows students to effortlessly extract information from visuals [5, 6]. To support sense-making competencies, instructions prompt students to verbally explain which visual features correspond to disciplinary concepts [4, 5]. To support perceptual fluency, instructions engage students in many short matching tasks [5, 6]. Prior research shows that combining support for both sense-making competencies and perceptual fluency enable students to overcome difficulties with visuals and enhance learning of disciplinary concepts [7].

However, research on representational-competency supports has mostly focused on structured learning environments (e.g., [5]) and has not examined these supports in educational games. Yet, visuals are ubiquitous within games [2] and can support game-based learning [1]. Nevertheless, students have difficulties understanding how visuals show concepts, especially if they are not central to game interactions [2]. Further, students often focus on intuitive understanding instead of critically reflecting on visuals [2].

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Thus, students encounter similar difficulties with visuals in educational video games as in structured learning environments. Thus, integrating supports for representational-competencies shown effective in structured environments may be helpful for students in game environments.

2 Methods

We recruited 142 undergraduate students without prior undergraduate astronomy courses from our institution via flyers and emails to participate in our study.

Students were randomly assigned to one of four conditions that resulted from a 2 × 2 design (sense-making support: yes/no; perceptual-fluency support: yes/no). Students received representational-competency supports in the form of five 2-min. videos and verbal reminders given at regular intervals during game play, which provided step-by-step guidance on how to interact with visuals. To control for any potential effects of the videos and reminders, the control condition received videos and reminders related to the benefits of educational video games and technical aspects of the game.

All students played At Play in the Cosmos, an astronomy game designed to help students make connections among multiple visuals of astronomical phenomena and to engage students visually with astronomy concepts [3]. In the game, students complete guided missions to explore galaxies where they acquire resources for the corporation. Students use a variety of visuals to gather information about celestial objects. Interactions with visuals are designed to intuitively engage students with astronomy concepts without having to compute mathematical formulas. In the game, visuals illustrate how to obtain variables for an equation and students drag values to corresponding color-coded locations. We selected 10 missions of the game for our study.

We assessed students' learning of astronomy content knowledge, sense-making competencies, and perceptual fluency with three isomorphic versions of a test that was delivered at three test times (pretest, intermediate test, posttest). Scores for content learning and sense making were computed as the average of correct answers on the items. Scores for perceptual-fluency were computed as an efficiency score to take accuracy and speed into account [8]. Students also completed a Mental Rotation Test (MRT) [9] and rated their cognitive load after each mission of the game [10].

The study involved two sessions, 1–5 days apart. In session 1, students took the pretest and MRT, watched videos, played the game, and took the intermediate test. In session 2, students continued watching videos and playing the game and took the posttest.

3 Results

We used a repeated measures ANCOVA with pretest, MRT, cognitive load, and sense-making pretest as covariates, test scores as dependent measures, test time (intermediate and post) as repeated, within-subjects factor, and sense-making and perceptual-fluency support as between-subjects factors. With respect to research question 1 (whether sense-making support is effective), we found no significant main effect of sense-making support ($F < 1$). With respect to research question 2 (whether perceptual-fluency support is effective), we found a medium significant main effect of perceptual-fluency support,

$F(1, 120) = 9.383$, $p = .034$, $\eta^2 = .077$. This main effect was qualified by a medium significant interaction between perceptual-fluency support and the content pretest scores, $F(1,120) = 7.580$, $p = .007$, $\eta^2 = .063$. Students with low prior content knowledge showed higher learning outcomes at the posttest if they had *not* received perceptual-fluency support. In contrast, students with high prior content knowledge showed higher learning outcomes at the posttest if they *had* received perceptual-fluency support. With respect to research question 3 (whether the combination of supports is effective), the interaction between the two types of support was not significant ($F < 1$).

4 Discussion

We investigated whether representational-competency supports that have proven effective in structured learning environments are effective in the context of an educational video game. Specifically, we tested the effects of two types of representational-competency supports. We found no evidence that sense-making support enhanced learning. Our results suggest that effects of perceptual-fluency supports depend on student characteristics. Specifically, we found that perceptual-fluency support enhanced content learning from the game, but only for students with high prior content knowledge.

A possible explanation for why the sense-making support was ineffective is that the game may not have provided enough information for students to reflect deeply about the information the visuals depict when they were prompted to do so. In the absence of this information, students may have engaged in shallow processing of the visuals. Further, students may have been unwilling to make sense of the visuals because the game fostered intuitive, game-like interactions more than reflection. Thus, our version of sense-making support might have been incompatible with the present game.

On the flipside, perceptual-fluency support might have been effective because it aligned with the game design that, as described above, aimed to intuitively engage students with astronomy visuals. However, the finding that perceptual-fluency support enhanced learning outcomes suggests that the game itself may not have sufficiently encouraged perceptual processing in ways that maximized students' content learning. Further, only students with high prior knowledge benefited from perceptual-fluency support. While this result corroborates prior research suggesting that perceptual-fluency support is most effective for students with prior content knowledge [7], it highlights a limitation of the game. Even though the goals of the game was to provide intuitive access to disciplinary practices with visuals [3], our results suggest that it may not be suitable as a first introduction to astronomy. Instead, it may be more effective if used after students have acquired some preliminary content knowledge.

Our study has several limitations. The game we used aimed to provide intuitive access to concepts like many educational video games. However, other video games may instead emphasize conceptual reasoning with visuals. Thus, future research should test representational-competency supports with other types of games. Further, our representational-competency supports were provided outside of the game. Future research should test whether integrated types of support are effective. Third, we conducted our study in a research lab to maximize internal validity, which may compromise external validity. Future research should examine these supports in realistic game-play contexts.

To conclude, our study suggests that representational-competency supports that are effective in structured learning environments are not necessarily effective in the context of video games. Specifically, sense-making support may be incompatible with video games that foster intuitive interactions with visuals. In contrast, perceptual-fluency support seems to be effective in such games. Our results suggest that designers of such games should add support for perceptual fluency but refrain from reflective prompts that support sense-making competencies during gameplay. Similarly, our results encourage instructors to prompt students' perceptual processing but caution against encouraging reflection during games that emphasize intuitive processing of visuals.

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