Focused Self-Explanations Lead to the Best Learning Outcomes in a Digital Learning Game

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Abstract: Prompted self-explanation, in which learners are induced to explain how they have solved problems, is a powerful instructional technique. Self-explanation can be prompted within learning technology by asking learners to construct their own self-explanations or select explanations from a menu. The menu-based approach has led to the best learning outcomes in the relatively few cases it has been studied in the context of digital learning games, contrary to some self-explanation theory. In a classroom study of 214 5th and 6th graders, in which the students played a digital learning game, we compared three forms of prompted self-explanation: menu-based, scaffolded, and focused (i.e., open-ended text entry, but with a focused prompt). Students in the focused condition learned more than students in the menu-based condition at delayed posttest, with no other learning differences between the conditions. This suggests that focused self-explanations may be especially beneficial for retention and deeper knowledge.

Introduction

Prompted self-explanation is used to promote learning by encouraging learners to self-explain what they are studying or how they have solved a problem (Wylie & Chi, 2014). As an instructional strategy, prompted self-explanation has proven to be one of the most robust and effective learning science principles (Pashler et al., 2007). Different forms of prompted self-explanation have been shown to be effective in a variety of studies with educational technology. Wylie and Chi (2014) cast the various forms of prompted self-explanation that have been used in learning technology along a continuum between what we describe as *unconstrained* and *highly constrained* self-explanations. Unconstrained self-explanations allow learners to freely create their own explanations, while presenting the highest cognitive challenge to learners (i.e., *open-ended self-explanations*). Highly constrained self-explanations, on the other hand, present the learner with a small set of options to choose from to self-explain and thus create the least cognitive challenge for learners (i.e., *menu-based self-explanations*). Between the two extremes are three other types of prompted self-explanation: *focused self-explanations*, which are constructive but focused in a specific way, such as prompting learners to identify relationships between mental models; *scaffolded self-explanations*, which provide support and/or feedback as learners construct explanations or fill in blanks of an explanation sentence; and *resource-based self-explanations*, in which explanations are selected by learners with the support of a resource, such as a glossary.

According to Chi and Wylie's (2014) Interactive-Constructive-Active-Passive (ICAP) framework for cognitive engagement, open-ended and focused self-explanations are constructive because the student must generate their own content. Scaffolded, resource-based, and menu-based self-explanations are active, because the student must actively select or manipulate information provided to them. The ICAP framework predicts that students should learn more from more cognitively engaging tasks, meaning constructive self-explanations should be more beneficial than active self-explanations. Only a limited number of studies have directly compared different types of self-explanation prompts. Evidence across these studies suggests that focused self-explanations may be the best, because they are constructive, yet direct students to ideas and explanations better than open-ended prompts, thus reducing cognitive load (Wylie & Chi, 2014) .

Self-Explanation in Digital Learning Games

Digital learning games are an interesting and important platform for exploring self-explanation, as they are now widespread in education, with a growing research base supporting their efficacy (Mayer, 2019). Despite contentions that prompted self-explanation within a digital learning game could disrupt game flow and induce extraneous cognitive processing (Adams & Clark, 2014), prompted self-explanation has been shown to support learning within games. For instance, Hsu and Tsai (2011) found that prompting learners to explain their errors from a menu of choices led to better learning gains than not prompting error explanations. However, not all studies have led to benefits of prompted self-explanations in digital learning games. For instance, Adams and Clark (2014) found no learning differences between two game conditions: menu-based self-explanation with explanatory feedback and a control condition with neither self-explanation nor explanatory feedback.

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We know of only one study that directly compared menu-based and open-ended self-explanations in learning games, and in that study Johnson and Mayer (2010) showed that menu-based self-explanations led to better transfer than open-ended self-explanations. While Johnson and Mayer argued that menu-based prompts likely led to better learning because they were less disruptive to game flow, Wylie and Chi (2014) argue that the open-ended prompts of the study may not have had the focus to direct students' attention in a game environment.

In light of the competing predictions that less disruptive self-explanations are best (Johnson & Mayer, 2010) and that more constructive self-explanations are best (Chi & Wylie, 2014), we decided to conduct a study with our learning game *Decimal Point* (McLaren et al., 2017) to investigate this issue. We hypothesized that constructive explanations could lead to deeper learning within a game context without disruption to game flow, provided that they are sufficiently focused.

A Self-Explanation Study with the *Decimal Point* Learning Game

Decimal Point is a single-player, non-competitive learning game based on an amusement park metaphor (McLaren et al., 2017). It is designed to help middle-school students practice their decimal knowledge. The student plays a variety of *mini-games* targeted at common decimal misconceptions within theme areas. Students make their way through the entire amusement park playing all of the mini-games in sequence. An example mini-game is "Rocket Science," which challenges the student to fill the gas of a rocket ship by choosing fuel canisters labeled with decimal numbers (e.g., 9.222, 9.3, 9.43, 9.2111) in the order from largest to smallest. If they make mistakes as they choose canisters, they are prompted to correct their solution by dragging and dropping the canisters into the correct order. The student continues playing the game until they correctly order the canisters. After correctly solving two problems within each mini-game, students are prompted to answer a self-explanation question, according to one of three different conditions and self-explanation formats.

The original version of the game employed a menu-based self-explanation approach and produced better learning outcomes compared to a non-game control (McLaren et al., 2017). In the current study we compared three forms of self-explanation to test competing hypotheses about the benefits of more constrained, active self-explanations (Johnson & Mayer, 2010) and less constrained, constructive self-explanations (Wylie & Chi, 2014) in digital learning games.

- *Menu-based self-explanations*: Students were presented with 3 or 4 explanation menu options, with the correct option being a conceptual description of the problem solution. We consider this form to be highly constrained and active according to the ICAP framework.
- *Scaffolded self-explanations*: Students were prompted to complete a fill-in-the-blank sentence, using a word bank of 4 or 5 words/phrases that could be inserted into the sentence. We consider scaffolded self-explanations to be moderately constrained and active according to the ICAP framework.
- *Focused self-explanation*: Students responded to focused self-explanation prompts about specific problems by filling in an open-text field. To assure that students would expend at least minimal effort, we required that their self-explanations contained at least four words with at least one of the words being from a relevant list (including common misspellings) that would legitimately be found in a correct explanation. We consider this form to be minimally constrained and constructive according to ICAP.

Across all conditions, students could not proceed to the next mini-game until they provided a correct self-explanation or, in the focused condition, an explanation that met the length and relevance requirements. The question prompts were written to align content across all three conditions. Our rationale for choosing these three prompted self-explanation approaches was to directly compare different levels of cognitive engagement (constructive and active), while also including the original menu-based approach used in previous versions of the game. Our research questions for the study were:

RQ1. Which form of prompted self-explanation – menu-based, scaffolded, or focused – leads to the best learning outcomes in the context of the Decimal Point learning game? Although prior results with self-explanation in digital learning games supported using menu-based prompts to avoid disrupting game flow (Johnson & Mayer, 2010), the theories proposed by other researchers suggest that constructive prompts are better than active prompts if they are sufficiently focused (Wylie & Chi, 2014; Chi & Wylie, 2014). Therefore, we predicted that focused prompts would be best.

RQ2. Which form of prompted self-explanation – menu-based, scaffolded, or focused – leads to the least enjoyment in the context of the Decimal Point learning game? This is an important question because one wouldn't want to lose the enjoyment aspect of game-based learning, given that engagement has been shown to explain the learning benefits of a game compared to the non-game equivalent (Richey et al., 2021). As less constrained prompts are likely to be more disruptive to game flow, we hypothesized that the order of enjoyment would be: menu-based self-explanation more enjoyable than scaffolded, which would, in turn, be more enjoyable than focused.

Method and Materials

Four schools, 1 rural, 2 suburban, and 1 urban, with a total of 357 5th and 6th grade students participated in the study during regular class time. One hundred and forty-three (143) students were dropped due to (a) failing to complete part or all of the learning materials or any tests and (b) having participated in a similar study the previous year. (Note that the relatively high attrition rate was due, at least in part, to running the study during the COVID-19 period.) Of the remaining 214 students, 75 were in the menu-based condition (mean age: 11.6; girls: 39; boys: 35; 1 did not respond), 72 were in the scaffolded condition (mean age: 11.6; girls: 44; boys: 28), and 67 were in the focused condition (mean age: 11.6; girls: 31; boys: 36)

During 45-to-55-minute class periods for up to a full week, students worked on the Internet-based materials at their own pace to complete a decimal pretest, the game intervention according to condition (i.e., They played all of the mini-games, with two problems per mini-game, followed by a prompted self-explanation, according to condition), an immediate posttest, and a questionnaire. One week after the posttest, a delayed posttest was taken during one class period. Each test consisted of 43 items, designed to probe for decimal misconceptions and conceptual understanding, with 52 points possible across these items. We used three isomorphic test forms that were positionally counterbalanced across conditions. The questionnaire included 3 items each from the mastery, meaning, and challenge subscales of the Player Experience Inventory (PXI). We also included 3 items targeting affective engagement and 3 items targeting behavioral/cognitive engagement. Finally, we included 5 items adapted from an enjoyment subscale, the Achievement Emotions Questionnaire.

Results

RQ1. Which form of prompted self-explanation -- menu-based, scaffolded, or focused -- leads to the best learning outcomes in the context of the Decimal Point learning game?

A one-way analysis of variance (ANOVA) showed there were no differences in pretest performance based on condition, $F(2, 211) = 1.90$, $p = .15$, $\eta^2_p = .018$ An ANCOVA revealed a significant effect of condition on delayed posttest when controlling for pretest, $F(3, 210) = 3.08$, $p = .048$, $\eta^2_p = .028$. Pairwise comparisons with Bonferroni corrections indicated that the focused condition performed significantly better than the menu-based condition, $p = .042$. There were no significant differences in performance between the focused and scaffolded conditions, $p = .76$, or between the menu-based and scaffolded conditions, $p = .55$. There was no significant effect at immediate posttest, also when controlling for pretest, $F(3,210) = 2.25$, $p = .11$, $\eta^2_p = .021$. Thus, our hypothesis that focused self-explanations would lead to the best learning outcome was confirmed (at least with respect to the focused versus menu-based comparison).

To better understand the different conditions' effects on students' learning processes, we also analyzed time spent and errors made. An ANOVA indicated a significant condition effect on time, $F(2, 211) = 13.27$, $p < .001$, $\eta^2_p = .11$. Pairwise comparisons with Bonferroni corrections revealed that the menu-based condition took significantly less time than the scaffolded condition, $p < .001$, and the focused condition, $p = .001$, but there was no significant difference in time between the scaffolded and focused conditions, $p = .88$. There was no significant condition effect on the number of errors during gameplay, $F(2, 211) = 0.72$, $p = .49$, $\eta^2_p = .007$.

Table 1. The mean and standard deviation of different learning and game play metrics by condition.

	Menu-based (n = 75)	Scaffolded (n = 72)	Focused (n = 67)
Pretest	26.01 (10.47)	24.63 (10.03)	27.96 (9.69)
Posttest	30.12 (9.58)	30.58 (9.88)	33.69 (9.33)
Delayed posttest	30.55 (10.29)	30.97 (10.23)	34.81 (9.88)
Time (minutes)	62.65 (24.68)	83.76 (27.56)	79.12 (26.09)
Errors	75.07 (50.52)	73.22 (46.94)	65.63 (49.67)

RQ2. Which form of prompted self-explanation -- menu-based, scaffolded, or focused -- leads to the least enjoyment in the context of the Decimal Point learning game?

We applied a series of ANOVAs to assess the impact of condition on each of the factors analyzed in the questionnaire: player mastery, player meaning, player challenge, affective engagement, behavioral/cognitive engagement, and enjoyment. There was a significant effect of condition on player mastery, $F(2, 211) = 4.15$, $p = .017$, $\eta^2_p = .038$. Pairwise comparisons with Bonferroni corrections revealed that the focused condition led to significantly greater feelings of mastery than the menu-based condition, $p = .014$. There were no significant differences in mastery between students in the focused condition and the scaffolded condition, $p = .19$, or between students in the scaffolded and menu-based conditions, $p = .96$. There was no significant effect of condition on any other questionnaire measure, $p = .16$, indicating that students' reported experiences of engagement, enjoyment, meaning, and challenge did not differ based on self-explanation condition.

Discussion and Conclusions

The central finding of this study is that focused self-explanations led to better learning outcomes than menu-based self-explanations in the context of a digital learning game. Although this is consistent with prior research comparing focused and menu-based prompts in interactive learning environments, it contrasts with the findings of Johnson and Mayer (2010), in which students playing a learning game attained a better learning outcome using menu-based prompts than students using open-ended self-explanations. An important difference between our study and the Johnson and Mayer study is that they used an open-ended prompt ("Provide an explanation for your answer in the space below"), while we used *focused* prompts that were specific to the values and misconceptions addressed by each problem. While Johnson and Mayer argue that less constrained prompts may be more disruptive to game flow than more constrained prompts, Wylie and Chi (2014) suggest that more constrained, constructive prompts can be beneficial in digital learning environments, including games, provided they are sufficiently focused. Our results appear to support the latter view.

The superior learning benefit of focused self-explanation was on a one-week delayed posttest, suggesting deeper, more conceptual learning. This further suggests that focused self-explanations may be especially beneficial for retention and deeper knowledge, consistent with the ICAP theory (Chi & Wylie, 2014) claim that this type of knowledge is better supported by constructive processes than active processes.

We also found that the learning benefit of focused explanations did not come at the expense of enjoyment. In particular, there were no differences in enjoyment across the three conditions. Thus, the benefits of enjoyment often claimed for digital learning games do not appear to have been undercut with less constrained self-explanations. Even though extra cognitive resources were likely expended by the students in the focused self-explanation condition, they enjoyed playing *Decimal Point* as much as the students in the other conditions and even expressed a greater sense of player mastery.

Determining the best way to infuse instruction into digital learning games, while maintaining the flow and enjoyment that is central to learning games, is an important research direction. While prior research indicated that menu-based self-explanations in games were superior to open-ended self-explanations in a game-based learning context, this study found that focused self-explanations led to a better learning outcome than menu-based self-explanations, suggesting that focused, constructive prompts can be effective in learning games.

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