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Adding self-explanation prompts to an educational computer game

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ABSTRACT

Proponents envision a role for computer games in improving student learning of academic material, including mathematics and science. Asking learners to engage in self-explanations during learning has been found to be an effective instructional method. In the present experiment, we examined the effects of adding a self-explanation prompt—asking players to answer one of three questions after completing each level of the game—within a children's math game on addition of fractions. Middle-school participants played either a base version of the game ($n = 57$) or the base version with a self-explanation instructional feature ($n = 57$). Participants' learning was measured by a fractions posttest and their learning processes measured via in-game measures of game progress and errors. When we separated the self-explanation condition into participants who used a focused self-explanation strategy versus those who did not, the focused participants had significantly fewer game level deaths, game level resets, and progressed significantly farther in the game, compared to the control group, than participants not using a focused self-explanation strategy. The major new contribution of this study is that self-explanation can help the process of playing educational games in some situations and hurt in others. In particular, the most effective self-explanation prompts were aimed at helping learners make connections between game terminology and mathematics terminology, whereas the least effective self-explanation prompts asked very simple or very abstract questions.

1. Introduction

Proponents envision a role for computer games in improving student learning of academic material, including mathematics and science (Honey & Hilton, 2011; Linn & Eylon, 2011). However, rigorous research is needed to determine how best to balance game features – which are intended to foster learner motivation to play the game – and instructional features – which are intended to foster learning of the instructional objectives (O'Neil & Perez, 2008; Tobias & Fletcher, 2011; Young et al., 2012). For example, Perez (2008, p. 287–288) summarizes the evidence base on educational gaming by noting that "there is a lack of empirical studies on the impact of games on learning and performance" and "current research has little empirical guidance for the developers of educational games."

In response to the call for an evidence-based approach to educational game design, Mayer (2011a) has proposed the *value added* genre of game design research, in which researchers compare learning and performance on a base version of a game versus the base version with an instructional feature added. Asking learners to engage in self-explanations during learning—e.g., generating explanations for inconsistencies in the instructional materials—is a good candidate for a value added feature because it has been found to be an effective instructional method in some reading and problem-solving tasks (Fonseca & Chi, 2011) and in some multimedia learning tasks (Roy & Chi, 2005). Self-explanation is recognized as one of the top 25 learning principles to guide instruction by an Association for Psychological Science task force (Halpern, Graesser, & Hakel, 2007), one of seven recommendations for improving instruction in an Institute of Education Sciences practice guide (Pashler et al., 2007), and one of eight evidence-based principles for effective studying in a review of techniques for applying the science of learning (Mayer, 2011b).

In applying the self-explanation technique to educational games, students can be asked to play an educational computer game on electrical circuits that either does or does not include self-explanation prompts – i.e., requests to type an explanation or to select a reason from a list for each move they make in the

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game (Johnson & Mayer, 2010; Mayer & Johnson, 2010). Using a value-added approach, (Johnson & Mayer 2010; Mayer & Johnson, 2010) found that asking college students to select a reason for their move from a list improved transfer test performance ($d = 0.71$, Johnson & Mayer, 2010; $d = 0.91$, Mayer & Johnson, 2010) but asking students to type an explanation did not improve transfer test performance ($d = -0.06$, Johnson & Mayer, 2010). Thus, the effects of self-explanation appear to depend on the details of how it is implemented in a game – with the highly intrusive method of asking students to type an explanation being completely ineffective and a less intrusive method of asking students to click on a reason from a menu being highly effective.

A major criticism of the foregoing experiments is that the learning environment – playing a 10-level game involving electrical circuits – may not have been sufficiently game-like in terms of visual appeal, story line, and overall game mechanics. In the present experiment, we extended this line of research by examining the effects of adding a different implementation of self-explanation – answering one of three questions after completing each level of the game – within a different kind of game – a children's math game on addition of fractions that was rich in visual appeal, story line, and game mechanics.

Learning how to add and subtract fractions is a fundamental part of the mathematics curriculum, but research shows that students have serious conceptual difficulties in working with fractions (Kilpatrick, Swafford, & Findell, 2001; Ma, 1999; Rittle-Johnson & Koedinger, 2005). For example, Ma (1999) found that not only do U.S. students harbor serious misconceptions about fraction arithmetic, but teachers also make serious mistakes in solving fraction problems. Computer-based learning environments for mathematics learning have been successful in improving mathematics achievement mainly when the lessons are focused on specific learning objectives based on an analysis of the underlying cognitive processes (Ritter, Anderson, Koedinger, & Corbett, 2007). In particular, a recent meta-analysis found that the use of concrete manipulatives can be an effective approach to helping students understand mathematical concepts and procedures as compared to learning only with mathematical symbols (Carbonneau, Marley, & Selig, 2013).

The present study builds on this work by creating a computer-based simulation that turns the mathematical symbols of fraction arithmetic into concrete objects that the student manipulates, along with self-explanation prompts to encourage reflection. The self-explanation prompts may tap different kinds of cognitive processing during learning (Mayer, 2009):

extraneous processing – The prompts could slow learners down and distract them from learning, which would be reflected in lower scores on learning process and learning outcome measures.

essential processing – The prompts could direct learners' attention towards relevant portions of the game that they might otherwise ignore (such as the fractions represented by the coils), which would be reflected in higher scores on learning process measures.

generative processing – The prompts could encourage learners to reflect on their game moves, resulting in deeper learning as reflected in higher scores on learning outcome measures.

minimal processing – Learners might pay minimal attention to the prompts so that they can continue game play as rapidly as possible, which would be reflected in no effect on learning process and learning outcome scores.

The present study investigates how to design self-explanation prompts that foster generative processing without creating excessive extraneous processing.

2. Method

2.1. Design and sample

A 2-group posttest-only design contrasted: (a) participants who received self-explanation questions at the end of each game level and (b) a control condition where participants did not receive self-explanation questions.

One hundred and fourteen participants were randomly assigned to conditions resulting in 57 participants in the self-explanation condition and 57 participants in the control condition. Participants were drawn from pre-algebra 6th grade classes from an urban middle school located in Los Angeles County. There were 50 males and 57 females. Thirty-one percent of the students were Latino/a, 22% White, 21% biracial, 12% African American, 9% Asian or Pacific Islander, 2% Native American, and 4% reporting other.

A check for pre-existing differences between the control and experimental conditions on self-reported sex, ethnicity, game experience, and perceived game skill showed no significant differences. However, a marginal ($p = .054$) difference was found for self-reported math grades on students' last report card, with the control condition reporting higher grades ($M = 3.6$, $SD = 0.84$) than the experimental condition ($M = 3.2$, $SD = 1.07$).

2.2. Game versions

Two versions of the game were developed for this study. One version of the game, the base version, was adopted from previous studies (Chung et al., 2010). The second version was the base version modified to provide self-explanation questions at the end of each game level. There were no other differences between the games.

Fig. 1 shows a screen shot of the game *Save Patch*. *Save Patch* is a puzzle-game that requires players to determine the distance from the first T-block to the goal position (X-block). Players help the character, *Patch*, bounce to the goal position by placing trampolines on the T-blocks and then energizing the trampolines by adding coils (unit or fractional coils) to the trampoline. The value on the trampoline reflects the distance *Patch* will bounce. Fraction concepts are represented in the game by the use of units (red bars), fractional pieces (green dots), and addition of fractions (adding

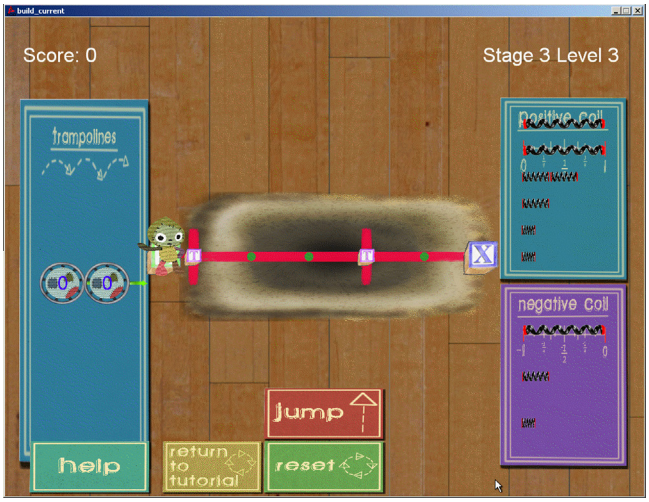

Fig. 1. Screen shot of *Save Patch*. Units are denoted by vertical red bars and fractional pieces by green dots or T-blocks or X-blocks. In this level, the fractional piece size is 1/3. The jump sequence for this level is 3/3 (first T-block to second T-block) followed by 2/3 (second T-block to X-block). The total distance is 3/3 + 2/3, which is 5/3.