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Paper-Based Aids for Learning With a Computer-Based Game

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The purpose of this study was to test the instructional value of adding paper-based metacognitive prompting features to a gamelike environment for learning about electrical circuits, called the Circuit Game. In Experiment 1, students who were prompted during Levels 1 through 9 to direct their attention to the most relevant features of the game and were provided with a list of its underlying principles to relate to their game actions performed better on an embedded transfer test (i.e., Level 10) than those not provided with the intervention ($d = 0.77$). In Experiment 2, the principles were not explicitly provided; instead, students were asked to fill in the correct features of each principle on a sheet while playing Levels 1 through 9 of the game. Results indicated that this method of prompting improved transfer performance only for learners who could correctly fill in the list of the game's principles ($d = 0.53$). Overall, paper-based aids for directing students' attention toward the most relevant features of a game and asking them to apply provided principles to solve game-based problems result in a deeper understanding of the game's academic content.

Keywords: educational games, metacognition, multimedia learning

Much has been written about the educational potential of learning with computer games (O'Neil & Perez, 2008; Tennyson & Jorczak, 2008; Tobias & Fletcher, 2011), but there is a continuing need for research that pinpoints the instructional features of games that promote learning (Clark, Yates, Early, & Moulton, 2011; Mayer, 2011). When people play educational computer games, they are engaged in processing sensory input (in the form of on-screen graphics and sounds), and they are engaged in motor output (in the form of behavioral activity, such as moving and clicking a mouse or controller). However, this heavy focus on sensorimotor activity during game playing may require so much cognitive capacity that little capacity is left to support players' reflecting on their learning experience, thereby reducing the chances for deep learning as measured by subsequent transfer test performance (White & Frederiksen, 1998). The goal of the present study is to examine the effectiveness of simple paper-based adjuncts that are intended to promote reflection during game playing and thereby lead to deeper learning.

What features can be added to an educational game to help guide students' attention toward the information most relevant for learning? Games are often credited with the inherent ability to engage and entertain students (O'Neil & Perez, 2008; Tobias & Fletcher, 2011); however, these motivating features by themselves do not necessarily result in improved learning. In fact, the same features meant to entertain students also have the potential to distract learners from the academic content associated with the game (Adams, Mayer, MacNamara, Koenig, & Wainess, in press; Mayer & Johnson, 2010). Therefore, it is important for game design to focus on incorporating an appropriate balance of features intended for entertainment and features intended to promote learning (Mayer & Johnson, 2010; Rittenfeld & Weber, 2006).

The goal of the current study is to contribute toward establishing this balance by testing the value of adding metacognitive prompting features to an educational game. In particular, we asked students to learn about electrical circuits (e.g., Parchman, Ellis, Christinaz, & Vogel, 2000) in a computer-based gamelike environment called the Circuit Game (DeLeeuw & Mayer, in press; Johnson & Mayer, 2010; Mayer & Johnson, 2010). Metacognitive prompting features (printed on paper sheets) were added to the base version of the game to encourage students to focus on essential components of electrical circuits and how each of those components impacts the circuit's rate of flow. In other words, students were prompted to relate their game activity to underlying principles associated with the academic content of the game.

The features consisted of a paper-based prelevel worksheet meant to direct students' attention to the most relevant features of the game and a paper-based sheet listing the underlying principles of the game. In two experiments, the game principles sheet prompted students to either apply a list of eight provided principles to solve game-based problems or to fill in the list of eight principles while they played the game. Specifically, the principles sheet consisted of the eight actions in the game that impact the flow rate of an electric circuit (e.g., add a battery in serial). In Experiment 1, some players were provided with the completed list of eight principles that included the corresponding outcome of each action (e.g., the flow rate increases), whereas in Experiment 2, some players were prompted to fill in the list of eight principles by discovering the outcome of each action through solving problems in the game. These added paper-based features were intended to encourage students to reflect on their own learning by relating the

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material from the sheets to the academic content of the game during game play. This research takes what is called a *value-added approach* to game research (Johnson & Mayer, 2010; Mayer, 2011), in which an instructional feature is incorporated within an educational game to investigate whether the added feature improves the player's learning of the academic content.

Rationale for Adding Metacognitive Prompting

Early research by Salomon (1983, 1984) showed that the level of mental effort or mindfulness that learners invest in a particular learning episode depends partly on the medium in which the learning takes place. An implication for the present study is that students involved in playing computer-based educational games may not believe that they need to reflect on their cognitive processing during game play, so metacognitive prompting may be warranted.

Hoffman and Spatariu (2008) defined metacognitive prompting as "an externally generated stimulus that activates reflective cognition or evokes strategy use with the objective of enhancing learning" (p. 878). This definition can account for several instructional methods, including questioning (Kramarski & Gutman, 2006), self-generated inferences (Wittrock, 1989), cueing (Veenman, Kerseboom, & Imthorn, 2000), self-monitoring (Kauffman, 2004), and self-reflection or self-explanation (Lin & Lehman, 1999; Roy & Chi, 2005). In short, these methods are all intended to prompt students to reflect on their understanding of the material or their selection and use of problem-solving strategies.

There is considerable evidence in support of metacognitive prompting across several educational domains, including writing (Scardamalia, Bereiter, & Steinbach, 1984), math (Hoffman & Spatariu, 2008; Kramarski & Gutman, 2006; Kramarski & Zeichner, 2001; Mevarech & Kramarski, 1997), and science (Davis, 2003; Mayer & Johnson, 2010). For instance, Hoffman and Spatariu (2008) found that questioning middle school students during complex multiplication problems (e.g., "What strategy can you use to solve these problems?") enhanced problem-solving accuracy and efficiency. In a recent study, Mayer and Johnson (2010) found that prompting students to select self-explanations for their responses while playing the Circuit Game resulted in greater transfer performance.

Overall, research supports metacognitive prompting "as a catalyst to evoke the use of self-regulation strategies" (Hoffman & Spatariu, 2008, p. 879). The current study incorporated metacognitive prompting by signaling students to attend to the most relevant features of the game, including the specific components of electrical circuits and the principles that determine how each component impacts the circuit's rate of flow. Specifically, the paper-based aids were intended to encourage students to reflect on their own learning experience in order to select appropriate problem-solving strategies. First, the prelevel worksheets prompted students to answer questions that directed their attention to the most relevant features of the game. This activity was meant to promote reflection on which features of the electrical circuits are most important for solving problems in the game. In other words, prompts were intended to help students relate the academic content associated with the game to their game play activity.

The goal of the game principles sheet was to help students select an appropriate strategy for solving problems in the game. Specifically, the rationale for this method of prompting is that it allows students to devote cognitive resources to applying the principles underlying how electrical circuits work to the problems they encounter in the game. Further, this prompting method was provided in one of two forms: Either students were explicitly given the list of principles or they had to fill in slots in a list as they played the game. In other words, the prompting either encouraged students to apply the provided principles toward solving problems in the game or required students to play the game to discover each of its underlying principles. In both cases, students were prompted to consider the information contained in the prompts related to the rules underlying problem solving in the game.

Rationale for Creating the Circuit Game

The Circuit Game was created for research purposes as a test bed to investigate the impact of incorporating different instructional methods within the game. It consists of 10 levels in which the player is given a problem situation involving electrical circuits and must click on a choice, drag-and-drop a component into an existing circuit to accomplish some goal, or type a number into a box. Levels 1 through 9 are focused on improving the player's knowledge of how the arrangement of batteries and resistors in a circuit affects a circuit's rate of flow. Level 10 is an embedded transfer test that requires players to apply their knowledge of electrical circuits to new situations.

The Circuit Game is not intended to match the entertainment value of commercially available games but is meant to include the essential components associated with game-based environments. Although definitions of games vary (O'Neil & Perez, 2008; Raessens & Goldstein, 2005; Vogel et al., 2006; Vorderer & Bryant, 2006), the literature generally supports that games should be rule based (i.e., games present a rule-based environment that players come to understand), responsive (i.e., games allow players to perform actions and experience what happens in response), challenging (i.e., games allow players to compete with each other or with themselves in situations that increase in difficulty over the course of the game), and cumulative (i.e., games ensure that player's previous actions are reflected in the current state of the game, such as in the scoreboard and the level of the game). The Circuit Game was created to include each of these features and also to contain the academic content necessary to create a game-based learning environment.

Rationale for the Value-Added Approach

Games research typically follows one of three main approaches (Mayer, 2011): cognitive consequences, media comparison, or value added. The cognitive consequences approach is concerned with testing the impact of playing an off-the-shelf game on a particular cognitive skill. For example, playing games has been associated with improved spatial cognition (e.g., De Lisi & Wolford, 2002; Sims & Mayer, 1992). A problem with this approach is that it is unclear which specific features of the game lead to the cognitive improvement, thereby limiting the ability of researchers to provide specific recommendations for game design. The media comparison approach involves comparing the effectiveness of learning with a game versus learning with conventional media, such as a narrated PowerPoint lesson (e.g., Moreno, Mayer, Spires, & Lester, 2001; Spires & Turner, 2008). This approach may be problematic because it is unclear why one media is more or less effective than another and because research suggests that it is the instructional methods that cause learning, not the media (Clark, 2001).

The current study takes a value-added approach to games research, which involves testing the impact of incorporating an instructional feature within an educational game to investigate whether the feature improves learning. The rationale for the value-added approach is that it allows researchers to identify which specific instructional features can be added to a game to enhance learning. Recent games research taking the value-added approach has begun to develop a collection of effective instructional features (Mayer, 2011). For example, this research indicates that games should incorporate the use of a polite and conversational speaking style (Moreno & Mayer, 2004; Wang et al., 2008), should use spoken words rather than text (Moreno & Mayer, 2002; Moreno et al., 2001), and should provide illustrations of concepts (Mayer, Mautone, & Prothero, 2002). Further, adding features such as worked examples (Shen & O'Neil, 2008), visual maps (Wainess & O'Neil, 2006), explanatory feedback (Moreno & Mayer, 2005), and self-explanation prompts (Johnson & Mayer, 2010; Mayer & Johnson, 2010) also leads to improved learning. Overall, there is a growing research base that is beginning to identify research-based instructional features for educational game design.

Theory and Predictions

According to the cognitive theory of multimedia learning (Mayer, 2005, 2009) and cognitive load theory (Sweller, 1999, 2005) from which it is partially derived, learners have a very limited processing capacity that they must use to engage in cognitive processing necessary for learning. One of the challenges associated with the design of educational games is that the features intended to motivate students may result in extraneous processing (i.e., processing that is irrelevant to learning). Therefore, the goal of game design should be to guide learners from extraneous processing toward engaging in more essential processing (i.e., basic cognitive processing for mentally representing the essential material in memory) and generative processing (i.e., deeper cognitive processing for making sense of the represented material).

The purpose of metacognitive prompting is to encourage students to reflect on their own learning and, therefore, to devote more cognitive resources toward developing their understanding of the academic content associated with the game (i.e., engage in generative processing rather than extraneous processing). The prompting methods used in this study were meant to activate these reflective processes by helping students select the most relevant material (i.e., through answering prelevel questions) and choose appropriate strategies for solving game-based problems (i.e., through using the list of game principles). In short, the goal of the prompting is to encourage students to engage in sense making by building connections between the abstract principles and their activity in the game. Thus, we were interested in testing the extent to which metacognitive guidance is necessary for engaging students in these processes.

Metacognitive prompting that explicitly provides students with the underlying principles governing correct responses in the game may help activate reflection. However, requiring students to fill in the correct outcomes of each principle on the worksheet while playing the game may be too cognitively demanding for novice learners, because asking novice learners to discover the solutions to problems on their own risks cognitive overload (Kirschner, Sweller, & Clark, 2006). On the basis of this analysis, it is expected that explicitly providing the underlying principles of the game for students to apply during regular game play will result in improved performance on an embedded transfer test, during which the principles are no longer provided. Further, requiring students to fill in the principles during regular game play will be beneficial only to those who are able to successfully generate correct principles on their own during learning.

A secondary question of interest was whether the prompting methods would impact the amount of effort students invested into playing the game, their perceived understanding of the material, and their level of satisfaction with the game. It is expected that participants receiving effective forms of prompting would report investing more effort into the game, a better understanding of the material, and higher levels of satisfaction with the game. The rationale is that if the prompting is effective it will allow students to devote more cognitive resources toward developing an understanding of the material, which will in turn create a more positive learning experience.

Experiment 1

The purpose of Experiment 1 was to determine whether adding a paper-based metacognitive prompting aid to supplement the Circuit Game would improve performance on an embedded transfer test. The metacognitive prompting aid involved (a) providing a worksheet for each game task that directed learners' attention toward the relevant features of the graphics on the screen and (b) providing a sheet with a list of the game's underlying principles to help guide learners' thinking about their actions during problem solving in the game.

Method

Participants and design. The participants were 50 college students recruited from the Psychology Subject Pool at the University of California, Santa Barbara, who participated to fulfill a course requirement. Twenty-four students served as the prompt group, and 26 students served as the control group. The mean age of participants was 18.44 years ($SD = 0.91$), and there were 17 men and 33 women. The groups did not differ significantly in terms of mean age or proportion of men and women. The participants' prior knowledge of electronics, as reported on a questionnaire with a possible score of 15, was low overall and did not differ significantly between the prompt group ($M = 4.83$, $SD = 1.95$) and the control group ($M = 4.23$, $SD = 2.23$).

Materials and apparatus. The paper-based materials consisted of a consent form, a demographics form, a reference sheet, nine prelevel worksheets, a game principles sheet, and a postexperiment questionnaire. The consent form described the details of the study, informed participants that their privacy was protected, and included a place for them to sign. The demographics form asked participants to provide their age, gender, major, and SAT scores. Prior knowledge was also assessed by asking participants to rate their knowledge of basic electronics and electricity on a scale from 1 (*very low*) to 5 (*very high*) and to place a check mark next to each of the following items that applied to them: "I have taken a course in physics," "I have replaced a fuse in my home or car," "I have worked on a circuit board," "I own a wire cutter," "I own an amp meter," "I know the difference between serial and parallel circuits," "I know whether an electron is positive or negative," "I know the formula for Ohm's Law," " I know what an amp is," and "I have installed a new light switch or electrical outlet." The reference sheet explained how to interpret circuit diagrams by showing simple circuit diagrams that signaled its key components (i.e., wires, batteries, and resistors) and arrangements (i.e., parallel or serial placement of batteries or resistors).

The nine prelevel worksheets (corresponding to Levels 1 though 9) each consisted of four multiple-choice questions that asked participants to identify how many batteries or resistors were present and how they were arranged for each electrical circuit they encountered in the game. For example, in Level 1, the game worksheet presented two circuits (i.e., Circuit A and Circuit B) and asked, "How many batteries are in Circuit A?" "How many resistors are in Circuit A?" "How many batteries are in Circuit B?" and "How many resistors are in Circuit B?" Each of the four questions was followed by three possible answer choices: "1," "2 in series," or "2 in parallel." The game worksheets were intended to direct learners' attention toward the most relevant features of each problem-solving activity before playing each level in the game.

The game principles sheet contained the eight possible actions that could be taken to manipulate the electrical circuits presented in the game and whether the actions increase, decrease, or do not change a circuit's rate of flow. Table 1 presents each of the eight principles. Learners were asked to relate each problem-solving activity they performed during the game to one or more of the principles.

The postexperiment questionnaire asked participants to report how much they agreed with each of six statements on a 7-point scale ranging from 1 (*strongly disagree*) to 7 (*strongly agree*): "I felt that the subject matter was difficult," "I enjoyed learning about how circuits work this way," "I would like to learn this way in the future," "I feel like I have a good understanding of how electric circuits work," "After this lesson, I would be interested in learning more about circuits," and "I found the lesson about circuits to be useful to me." It also asked participants to rate the amount of mental effort they put into the game on a scale ranging from 1 (*very low effort*) to 7 (*very high effort*). Finally, the postexperiment questionnaire asked participants to write any additional comments they had about the study.

The computer-based materials consisted of a basic version of the Circuit Game (Johnson & Mayer, 2010; Mayer & Johnson, 2010). The game consisted of 10 levels, with each level containing a series of predetermined circuit problems. Players had to click on a choice between two circuits, drag and drop a component into an electrical circuit to change its rate of flow, or type in a numerical answer to report a circuit's flow rate. Figure 1 provides a screen shot of a problem in Level 1 of the game in which the player must determine which of two circuits has a higher rate of flow. If a player provided a correct response, the game made a positive sound ("ding") and added 50 points to a scoreboard at the top of the screen; if the player provided an incorrect response, the game made a negative sound ("buzzer") and subtracted 10 points from the scoreboard at the top of the screen. A scoreboard showed the total number of points the player earned and the elapsed time. At the end of each level, the screen presented the points earned on the just-completed level, the total points possible for the just-completed level, and the cumulative number of points earned so far in the game.

Table 1
Game Principles Sheet for Experiment 1

No.	Principle
1	If you add a battery in serial, the flow rate increases.
2	If you add a battery in parallel, the flow rate does not change.
3	If you add a resistor in serial, the flow rate decreases.
4	If you add a resistor in parallel, the flow rate increases.
5	If you take away a battery in serial, the flow rate decreases.
6	If you take away a battery in parallel, the flow rate does not change.
7	If you take away a resistor in serial, the flow rate increases.
8	If you take away a resistor in parallel, the flow rate decreases.

Table 2 provides a description of the 10 levels of the game. In Levels 1 through 9, the problems involved the player making judgments about the circuits' rate of flow of the current. Level 10 consisted of 25 problems that constituted an embedded transfer test because it required applying what was learned about how circuits work to new kinds of problems. Specifically, Level 10 involved comparing the brightness of bulbs and choosing which bulb was brighter on the basis of the components of the circuits. No mention was made during the game about how flow related to bulb brightness. An example of a problem from Level 10 is shown in Figure 2.

The apparatus consisted of five iMac computers with 17-in. screens and five Cyber Acoustics headphones.

Procedure. Participants were randomly assigned to a treatment group. There were up to four participants in each session, with each participant seated in an individual cubicle facing a computer screen. First, the experimenter provided a brief verbal introduction to the experiment, passed out the consent forms for participants to sign, answered any questions, and collected the signed consent forms. Second, the experimenter handed out the demographics questionnaires and collected them when the participants were finished. Third, the experimenter explained how to play the Circuit Game and handed out the reference sheet showing the symbols used to represent the components of a circuit. Participants could refer to the reference sheet during the game. Participants randomly assigned to the control group were then able to begin playing the game. Participants randomly assigned to the prompt group were handed the game principles sheet and told to refer to it while playing the game. They were then given the prelevel worksheet for Level 1 and asked to complete it before they began playing Level 1. They were also instructed to raise their hand after finishing each level so that they could be given the respective worksheet for that level. After completing the instructions, participants in the prompt group began playing the game. After completing Level 9, the game principles sheet was collected and no prelevel worksheet was given before Level 10. All participants were asked to raise their hand after finishing Level 10 (i.e., the embedded transfer test). After completion of the game, participants were asked to answer the postexperiment questionnaire. Finally, they were debriefed and thanked for their participation. The total duration of the experiment was approximately 30 min.

Results

The main focus of the experiment is on whether adding paper-based aids improved student learning outcomes as measured by performance on an embedded transfer test. Table 3 shows the mean

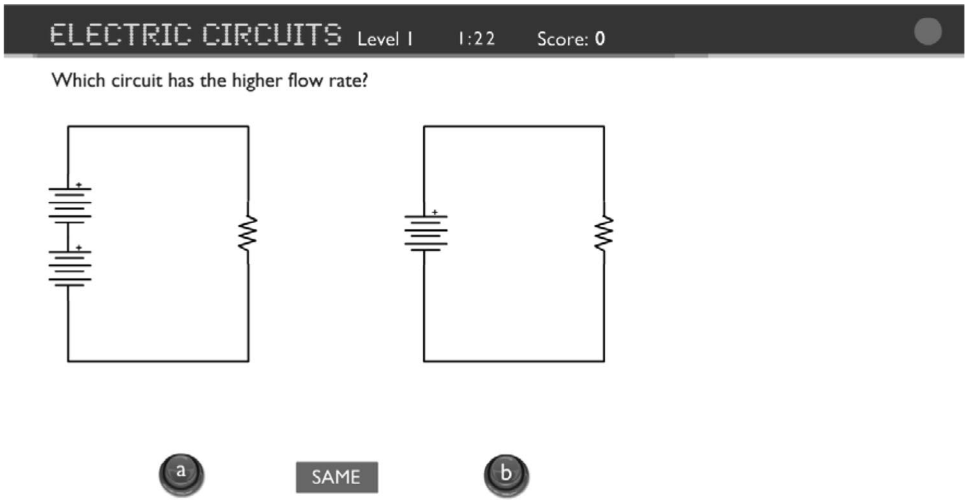

Figure 1. Screen shot of a problem from Level 1.

and standard deviation of each group on the embedded transfer test (i.e., Level 10) out of a total possible score of 25. An independent samples *t* test indicated a significant difference between groups, $t(48) = 2.72$, $p = .01$, $d = 0.77$, with the prompt group outperforming the control group. As predicted, transfer test performance was enhanced by providing paper-based aids aimed at prompting students to engage in deeper processing during game playing.

A secondary question concerns whether the paper-based aids affected students' level of effort, perceived level of difficulty, and satisfaction. First, although there was no significant difference between the prompt group ($M = 5.5$, $SD = 1.1$) and the control group ($M = 5.0$, $SD = 1.1$) regarding self-reported effort during learning, $t(48) = 1.74$, $p = .09$; $d = 0.45$, students in the prompt group ($M = 4.3$, $SD = 1.5$) reported significantly lower perceived difficulty than the control group ($M = 5.7$, $SD = 1.3$), $t(48) = 3.42$, $p < .01$, $d = 1.00$. Second, on each of five questions tapping learner satisfaction, the prompt group reported higher ratings than the control group: enjoyment (prompt: $M = 5.0$, $SD = 1.8$; control: $M = 2.8$, $SD = 1.1$), $t(48) = 5.22$, $p < .01$, $d = 1.52$; preference to learn the same way in the future (prompt: $M = 4.9$, $SD = 1.5$; control: $M = 2.7$, $SD = 1.4$), $t(48) = 5.46$, $p < .01$, $d = 1.52$; understanding of electric circuits (prompt: $M = 4.5$, $SD = 1.4$; control: $M = 2.2$, $SD = 1.1$), $t(48) = 6.78$, $p < .01$, $d = 1.84$; interest in learning more about electric circuits (prompt: $M = 4.1$, $SD = 1.9$; control: $M = 3.0$, $SD = 1.9$), $t(48) = 2.07$, $p < .05$, $d = 0.58$; and usefulness of the lesson (prompt: $M = 5.0$, $SD = 1.5$; control: $M = 3.0$, $SD = 1.7$); $t(48) = 4.22$, $p < .01$, $d = 1.25$. Although these constructs were measured using single-item self-report items and, therefore, are subject to possible reliability concerns, the pattern of data is consistent with the idea that the paper-based prompts made the game easier and more satisfying for students to play. In short, the data suggest that adding effective instructional aids can enhance student satisfaction with an educational game.

Regarding performance on the prelevel worksheets, these data were not analyzed because the worksheets were meant to simply direct learners' attention to the relevant features of the game, rather

Table 2
Descriptions of the 10 Levels in the Circuit Game

Level	No. of items	Action	Description
1	8	Click	Choose which of two circuits that differ in one feature has a higher rate of flow or whether they are the same.
2	11	Click	Choose which of two circuits that differ in two features has a higher rate of flow or whether they are the same.
3	5	Drag and drop	Given two identical circuits add one of four presented components to make the circuit on the left have a higher rate of flow.
4	10	Drag and drop	Same as Level 3 but must solve in two ways.
5	15	Drag and drop	Same as Level 3 but must solve in three ways.
6	8	Type into box	Given two circuits that differ in one way and the value of rate of flow for one circuit, type in the value for the other circuit.
7	12	Type into box	Same as Level 6 but circuits differ in two ways.
8	5	Click	Given a circuit with a value for its rate of flow, choose one (out of four) circuits that has half (or double) the rate of flow.
9	5	Click	Same as Level 8 but must solve in two ways.
10	25	Click	Given one or two circuits with labeled lightbulbs, choose which bulb is brighter or whether they are the same. This is the embedded transfer test.

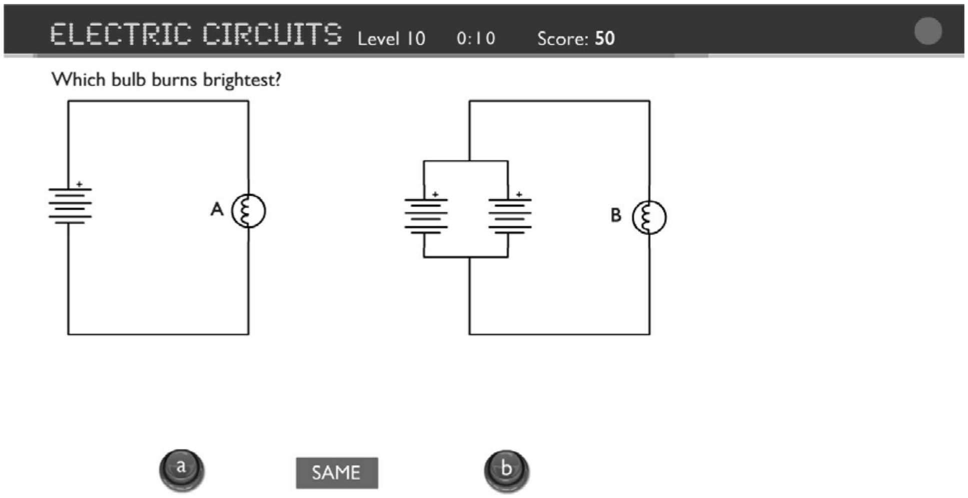

Figure 2. Screen shot of a problem from Level 10.

than to assess their knowledge of electrical circuits. Thus, it was not expected that the groups would differ in performance on the prelevel worksheets. Further, because of technical issues associated with logging the time students spent playing the game, these data could not be analyzed. However, given that participants in all conditions completed the same number of levels and questions within the game, it is not expected that additional time playing the game would influence performance on the embedded transfer test.

Experiment 2

The purpose of Experiment 2 was to test whether asking students to fill in the list of game principles while playing the game (rather than being provided with the list as in Experiment 1) also results in better performance on the embedded transfer test. In particular, we were interested in testing whether it is sufficient to prompt participants to be aware that the game contains underlying principles, without telling them the outcomes of each principle. Thus, the game principles sheet was modified to require students to complete the list of principles by selecting whether each action (e.g., adding a battery in serial) results in an increase, a decrease, or no change in a circuit's rate of flow, on the basis of their game-playing activity (as shown in Table 4). They also completed the same prelevel worksheets as in Experiment 1, which were intended to guide their attention.

Table 3
Transfer Performance of Two Groups in Experiment 1

Group	Transfer score *M*	Transfer score *SD*	Effect size (*d*)
Control ($n = 26$)	13.7	3.0	
Prompt ($n = 24$)	16.0*	2.8	0.77

Note. Total possible score is 25.
* Significantly different at $p < .01$.

Method

Participants and design. The participants in Experiment 2 were 114 college students recruited from the Psychology Subject Pool at the University of California, Santa Barbara, who participated to fulfill a course requirement. Fifty-seven students served in the prompt group, and 57 students served in the control group. The mean age of the participants was 18.50 years ($SD = 1.43$), and there were 35 men and 79 women. The groups did not differ significantly in terms of mean age or proportion of men and women. The prior knowledge of participants was low overall, as reported on a questionnaire with a total possible score of fifteen, and did not differ significantly between the prompt group ($M = 4.56$, $SD = 2.49$) and the control group ($M = 4.40$; $SD = 1.99$).

Materials and apparatus. The materials and apparatus were identical to those of Experiment 1, except that the game principles sheet (given to the prompt group) did not explicitly tell participants the outcome of each principle. Instead, the outcomes of each of the

Table 4
Game Principles Sheet for Experiment 2

No.	Principle
1	If you add a battery in serial, the flow rate (circle one): increases, decreases, or does not change.
2	If you add a battery in parallel, the flow rate (circle one): increases, decreases, or does not change.
3	If you add a resistor in serial, the flow rate (circle one): increases, decreases, or does not change.
4	If you add a resistor in parallel, the flow rate (circle one): increases, decreases, or does not change.
5	If you take away a battery in serial, the flow rate (circle one): increases, decreases, or does not change.
6	If you take away a battery in parallel, the flow rate (circle one): increases, decreases, or does not change.
7	If you take away a resistor in serial, the flow rate (circle one): increases, decreases, or does not change.
8	If you take away a resistor in parallel, the flow rate (circle one): increases, decreases, or does not change.

eight principles were replaced with blanks, and participants were asked to choose whether each one increased, decreased, or did not change the flow rate of a circuit as they played the game. The game principles sheet for Experiment 2 is shown in Table 4.

Procedure. The procedure was identical to that of Experiment 1, except that participants in the prompt group were asked to fill in the blanks on the list of game principles sheet as they completed Levels 1 through 9. They were told to have the sheet completed by the end of Level 9, when the experimenter then collected it. All participants completed the sheet, although it was not possible to determine when they entered their answers.

Results

The main issue addressed in this study is whether the paper-based aids improved student learning outcomes, as measured by performance on the embedded transfer test in Level 10 of the game. An independent samples t test revealed no significant difference between the prompt group ($M = 15.1$, $SD = 4.0$) and the control group ($M = 14.4$, $SD = 3.4$) regarding performance on the embedded transfer test (Level 10), $t(112) = 1.00$, $p = .32$.

To explore the data in more detail, the prompt group was then divided into two subgroups based on the participants' performance on the game principles sheet that they completed during Levels 1 through 9 of the game. Thirty-one participants were classified as having low performance on the game principles sheet (i.e., fewer than six correct responses out of eight), and 26 participants were classified as having high performance on the game principles sheet (i.e., six or more correct responses out of eight). Table 5 shows the mean and standard deviation of each of the three groups on the embedded transfer test (Level 10) out of a total possible score of 25. A one-way analysis of variance (ANOVA) revealed that the groups differed significantly, $F(2, 111) = 3.24$, $p = .04$. Dunnett post hoc tests with $p < .05$ revealed that the high principles group significantly outperformed the control group ($d = 0.53$), whereas the transfer test score of the low principles group was not significantly different from that of the control group ($d = -0.08$). Thus, the principles sheet in Experiment 2 was effective only for students who were able to fill it out correctly based on their game play.

A one-way ANOVA revealed that the subgroups differed significantly regarding prior knowledge, $F(2, 111) = 3.10$, $p = .049$. Dunnett post hoc tests with $p < .05$ revealed that the high game principles subgroup ($M = 5.4$, $SD = 2.7$) had significantly higher prior knowledge than the low game principles subgroup ($M = 3.9$, $SD = 2.1$); however, there was no significant difference in prior knowledge between the high principles group and the control group ($M = 4.4$, $SD = 2.0$). Thus, the superiority of the high principles group on the embedded transfer test cannot be attributed to differences in prior knowledge.

Table 5
Transfer Performance for Three Groups in Experiment 2

Group	Transfer score		Effect size (d)
	M	SD	
Control ($n = 57$)	14.4	3.4	
Low principles ($n = 31$)	14.1	3.7	−0.08
High principles ($n = 26$)	16.4*	4.2	0.53

Note. Total possible score is 25.
* Significantly different from control group at $p < .05$.

The subgroups were also compared with regard to self-reported levels of effort, perceived difficulty, and satisfaction. A one-way ANOVA revealed significant differences across groups regarding perceived understanding of how electric circuits work, $F(2, 111) = 3.91$, $p = .023$. Dunnett post hoc tests with $p < .05$ revealed that the high principles group ($M = 3.7$, $SD = 1.5$) felt that they understood the material significantly more than the control group did ($M = 2.7$, $SD = 1.5$); however, there was no difference in perceived understanding between the high principles group and the low principles group ($M = 2.9$, $SD = 1.5$). No other significant differences across conditions were found regarding the other six questions on the postexperiment questionnaire. Apparently, the work required to fill in the worksheet for the prompt group in Experiment 2 diminished the positive ratings about satisfaction and ease of play as compared with Experiment 1 in which the sheet was already filled in.

Discussion

Empirical contribution. The goal of this study was to determine the instructional value of adding one method of metacognitive prompting to an existing educational game. The findings indicate that using printed sheets to prompt learners to pay attention to the relevant features of the game and its underlying principles improved transfer performance. However, requiring learners to determine the game's principles on their own as they played the game appeared to be effective in improving subsequent transfer test performance mainly for players who were successful on constructing the correct principles, despite still being prompted to pay attention to the relevant features of the game. These findings suggest that transfer performance was affected by understanding how the games principles could be effectively applied within the game. Further, the results indicate that effective instructional aids can increase enjoyment as well as learning. This suggests that that although enjoyment does not necessarily result in improved learning, improved learning may help increase enjoyment. In short, a unique contribution of this study is the use of a very simple form of metacognitive prompt (i.e., contained on a sheet of paper) to improve deep learning within the context of an educational game.

Theoretical contribution. On the theoretical level, the results are consistent with the predictions of the cognitive theory of multimedia learning (Mayer, 2005, 2009), which posits three demands on learner's limited processing capacity—extraneous processing, essential processing, and generative processing. One of the potential pitfalls of educational games is that their entertaining features may distract learners from the academic content of the game, resulting in extraneous processing. Thus, instructional features added to games should guide learners toward more essential and generative processing. The forms of metacognitive prompting provided in the two experiments were intended to help achieve this goal by directing learners' attention to the most relevant features of the game and connecting their game-playing activity to the principles underlying the game's academic content. The findings suggest that using prompts to explicitly encourage these cognitive activities during normal game play (i.e., Levels 1–9) led to greater performance on a transfer task (i.e., Level 10). However, requiring learners to determine the game's principles on their own was relatively ineffective unless they were successful in determining the principles. In short, this study shows how basic work on metacognition can be applied to game design (Azevedo & Aleven, 2010; Hacker, Dunlosky, & Graesser, 2009; Waters & Schneider, 2010).

A reasonable next step in this line of research is to focus on describing the specific cognitive mechanisms underlying how the prompts promote metacognitive processing during learning. For example, the prelevel worksheets were intended to guide the participants' attention toward relevant aspects of the game and thereby reduce extraneous processing. Similarly, the principles sheet was intended to manage essential processing by helping participants manage the complexity of the material. The questionnaire results may provide preliminary evidence at a gross level by indicating that the prompt group reported experiencing less difficulty and more satisfaction than did the control group. Overall, we propose that the prompts enabled deeper reflection during learning (i.e., fostered generative processing) by helping game players focus on how they are allocating their attention and how their game experience is related to the underlying rules of the game, but this proposal needs to be tested with direct measures of cognitive processing during game playing, such as using eye-tracking methodology or thinking aloud methodology.

Practical contribution. On the practical level, the current study provides preliminary support for the benefits of prompting learners to pay attention to the game's relevant features and explicitly providing them with the principles that they can connect with the academic content of the game as they play. In particular, it demonstrates how a modest addition of simple, paper-based materials to an existing educational game can effectively enhance performance on a transfer task. This finding suggests that simple and inexpensive interventions can be effective instructional tools without disrupting the unique motivational and entertainment features of gamelike environments.

Limitations and future directions. One criticism of the current study is that the educational game we used does not match the level of sophistication or the entertainment value of typical commercially available games. The Circuit Game is a very simple puzzle game that contains essential gamelike features and is used as a feasible means to conduct research testing the value of adding instructional features to educational games. Therefore, further investigation is needed to determine the applicability of adding the version of metacognitive prompting used in the current study to other educational games. For example, commercially available games may consist of more extraneous material (e.g., additional graphics or sounds that are irrelevant for learning) than the Circuit Game and, therefore, might interfere more with learning. Thus, it is possible that such games would be more sensitive to adding forms of metacognitive support.

Another consideration for future research is that the length of time spent playing the game also needs to be considered in future studies. It is possible that the use of paper-based aids is more effective during relatively short durations of game play, such as playing the Circuit Game. Longer games may cause students to be less likely to use added support features, particularly when they are optional.

Another potential limitation lies in the instructional feature added to the game. The version of metacognitive prompting referred to in the current study consisted of two components (i.e., providing prelevel prompting and stating the principles of the game). The findings of the current study do not make clear the differential impact of each component. The data suggest that the game principles sheet (as shown in Table 1 for Experiment 1 and Table 4 for Experiment 2) may have had greater influence on subsequent transfer performance than the prelevel worksheets; however, further investigation is needed to fully disentangle and quantify their respective effects. Our study was focused on how metacognitive prompting could be added to an educational game to improve learning. It would be useful to investigate the minimum amount of prompting necessary to offer the same benefits as the version of prompting used in our study. It would also be useful to investigate which specific methods of metacognitive prompting have the most impact.

Finally, another possible issue with this study concerns the degree to which the prompts used in the study should be considered performance aids or metacognitive aids. They are performance aids in the sense that they are intended to scaffold the learning experience in ways that improve test performance, and they are metacognitive aids in the sense that they are intended to increase the game players' awareness of the need to focus attention on the relevant features of the situations presented on the screen and to reflect on the implications of game play for determining the underlying rules of the game. In short, by guiding the game player's cognitive processing during learning in ways that promote deeper reflection, the prompts can both improve performance and foster the development of game-relevant metacognitive strategies. Overall, the present study serves to show the importance of extending the study of metacognitive processes—such as reflecting on the rules underlying game play—to the relatively new domain of learning with educational games.

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