The Role of Surprising Events in a Math-Game on Proportional Reasoning

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Abstract: Reviews regarding serious games show that the effect on learning can be qualified as moderately positive. Despite the active involvement of players it seems that they sometimes refrain from relevant cognitive processes during game play. This study addresses a technique involving the generation of manageable cognitive conflicts to stimulate these cognitive processes. Surprise comprises events that undermine an expectation which trigger players to evaluate the new situation more extensively. Participants (N = 94) played a game in which they practiced proportional reasoning skills. The pretest-posttest design involved two factors: *Surprise* (surprise vs. no surprise) and *Expectancy* (strong vs. weak). Surprise was implemented as an appearing game character that modified some parameters of a problem while the player was solving that problem. We expected that this would prompt players to evaluate their solution strategy and decide whether another strategy was more appropriate. Expectancy pertains to the type of problems that players expect. In the strong expectancy version players received a series of problems with the same structure as before. In the weak expectancy version problems with different structures are randomly presented to the players and each problem may involve a different solution strategy. We hypothesized an interaction between Surprise and Expectancy, next to a main effect of Surprise. The results show that participants learned from the game. We also did find a weak positive effect of Surprise, but no effect of Expectancy nor interaction effect on learning. The facilitating effect of Surprise was stronger when existing proportional reasoning skill was included as factor. These results indicate that surprise as implemented in the game has effect on learning regardless whether expectancy was weak or strong. We discuss some suggestions for finding stronger effects of surprise such as the fact that the repetitive nature may have weakened the ‘surprisingness’ of the surprises and the observation that our sample may not have possessed a sufficient level of metacognitive skills to interpret the changes caused by the surprises.

Keywords: serious games, mathematics, surprise, learning, motivation

1. Introduction

Despite the increasing popularity of serious games or game-based learning (GBL), recent meta-analytic reviews have shown that GBL is only moderately more effective and not more motivating than traditional instruction (Wouters et al., 2013, Clark, Tanner-Smith & Killingsworth, 2015). For example, in their meta-analysis Wouters et al. found only a moderate effect size (d = .29) for learning in favor of GBL. Likewise, they found a moderate, but statistically non-significant, effect for motivation in favor of GBL. GBL influences learning in two ways, by changing the cognitive processes and by affecting the motivation (Wouters et al., 2013). Preferably both mechanisms should be applied in order to maximize learning. A potential problem with GBL is that the outcomes of players’ actions in the game are directly reflected in the game world. This may lead to a kind of intuitive learning: players know how to apply knowledge, but they cannot explicate it. In other words: they don't necessarily acquire the underlying rules (Leemkuil & de Jong, 2011). It is possible that studies therefore find no relation between success in the game and success on a knowledge test. The articulation of knowledge is important, because it triggers learners to *organize* new information and *integrate* it with their prior knowledge (Mayer, 2011, Wouters, Paas & van Merriënboer, 2008) and thus construct a mental model that is more broadly applicable. This implies that genuine learning in GBL requires additional features in the game that will provoke the player to engage in the process of knowledge articulation. Typically in learning environments such knowledge articulation is often prompted by explicitly asking learners to reflect on their actions and thoughts. In GBL, however, such an intervention may compromise the motivating or engaging quality of the game because it is likely that it will disturb the flow of the game, and consequently undermine the entertaining nature of the game and reduce motivation and learning as well.

The question raised in this paper is how we can stimulate players to engage in relevant cognitive processes (organizing and integrating knowledge) that foster learning without jeopardizing the motivational appeal of the game. A promising technique is the generation of manageable cognitive conflicts by introducing surprise. Surprise involves an emotional reaction, but it also serves a cognitive goal as it directs attention to explain why the surprising event occurred, and to learn for the future (Foster & Keane, 2015; Howard-Jones & Demetriou, 2009; Ranganath & Rainer, 2003). On the domain of narratives and text comprehension it has been shown that surprise has a beneficial effect on learning. Hoeken and van Vliet (2000) found that surprise improved text comprehension and appreciation more than other techniques such as events that aroused curiosity and suspense. Likewise, O'Brien and Myers (1985) confronted participants with a word that was either predictable or unpredictable from a preceding context and observed that the texts that preceded unpredictable words were better recalled. In the context of learning a medical procedure with as serious game van der Spek, van Oostendorp and Meyer (2013) demonstrated that surprise yielded superior knowledge structures, indicating that such events foster deep learning.

Readers understand a story because they construct a situation model in which dimensions such as time, space, and causality are related. Likewise, in computer games players construct a mental model and/or situation model based on the story line, the events and the underlying rules of the game (van der Spek, van Oostendorp & Meyer, 2013). The situation or mental model makes new events plausible (although such events may cause adaptations in the model) and is the starting point for expectations of the reader or player. A surprising event on the other hand is unexpected and not logically follows from the situation/mental model. Readers/Players will wonder what they have missed and start to re-evaluate preceding events. In this process the mental model will be activated, retrieved and updated, thereby enhancing learning.

The assumption of this study is that the effect of surprise also pertains to problem solving in serious games. Ideally, the mental model will enable the learner to recognize specific characteristics of a problem and how to solve that problem. When a surprising event changes some of the problem characteristics, the chosen solution is no longer applicable and the player has to re-evaluate the situation and decide which problem characteristics are relevant and which solution is now most appropriate. We expect that surprise has a positive effect on learning because it stimulates relevant cognitive processes such as organizing and integrating information without compromising the motivational appeal of computer games. In addition, we expect that the effect of surprise depends on the strength of the expectation: the stronger the expectation, the stronger the unexpectedness of 'surprisingness' of the surprise and thus the necessity to re-evaluate the situation. Taken together, we hypothesize an interaction effect of surprise and expectancy, next to a main effect of surprise.

In this study we investigate the impact of surprise on learning and how this impact is moderated by the expectancy of the learner. We used the GBL environment 'Zeldenrust' that was specifically developed for learning proportional reasoning in secondary prevocational education (see VanderCruysse et al., 2014). Proportional reasoning was chosen because it is a relevant and well-defined domain and existing methods for proportional reasoning are often ineffective (Rick, Bejan, Roche & Weinberger, 2012).

2. Method

2.1 Hypotheses

We tested three hypothesis:

> *Playing the game will improve learning*
>
> *We expect that surprise will increase learning more because it triggers students to interpret the changes in the problem characteristics caused by the surprise and the consequences for the solution process.*
>
> *In addition, we hypothesize that surprise after multiple problems with the same characteristics will have the largest learning effect because the unexpectedness of the surprise will incite students more to think about the changes in the characteristics of the problem characteristics caused by the surprise and the consequences for the solution process.*

2.2 Participants and design

The participants were 94 students from second year prevocational education with a mean age of 13.9 (*SD* = .81) recruited from five classes of one school. They were randomly assigned to conditions. We adopted a pretest-posttest design with the independent variables *Surprise* (Yes or No) and *Expectancy strength* (Strong or Weak) resulting in 4 conditions: Surprise and Strong expectancy (N = 22), Surprise and Weak expectancy (N = 23), No surprise and Strong expectancy (N = 26) and No surprise and Weak Expectancy (N = 23). The dependent variable was proportional reasoning skill.

2.3 Materials

2.3.1 Domain

The domain of proportional reasoning comprises three problem types: comparison problems, missing value problems, and transformation problems (cf., Tourniaire & Pulos, 1985). In comparison problems learners have to find out whether one proportion is “more than”, “lesser-than” or “equal to” another proportion. These problems can be classified in difficulty levels ranging from equal values of proportions (e.g., 2/11 and 3/11), proportions with simple multiplication (e.g., 11/20 and 22/36) or complete calculation. In missing value problems one value in one of two proportions is missing. Learners have to find this “missing value” in order to ensure that both proportions are equal. Transformation problems involve two proportions as well and all values are known, but the proportions are not equal. Learners have to find out how much has to be added to one or more of the proportions in order to make both proportions equal (for a more extensive description see Vandercruysse et al, 2014). Both missing value and transformation problems can be classified in one of four difficulty levels based on the integrity of the ratio within (comparing the same term of two proportions) or between (comparing the different terms of the proportions) two proportions. For example, a problem with 1/2 and 3/6 can be classified as level 1 (easy) because both the ratio within (in this case 1 and 3, or 2 and 6) and the between ratio (in this case 1 and 2, or 3 and 6) are integer.

2.3.2 Game environment

In the 2D game – developed in Flash/ActionScript 3 - players have a summer job in a hotel. By doing different tasks the players can earn money that can be used to select a holiday destination during the game: the more money they earn, the further they can travel. During the game the player is accompanied by the manager, a non-playing character, who provides information about the task and gives feedback regarding the performance on the task. The game comprises a base game and several subgames. The base game provides the structure from which the subgames can be started. After selecting an avatar, the players receive an introduction animation in which the context of the game is presented, and finally enter the “Student room” from which the player can control the game (e.g., for example by choosing a specific subgame). Each task is implemented as a subgame and covers a specific problem type in the domain of proportional reasoning. The tasks are directly related to proportional reasoning (e.g., mixing two drinks to make a cocktail according to a particular ratio directly involves proportional reasoning skills). In addition, mental operations with respect to proportional reasoning are connected with the game mechanics (e.g., in order to get the correct amount of bottles in the refrigerator the player has to drag the correct number of bottles in the refrigerator). Table 1 shows the subgames and the distribution of difficulty levels across the game levels.

Although the subgames cover different problem types, they have several common elements. The actual assignment is described on a *whiteboard*. With drag-and-drop or clicking the player can accomplish the assignment, but the specific action depends on the subgame. To further motivate the player, a *“geldmeter” (money meter)* is implemented which visualizes the amount of money that the player will receive after an assignment. Correct and incorrect actions during an assignment are directly reflected in the money meter. For example, if the player breaks a bottle, the money meter will decrease (and the color becomes redder); if the player places bottles in the refrigerator the money meter will increase (and becomes greener). The money meter also shows the (accumulated) amount of money that the player has earned. The player can use a built-in *calculator*, but using it will cost some money. Depending on the subgame, the player has to perform a typical action (e.g., closing the door of the refrigerator) to receive *verbal feedback* from the manager of the hotel who tells whether the answer is correct or not (e.g., ‘Excellent’ or ‘You have too much Cola in relation to Fanta’). If the answer is correct the money meter will be increased.

Surprise comprised a non-playing niece character in the introduction animation who tells she is bored. When a surprising event occurred, the screen first became bright and then normal again, the niece character popped up and told that she had changed something. This change comprised specific characteristics of the task whereby the solution of the player doesn't apply anymore and the player has to reconsider the original solution. Figure 1 gives an example of the occurrence of a surprise.

Table 1: Overview of level structure per subgame

Subgame	Problem type	Example of problem	Game level: difficulty of proportional problem
Jugs	Comparison	"There are two jugs of juice on the counter. A customer asks for the sweetest juice mix. Which juice mix will you give to the customer?" The ratio of water/fruit is presented on the jugs. The student has to click on the correct jug to answer.	1: contains level 1 problems 2: contains level 2 problems 3: contains level 3 problems 4: contains a mix of all levels
Fridge	Missing value	"This is the reception desk refrigerator. This refrigerator always contains 3 bottles of water for every bottle of juice. It already contains 9 bottles of water. Fill the refrigerator so it will contain the right amount of juice." The given ratio of 3/1 is presented next to the ratio with the missing value 9/?. The student has to answer the question by dragging and dropping the juice bottles into the refrigerator.	1: contains level 1 problems 2: contains level 2 and 3 problems 3: contains level 4 problems 4: contains a mix of all levels
Blender	Transformation	"A fruit cocktail contains 10 berries for every 100 ml of yoghurt. How many berries should you add to 500 ml of yoghurt if you want to maintain the flavor?" The given ratio of 10/100 is presented and the student has to answer the question by dragging and dropping the berries into a blender that contained the 500 ml of yoghurt.	1: contains level 1 problems 2: contains level 2 and 3 problems 3: contains level 4 problems 4: contains a mix of all levels

Figure 1a depicts the starting situation. The solution strategy of the player can be as follows: the number of Fanta in the refrigerator is twice as much as the number of Fanta in the desired proportion (12 Fanta) since 12 * 2 =24, so the number of Cola also has to be doubled (9 * 2 = 18 Ccola). When the player is implementing the solution the surprising event occurs (Figure 1b). When the niece character has disappeared the characteristics of the task are modified (Figure 1c), that is, the desired proportion is now 6 Cola per 12 Fanta. In total the players received 8 surprises (four in both the missing value and the transformation subgames).

Figure 1a: Starting situation in a task with a surprising event

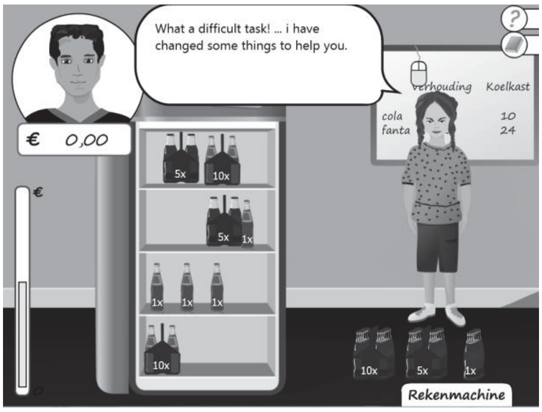

Figure 1b: Occurrence of the surprising event

Figure 1c: Task characteristics have been modified

For the implementation of Expectancy strength, we classified the problems according to their characteristics into three groups

- Problems with an integer intern ratio but not an integer extern ratio
- Problems with an integer extern ratio but not an integer intern ratio
- Problems have neither an integer extern ratio nor an integer intern ratio

We defined strong expectancy as a series of problems with the same characteristics (e.g., 3 problems from group 1). Weak expectancy was defined as a series of problems in which the characteristics varied.

In all conditions the players received three levels with five problems in each level, but the distribution of problems with specific problem characteristics was different.

2.3.3 Tests

The arithmetic tempo test, the TTR (Tempo Test Rekenen), measures the degree of fluency in basic arithmetic operations i.e., addition, subtraction, multiplication, and division (de Vos, 1992). For each operation there is a column with 40 arithmetic problems (so four columns in total). A fifth column contains problems with mixed operations. The students have one minute per column to solve as many arithmetic problems as possible.

Proportional reasoning skill was measured with 12 open questions: 4 questions for each problem type. The questions were comparable with the assignments in the game. An example (missing value) is:

> *"For a banana milkshake you have to use 28 bananas and 48 units of ice. How many units of ice do you need if you are going to use 56 bananas and you want to remain the same proportion?"*

There were two versions of the test. The structure of these versions was the same, but the numbers were different. The comparability of both versions was tested in pilot study.

2.4 Procedure

The experiment was run on the computers of the schools. The experiment took 150 minutes divided into three sessions of 50 minutes. In the first session the experiment was introduced and the pre-test was administered (40 minutes). When participants had finished the pre-test they could do their homework. In the second session, a week later, the participants played the game (40 minutes). At the beginning of the session the participants were seated at a designated computer and received a login code. All actions of the players during playing the game were logged. The post-test was administered in the third session (40 minutes, a week after playing the game). One version was used in the pre-test, the other version in the post-test.

2.5 Scoring

TTR. The TTR score is calculated as the sum of correct answers in the five columns. The range of possible scores is 0 – 200.

Skill test. Each answer of the pre-test and post-test was coded as 0 (wrong answer or no answer) or 1 (correct answer). For the analysis we focused on the performance on the three problem types (4 questions each) and on the overall performance (12 questions).

3. Results

An ANOVA with posthoc analysis revealed no differences in prior knowledge between the conditions. To test hypothesis 1 we conducted a paired samples T-test. The results show that playing the game improves learning ($t(93) = 2.39$, $p = .019$, $d = .25$). To test the effect of Surprise and Expectancy we looked separately to the surprise items consisting of the two problem types in which these factors were applied (missing value- Refrigerator sub game and transformation - Blender subgame) and the items for the comparison problem type (Jugs subgame). The results are shown in Table 2. A 2*2 ANCOVA was conducted with Surprise and Expectancy strength as independent variables, posttest score as dependent variable and TTR and pretest scores as covariates.

Table 2: Mean scores and standard deviations on the dependent variable for all conditions

	Surprising events				**No surprising events**			
	Strong expectancy		Weak expectancy		Strong expectancy		Weak expectancy	
TTR	118 (30)		130 (20)		121 (27)		124 (31)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
All items	5.71 (2.34)	6.90 (3.18)	6.00 (3.05)	6.95 (3.29)	5.07 (2.41)	5.53 (3.46)	5.56 (1.61)	5.86 (3.16)
Surprise items	3.04 (1.88)	4.28 (2.23)	4.00 (2.41)	4.79 (2.53)	3.11 (2.41)	3.57 (2.14)	3.21 (1.44)	3.47 (2.44)
Comparison	2.66 (1.06)	2.61 (.97)	2.00 (1.06)	2.17 (1.20)	1.96 (.95)	1.96 (1.18)	2.35 (1.07)	2.39 (1.40)

Note: Range of all items is 0 to 12. All items means all proportional reasoning skill items. Surprise items (are missing value and transformation items) range is 0-8. Range comparison is 0-4.

For the surprise items we found a marginally significant main effect for Surprise ($F(1, 90) = 3.161$, $p = .079$). The main effect for Expectancy strength and the Surprise*Expectancy strength interaction were not significant (both $F(1, 90) < 1$). For the comparison items we did not find main or interaction effects (all $F < 1$).

The participants in this study represent a heterogeneous population which is reflected in the large SD, in each condition there are large differences. We assumed that better performing students would possess the (meta)cognitive skills to deal with the surprises and benefit from the cognitive processes that they trigger. We divided the sample in low and high level students based on the median score of 6 on the pretest. Figure 2 shows the posttest scores on the surprise items for low and high level students. We ran an ANCOVA with the posttest score on the surprise items as dependent variable; surprise, expectancy strength and level as fixed factors and TTR as covariate.

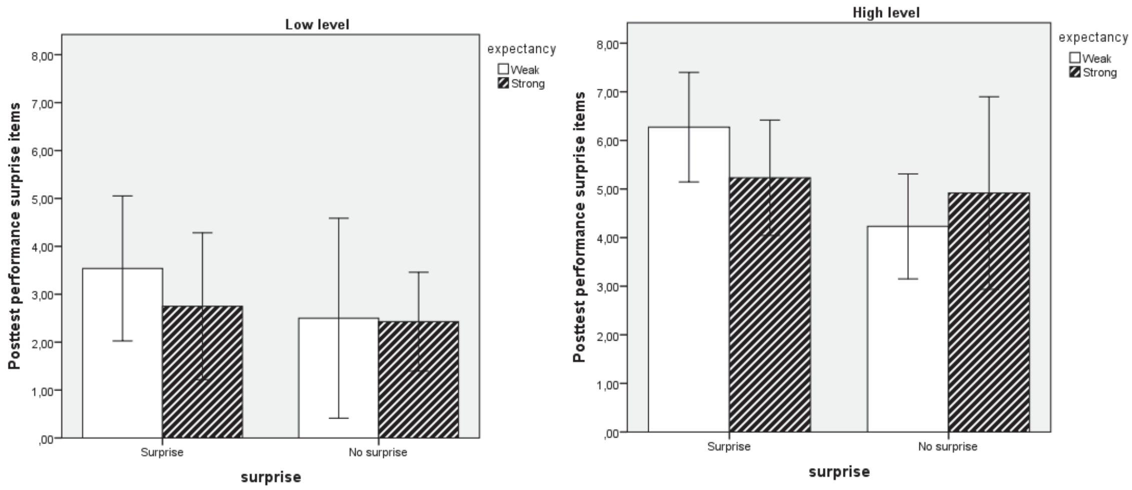

Figure 2: Post performance on surprise items (missing value and Transformation) for low (left) and high (right) level students

We expected to see an interaction between surprise and level, indicating that high level students would benefit more of surprises than low level students. The results, however, only show significant main effects for Surprise ($F(1, 85) = 4.120$, $p = .046$) and Level ($F(1, 85) = 18.980$, $p = .001$), but all other main or interaction effects were not significant (Expectancy*Surprise: $F(1, 90) = 1.057$, $p > .05$; all other effects $F < 1$).

4. Conclusion and discussion

We found that learning improves by playing the game. This corroborates earlier findings regarding serious games in general (cf. Wouters et al., 2013) and other studies with the game Zeldenrust (ter Vrugte et al., in press). An important precondition for effective surprise is that players have sufficient cognitive flexibility and metacognitive skills to orientate on the task, to re-evaluate the results at the moment when the surprise occurs and to reflect on the performed actions. Earlier we found indications that surprise hampered learning for learners with a low educational level, while it seemed that high educational level learners benefitted more from these events (Wouters et al., 2015). In the current experiment we only used high educational level students. We found a marginal effect of surprise on learning indicating that students who experienced surprises learned more than students who were not exposed to these surprises but we found a stronger effect of surprise when we included existing proportional reasoning skill as factor. These results connect with other studies that find cognitive effects of narrative techniques (e.g., surprise, curiosity, suspense) in games (van der Spek et al., 2013; Wouters, van Oostendorp, Boonekamp, & van der Spek, 2011). These results imply that instructional techniques such as surprises should be applied with care. Students with sufficient (meta)cognitive capabilities can handle surprises in complex learning environments such as computer games, students who lack these competencies can be overwhelmed by the additional cognitive demands that are introduced by these surprises. More research is required to investigate the robustness of the surprise effect and the underlying cognitive mechanisms. Possibly, the effect of surprise can be increased by offering students additional instructional support during the problems before the surprise intervention occurs which may help them to select an appropriate method for a problem. One could think of exercises that help them to automatize part-tasks such as multiplication tables so that they can more easily identify intern or extern ratios and/or worked examples in which strategies for specific types of problems are modelled.

Two other lines of research can be interesting. First, there is some evidence that metacognitive skills in math improve with small differences in age (van der Stel et al., 2010). The students in this study had a mean age of 13.9 years (second year class) and the metacognitive skills of some may have been insufficiently developed. Another point is that the students come from the least advanced of three Dutch educational tracks in which students are prepared for intermediate vocational education. It would be interesting to replicate this study with older students in the same educational level (third or fourth year class) or students from a higher educational track. A second research avenue pertains to the characteristics of the game. The game Zeldenrust has a repetitive character, students engage in the same type of tasks which require similar actions. It is not unlikely that students finally will expect that the niece character will reappear and modify the nature of the task. In that case they may anticipate these events and thus undermine the potential effect of surprise. If that is the case more variation in surprise can perhaps further increase their effectiveness.

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