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Computer game-based mathematics education: Embedded faded worked examples facilitate knowledge acquisition

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ABSTRACT

This study addresses the added value of faded worked examples in a computer game-based learning environment. The faded worked examples were introduced to encourage active selection and processing of domain content in the game. The content of the game was proportional reasoning and participants were 12- to 15-year-old students from prevocational education. The study compared two conditions in which students worked with the environment with faded worked examples ($n = 49$) or without worked examples ($n = 44$). The students who received the faded worked examples performed better on a posttest measuring their proportional reasoning skills, and this performance was related to the number of times they had interacted with the worked examples. Though already effective, there is still room for improvement which potentially can be found in the level of explanation given in the worked example before this was faded.

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1. Introduction

Despite the potential of game-based learning environments, research focusing on the effectiveness of game-based learning is inconclusive (Girard, Ecalle, & Magnan, 2013; Kebritchi, Hirumi, & Bai, 2010; Li & Tsai, 2013; Vandercruysse, Vandewaetere, & Clarebout, 2012). One major challenge seems to originate from the possibly tacit nature of the knowledge gathered during game-based learning and students' struggles to make it explicit. In consequence, students experience difficulty connecting knowledge gained in the game with knowledge required for school, and there is an evident lack of transfer of what is learned in the game to school tests and other situations (Barzilai & Blau, 2014; Habgood & Ainsworth, 2011; Leemkuil & de Jong, 2011; Wouters, Paas, & van Merriënboer, 2008). Wouters et al. (2008) discuss the importance of having students articulate and explain their knowledge, because this stimulates the accessibility and recall of the information and fosters transfer. Educational games do have the potential to assist students with this process of explication by offering instructional support (Clark & Martinez-Gaza, 2012; Mayer, 2014).

Although in general support is thought to have the potential to optimize game-based learning (Moreno & Mayer, 2005; ter Vrugte & de Jong, 2012; Wouters & van Oostendorp, 2013), there seems to be little consensus on what this support should look like. Recent review studies of value added approaches in game-based learning environments, however, show that instructional support for game based learning that contains features that helps players select and represent relevant information, coaches players (i.e., providing advice and/or explanations), or stimulates self-explanation is promising (Mayer, 2014; Wouters & van Oostendorp, 2013). We argue that faded worked examples align with these promising features and so can positively affect game-based learning. Therefore, the current study adopted a value-added approach (as described in Mayer, 2011) to investigate faded worked examples as a means to foster students' problem solving and knowledge representations when learning from an educational mathematics computer game-based learning environment.

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1.1. Selection of relevant information

Game-based learning environments are often complex environments in which the learning content is camouflaged by, intertwined with, and embedded in a game setting. Therefore, educationally relevant information is often masked by decorative additions that are educationally irrelevant, but essential to the game experience. This can cause students to have difficulty discriminating between educational content (relevant information) and game content (other information), and therefore introduces extra processing demands (Mayer, 2005). Consequently, students can easily get overwhelmed and distracted from the instructional objective (Johnson & Mayer, 2010; Mayer, 2014). Low-level learners, in particular, can suffer from these extra processing demands (Magner, Schwonke, Aleven, Popescu, & Renkl, 2014). Support that fosters the selection of relevant information can decrease processing demands (Mayer & Moreno, 2003), is likely to optimize learning (Wouters & van Oostendorp, 2013) and can prevent failure and subsequent feelings of frustration.

In their meta-analysis, Wouters and van Oostendorp (2013) concluded that modeling is an effective technique for supporting the selection of relevant information in game-based learning environments. Modeling is an instructional strategy that provides learners with an example of what they are expected to do. Worked examples are a widely recognized method for modeling problem solving. Worked examples are detailed problem solutions that usually contain the following elements: a problem definition, solution steps, and a final solution (Anderson, Fincham, & Douglass, 1997). Because worked examples provide information-rich, easy to follow, step-by-step, expert models for a specific task, learners can use them as guidance for their own problem solving until, through practice and repetition, the useful information related to the solution path is retained in their long-term memory. Research indicates that worked examples can positively affect problem-solving performance, and can help to reduce the time it takes to adopt problem-solving techniques (Carroll, 1994; Cooper & Sweller, 1987; Tarmizi & Sweller, 1988). In a game-based learning environment or a complex multimedia environment, worked examples are likely to help students to make a distinction between educationally relevant and irrelevant information because the worked example contains information that defines the problem to be solved.

1.2. Active organization of relevant information

The second process that effective instructional support should facilitate (according to Wouters & van Oostendorp, 2013) is the active organization of relevant information. Game-based learning environments capitalize on experiential learning or learning by doing. This means that students acquire knowledge through experience and practice (Eraut, 2000; Sun, Merrill, & Peterson, 2001). As a consequence of this experiential approach to learning, the learning is likely to become more intuitive and implicit. In a study specifically about knowledge gain in game-based learning, Leemkuil and de Jong (2012) found no correlation between knowledge gain and game performance. Students developed implicit knowledge (shown by improved performance during the game), but this did not translate into a gain in explicit knowledge (i.e., improved performance on knowledge tasks/transfer tasks). It has been found that instructive support that stimulates students to actively process the educational content (i.e., relevant information) helps students to make their new knowledge explicit (Erhel & Jamet, 2013). A way to have students actively process educational content is self-explanation: “a constructive activity that engages students in active learning, and ensures that students attend to the material in a meaningful way” (Roy & Chi, 2005, p. 273). Self-explanation is an instructional feature that has proven to be successful in game-based learning (Mayer, 2014).

When self-explaining students consciously analyze the output generated by implicit knowledge and reflect on it (Boud, Keogh, & Walker, 1985; Jordi, 2010). This is an essential process for experiential learning (Jordi, 2010) which is the type of learning often encountered in computer game-based learning environments. In game-based learning self-explanation can help students to generate more explicit representations of their knowledge, and, in turn, can positively affect accessibility, recall and transfer of the knowledge (ter Vrugte & de Jong, 2017; Wouters et al., 2008). However, in game-based learning environments students often employ trial-and-error practices (i.e., keep experimenting until their scores improve) that rarely enhance explicit knowledge (Kiili, 2005) and students seldom engage in spontaneous self-explanation (Ke, 2008). In his review, Mayer (2014) reasons that even though students may have the processing capacity available, they do not use this to make sense of the educational content in the game based learning environment, but that the inclusion of instructional features that trigger students to explain the educational content might foster deeper cognitive processing that is needed for learning.

Self-explanation can be triggered in a variety of ways (see ter Vrugte & de Jong, 2017 for an overview), but prompts are most likely to be effective when they are least intrusive (Mayer, 2014). Studies show that the use of incomplete worked examples and the fading of worked out steps can encourage self-explanations (Atkinson & Renkl, 2007; Atkinson, Derry, Renkl, & Wortham, 2000).

1.3. Faded worked examples

Research on the effectiveness of worked examples and practice problems shows that a combination of the two (worked examples paired with practice problems in an instructional approach) generates better results than an instructional approach that uses one or the other (Sweller, van Merrienboer, & Paas, 1998). Therefore, the gradual fading of worked solutions in a worked example (i.e., omitted steps) has been introduced as a way to pair worked examples with practice problems (Atkinson, Renkl, & Merrill, 2003; Renkl & Atkinson, 2003).

Fading means that students first receive a complete worked example, then a partial worked example with one step missing (guided problem solving), after which worked-out steps are omitted one by one until the students are engaging in independent problem solving. With regard to the order in which the steps can be faded, the final step could be the first to be omitted, with consecutive fading of previous steps (i.e., backwards fading), or the first step could be the first to be omitted, with consecutive fading of subsequent steps (i.e., forward fading). Renkl and Atkinson (2003) found that though both yielded positive results, backward fading was more time-efficient; the learners spent less time on the examples without loss of transfer performance.

In general, positive effects of the fading of worked-out steps can be attributed to the following reasons: the gaps in the worked examples can elicit interaction and stimulate self-explanations (Atkinson et al., 2000; Atkinson et al., 2003; van Merriënboer & de Croock, 1992); the fading makes it possible to gradually adapt support to the student's increase in knowledge, consequently eliminating redundant information (Jin & Low, 2011); the progressive fading can attract students' attention to important steps (Hilbert, Renkl, Kessler, & Reiss, 2008); and the use of faded worked examples make it possible to effectively combine practice problems and example-based learning (Atkinson et al., 2003; Renkl & Atkinson, 2003).

1.4. Current study

Research on computer game-based learning shows that providing guidance (Moreno & Mayer, 2005; Wouters & van Oostendorp, 2013), stimulating active processing of educational content (Erhel & Jamet, 2013; Wouters & van Oostendorp, 2013), and prompting self-explanation which foster students' connections between game terminology and mathematics terminology (O'Neil et al., 2014) can optimize the effectiveness of game-based learning in mathematics. Faded worked examples seem to provide the means to meet with these requirements because, in summary: they offer an explicit representation of the embedded learning content which can support students' selection of relevant information and help them to successfully extract learning content and procedures and make a connection between game terminology and mathematics terminology. In addition, the fading of worked-out steps can stimulate students to actively process the educational content and makes them attractive to use in computer game-based learning environments—where students' knowledge often increases as they progress—because it allows for gradual adaption of the instructional support to the progress of the student.

In the current study, the possibility that 'faded worked examples' can stimulate knowledge acquisition from game-based learning is investigated. To that end, two conditions are compared: an experimental condition in which students worked with a computer game-based learning environment with faded worked examples, and a control condition in which students worked with the environment but did not receive worked examples.

The study was performed with prevocational students and employed the computer game-based learning environment 'Zeldenrust' (see Vandercruysse et al., 2015 for a description) which was designed to teach and train prevocational students proportional reasoning and focuses on measures of computational fluency and proportional reasoning as well as students' activities and performance in the computer game-based learning environment in order to evaluate the effectiveness of in-game support in the form of faded worked examples. It is expected that faded worked examples can effectively improve both performance in the environment (reducing the number of incorrect solutions) and performance on a paper-and-pencil proportional reasoning test afterwards. In addition, it is expected that the game with faded worked examples will affect the quality of knowledge that students acquire, enabling them to generate more explicit knowledge structures which will show in an increased ability to provide and carry out correct proportional calculations and better performance on transfer problems.

2. Method

2.1. Participants

The sample included 103 students, 47 boys and 56 girls, aged 12.3–15.3 years old (M = 13.8, SD = 0.75) from the first ($N = 29$) and second ($N = 74$) year in the program of study from two different prevocational schools. All of the participants were familiar with computers and educational software, but were new to the game that was used in the current study.

Prevocational education is a specific track in Dutch secondary education. It is the least advanced of three tracks and prepares students for vocational education. A significant number of prevocational students have a history of poor learning and are dealing with motivational issues that increase the risk of educational dropout (Hamstra & van den Ende, 2006). A study amongst prevocational students identified 'student centered instruction' and 'variation in learning tools' as factors that can help improve these students' motivation to stay in school (Dienst Stedelijk Onderwijs Gemeente Rotterdam, 2005). In addition, van der Neut, Teurlings, and Kools (2005) identified that these students deemed ICT based environments motivational. Therefore, computer game-based learning environments might provide an attractive alternative way of instruction: they can be used to create a setting of students-centered learning, can help vary learning tools, and the interactive and multimodal features may provide these students with new insights they would have missed with other methods of instruction. Though, as already outlined in the introduction, computer game-based learning environments are in need of instructive support that guides students' selection of relevant information and active processing to be effective. This might be even more crucial when using game-based learning approaches with prevocational students. Since these students regularly experience difficulty with the identification, selection, and processing of information (van der Neut et al., 2005).

2.2. The design

The study incorporated two conditions. Students were randomly assigned to conditions. The two conditions were identical in terms of embedded learning objectives (proportional reasoning) and learning material (the game environment) and differed on only one variable: the presence or absence of faded worked examples in the game.

3. Materials

3.1. Domain

The computer game-based learning environment in this study was designed to teach students the mathematics sub-domain of 'proportional reasoning'. The following reasons encouraged the selection of this specific domain: first, it is a fundamental skill for future mathematical understanding and success (Rick, Bejan, Roche, & Weinberger, 2012). Second, traditional instructional methods for proportional reasoning are often ineffective (Rick, Bejan, Roche, & Weinberger, 2012), and therefore students regularly lack proportional reasoning skills (Lawton, 1993; Tourniaire & Pulos, 1985). And third, recent reports of the CITO (an internationally recognized organization for tests, assessments and examinations) show a severe deficiency in prevocational students' mathematics skills (CvE, 2014) and, more specific, in proportional reasoning skills (Cito, 2011).

Within the domain of proportional reasoning, three types of problems can be identified: The first type is comparison. In comparison problems the students are provided with two ratios and the goal is to determine the relationship between two ratios. Possible answers are: ratio one is 'more than', 'less than' or 'equal to' ratio two. The second type is missing value. In missing value problems the students are provided with one complete ratio and a ratio with a missing value. The students have to calculate the missing value, assuming that the two ratios are equal (e.g., 3:6 = ?:12). The third type is transformation. In transformation problems the students are provided with two unequal ratios (e.g., 3:6 ≠ 4:12) and students have to calculate how much needs to be added to one ratio to make the two ratios equal.

Proportional reasoning problems can typically be solved using more than one type of strategy. Depending on the problem characteristics, one strategy might be more practical or efficient than the other. Students can use the strategy of the 'internal ratio', meaning that their calculations focus on the internal ratio of the proportion (i.e., ratio of quantities of the same variable). This strategy is most efficient when the multiplicative relationship expressed by the internal ratio of the proportion has an integer value (i.e., a positive or negative whole number). Students can also use the strategy of the 'external ratio', meaning that their calculations focus on the external ratio of the proportion (i.e., ratio of quantities of different variables). This strategy is most efficient when the multiplicative relationship expressed by the external ratio of the proportion has an integer value. A more elaborate and more universal strategy is the strategy of simplification. In this strategy, students first adjust the first ratio (create an equivalent ratio with smaller digits). The adjustment makes the strategy effective when working with both integer and non-integer internal and external ratios. After the adjustment students can use the strategy of the internal ratio or the strategy of the external ratio to solve the problem. In addition to these three strategies, students also use cross-multiplication and (correct) additive reasoning (addition or subtraction of equivalent ratios) to solve proportional problems.

3.2. Game-based learning environment

The current study employed the educational game-based learning environment 'Zeldenrust', a two-dimensional, cartoon-like, educational computer game-based learning environment. It is designed for prevocational students (ages 12–16) and aims to teach and train proportional reasoning skills. This game-based environment employs, among others, a series of design elements that Papastergiou (2009) identified as being valuable for student involvement within an instructional gaming environment: clear goals, a storyline that can be linked to the users daily activity, progressive difficulty, and direct feedback. In Vandercruysse et al. (2015) the development of the environment and a detailed description of the design principles is provided.

In Zeldenrust, students are encouraged to earn as much money as possible. To earn this money, they have to complete challenges at hotel 'Zeldenrust', such as filling refrigerators and serving guests. These challenges all take place in a challenge-related environments (subgame) that students can enter from a central point in the environment (their hotel room). The more effectively and efficiently the students complete the subgames, the more money they earn. Inefficiency (e.g., dropping bottles from the fridge, incorrect solutions) reduces the amount of money that can be earned. In addition, students can access a handbook that provides them with information about proportional reasoning and complete worked examples for challenges (one worked example per subgame) and they can buy support (i.e., calculator). This support can help them to complete the challenges correctly.

The environment contains a total of three types of subgames with four levels per subgame. Each subgame represents a proportional problem type. In the subgame 'jugs' students must serve the requested beverage mix (comparison problems). For example: "*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?*". In the subgame 'refrigerators' students must refill the fridge (missing value problems). For example: "*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*." And last, in the subgame 'blender' students must 'fix' improperly executed recipes (transformation problems). For example: "*A fruit cocktail recipe prescribes 10 berries for every 100 ml of yoghurt. How many berries should you add to a mix of 10 berries and 500 ml of yoghurt if you want to complete the recipe?*". All problems are introduced by a non-playable character after which the students are provided with an embedded representation.

All of the subgames start at the first level with a tutorial. After this, the first challenge is introduced. The students can solve the challenges using drag-and-drop and point-and-click modalities. Once they give their answers, feedback is provided. Feedback depends on the number of times the student has tried to complete the challenge and whether the answer was correct. After the first trial, the feedback states whether the answer was right or wrong. After a second trial, the feedback either states that the answer was correct or whether the answer was more or less than the correct answer (e.g., "This number is not correct. You used too much juice."). After a third trial, the feedback states whether the answer was right or wrong and the game proceeds to the next challenge. After working on four challenges, students receive the money they earned during the subgame, and return to their room. Every subgame can be opened only once per level and has to be completed after opening. After completion of all three subgames at one level, students move on to the next level.

In the current study two versions of the educational game 'Zeldenrust' were employed: one with partial worked examples that were faded and one without worked examples. Other from the addition of faded worked examples, the games were identical. Fig. 1 shows an example of the fridges subgame with worked example (left) and the fridges subgame without worked example (right).

3.3. Faded worked examples

Students in the faded worked examples condition received worked examples with every challenge in the blender and fridges subgame. The worked examples would be almost complete in the first level, and gradually faded (backwards) as the game progressed. Fig. 2 presents examples of the worked examples in the different levels of the fridges subgame. In the first example (top left, level 1) the 5 elements that were faded are outlined. In comparison, students in the condition without worked example would receive a whiteboard with only the table and provided content.

Students could interact with the worked examples by clicking on them and filling out the blanc cells in the tables. In addition, when students hovered the mouse-pointer over an 'i', 'x' or ':' they would receive additional information. The representation, orientation, and content of the worked examples in the current study were specifically matched to the population (prevocational students) and educational domain (proportional reasoning). The following section briefly presents these design considerations.

3.3.1. Representation

Based on learner characteristics (significant amount of poor readers), features of the learning environment (both practice problem and worked example should be visible simultaneously), traditional representation of the educational content (based on tables), and research indicating that diagrams are more effective than textual representations (Ainsworth & Loizou, 2003), the *representation* of the worked example was mainly graphical. The graphical representation consisted of the following elements: a table, arrows, and mathematical symbols (i.e., 'x' to indicate multiplication and ':' to indicate division). Because research has found positive effects for textual explanations (Atkinson et al., 2000), these were made available on student demand. Students received a short textual explanation about the content of the table (for each column) and each step of the solution (for each arrow).

3.3.2. Orientation

The worked examples were *product-oriented*, meaning that they presented the solution steps but not the reasoning behind the steps (as seen in *process-oriented* examples). This decision was based on practical as well as theoretical considerations. Practically, the

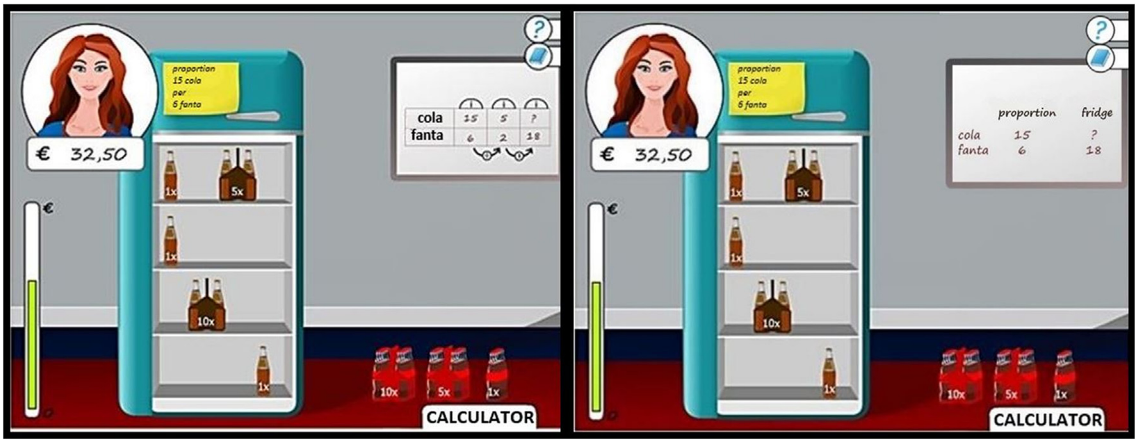

Fig. 1. Fridges subgame faded worked example condition (left) and control condition (right).

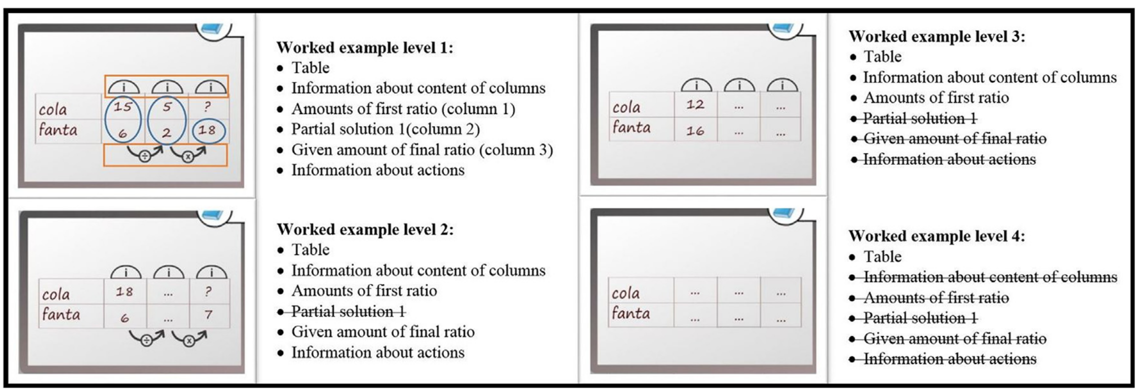

Fig. 2. Example of the faded worked example as presented in the fridges subgame level 1–4.

reasoning behind the steps would involve too much text, and displaying this information would be difficult in the game environment. Theoretically, research has shown that although process information can lead to higher efficiency, it becomes redundant and may impose ineffective load as training progresses. Because the students are not unfamiliar with the domain (proportional reasoning is a domain that is taught to the students since primary school), we chose to use product-oriented worked examples.

3.3.3. Content

Proportional reasoning is a complex domain in which multiple solution strategies can generate identical outcomes. Because research shows that prompting multiple strategies can easily confuse students (Swanson, 1989), in the current study only one strategy was chosen to be presented in the worked examples: ‘simplifying’. This strategy is in line with the most common proportional reasoning strategy taught at prevocational education. In addition, this is a universal strategy, meaning that it can be used to solve all levels of missing value and transformation problems. Another benefit of this strategy is that it consists of three steps with partial solutions which can be presented as three separate chunks of information. This makes the presentation of this strategy fit well with the *process principle* of worked examples. The process principle explains that worked examples consist of meaningful chunks or partial solutions and shows that modular worked examples (where the worked example is broken down into smaller, meaningful solution elements) are more beneficial for learning (Shen & Tsai, 2009).

In the current study, the worked example was meant to guide students but not restrict their problem solving. Therefore, the worked example prompted a possible strategy, but the use of the strategy given in the worked example was optional. The worked example was carefully designed to prevent interference with students' use of other strategies.

3.4. Test materials

Paper-and-pencil tests were used to assess *computational fluency* and *proportional reasoning*. The computational fluency test (i.e., the TTR (de Vos, 1992)) was timed (5 min) and consisted of 200 arithmetic items which were scored for number of correct answers. The proportional reasoning test was not timed and consisted of 16 constructed response items from which four were designed to measure transfer. The constructed response items required students to provide both the mathematical calculation and the answer to a proportional reasoning problem that was presented in a short story. The short story would either match contexts that students encountered in the computer game-based learning environment (i.e., in the learning items), or not (i.e., in the transfer items). Both the answers and the calculations were scored. A correct answer indicated that the student was able to successfully apply the knowledge while a correct calculation provided insight in the ability to extract and represent the knowledge.

The calculations that students provided were categorized using Karplus's strategy coding scheme, which was also used as a coding scheme by Tourniaire (1986). For each problem the calculation was coded as either: missing, incomplete, qualitative, additive or proportional. It was first assessed whether students had provided more than just an answer to the problem. If not than the calculation was coded as missing. If so, then it was assessed whether the calculation provided a complete line of reasoning for the answer. If not, then the calculation was coded as incomplete. If so, then the line of reasoning was assessed. This could be coded as qualitative (e.g., there is more milk than juice, so there should also be more juice), additive (e.g., they added two cups of milk, so you should also add two cups of juice), or proportional (e.g., the amount of milk has doubled, so the amount of juice should also be double). The number of calculations in each category was counted.

The proportional reasoning test was administered both before and after the intervention. Therefore, two parallel versions of this test were developed. Both consisted of the same structure and text, but with different numbers. The two versions were administered in a counterbalanced design, with approximately 50% of the students in each condition receiving version A as pretest and B as posttest, and the other 50% receiving version B as pretest and A as posttest. Reliability analysis on the overall scores revealed a Cronbach's Alpha of 0.68 on the pretest and a Cronbach's Alpha of 0.85 on the posttest.

3.5. Process measures

The *process measures* logged in the computer game-based learning environment represented how many attempts students needed to complete a challenge, how much time they spent on each attempt, and whether they were able to find the correct answer for a challenge. In addition, interaction with the worked examples was logged. These loggings were used to calculate in how many challenges students interacted with the worked example by typing and in how many challenges students accessed the textual explanations. Also, accuracy of the interaction was coded (i.e., number of times students provided correct ratio's in the worked examples).

4. Procedure

The experiment was completed in four sessions of 50 min each. During the *first session* students received an introduction and individually completed the TTR and the proportional reasoning test. During the *second* and *third session* students would work with the computer game-based learning environment. Before entering the environment, students received a short introduction (10 min) which was supplemented with a hand-out to show students an example of each subgame and they were shown a screenshot of one challenge per subgame accompanied by a worked example that explained how to solve proportional problems. The information on the hand-out was in-line with information offered in the handbook section of the game. The goal was to inform the students and to activate their prior knowledge about proportional reasoning so that they were able to work on the game without help from the teacher or researcher. After the introduction students had to hand-in the hand-out and expectations were made clear (work individually, no help during the game, keep calm and quiet, and only pay attention to your own screen). Hereafter, students opened the environment. During the *fourth session* students individually completed a parallel version of the proportional reasoning test.

Though the teacher was present at all time, the researcher would provide the students with the necessary information (introduction and guidance) and material. The teacher was instructed to only intervene when students did not behave as instructed.

5. Results

A total of 103 students participated in the current study. However, some students failed to attend all four sessions: three students did not attend the first session and seven students did not attend the fourth session. The following statistics are therefore based on the data of the 93 students who attended all sessions. In 2 of these 93 cases, the logging of game-play failed. These two cases were excluded from the logfile analyses, for which case data from 91 students are reported. Table 1 summarizes the descriptive statistics for the participants' proportional reasoning test scores per condition. Both conditions show an increase in average score from pretest to posttest. The average improvement in the control condition is 0.4 (SD = 2.9) and in the worked example is 2.1 (SD = 2.8). This difference in improvement between conditions is significant, $t(91) = -2.73$, $p = 0.008$, with effect size $d = 0.60$. Paired samples t-test analyses indicate that only in the worked example condition the improvement was substantial enough to generate a significant effect: control condition $t(43) = -0.99$, $p = 0.330$, $d = 0.11$, worked example condition $t(47) = -5.070$, $p < 0.001$, $d = 0.62$.

An independent samples t-test revealed no differences in the level of computational fluency between the control condition (M = 107.8, SD = 20.3) and worked example condition (M = 112.5, SD = 30.5), $t(84.2) = -0.88$, $p = 0.383$, $d = 0.18$. For proportional reasoning no differences were found on the total correct solutions on the pretest, $t(91) = 0.44$, $p = 0.661$, $d = 0.09$. Likewise, no differences were found on students' calculations on the pretest: independent samples t-tests indicated no difference between the two conditions in the number of missing, incomplete, qualitative, additive or proportional calculations on the pretest (see Table 2 for the results).

Multivariate analysis was chosen to further evaluate the effect of the faded worked examples on students' proportional reasoning skills, because the proportional reasoning test comprised different item types (learning items and transfer items) which were evaluated on different levels (correct calculation and correct answer) creating meaningful variables that are unique but closely related, a mixed-design multivariate analyses with 'condition' as between-subject factors, and 'time' as within-subject variable was conducted. The within-subject variable was a repeated measure that represents the students' multivariate scores on the proportional reasoning pre- and posttest. The underlying univariate measures were the number of correct solutions and the number of proportional calculations that students included with their solutions for each of the item types on the proportional reasoning test. Computational fluency was included as a covariate, because research shows that students' ability interacts with the effects of provided (instructional) support (ter Vrugte, de Jong, Vandercruysse, et al., 2015; ter Vrugte, de Jong, Wouters, et al., 2015; van Gog, Paas, & van Merriënboer, 2008).

Results of the MANCOVA show a multivariate main effect for computational fluency, $F(4,87) = 10.66$, $p < 0.001$ (Wilk's $\Lambda = 0.671$, $\eta_p^2 = 0.329$) no multivariate main effect for time, $F(4,87) = 1.04$, $p = 0.393$ (Wilk's $\Lambda = 0.955$, $\eta_p^2 = 0.045$), no multivariate main effect for condition $F(4,87) = 1.18$, $p = 0.327$ (Wilk's $\Lambda = 0.949$, $\eta_p^2 = 0.051$), and a significant multivariate interaction effect $F(4,87) = 3.05$, $p = 0.021$ (Wilk's $\Lambda = 0.877$, $\eta_p^2 = 0.123$). The significant multivariate interaction tells us that the two conditions are changing over time and that they are changing in different ways. The descriptive statistics indicate an effect in favor of the students who received the faded worked examples. Given this significance univariate effects were examined. Table 3 summarizes the output of the univariate analyses.

The univariate effects indicate that students in the worked example condition specifically performed better on the learning

Table 1
Descriptive statistics for proportional reasoning test scores by condition.

Proportional reasoning	Control condition (n = 44)				Worked example condition (n = 49)			
	Pretest		Posttest		Pretest		Posttest	
	M	SD	M	SD	M	SD	M	SD
Correct solutions total test	5.7	2.8	6.1	4.1	5.5	2.8	7.5	3.6
Correct solutions learning items	5.0	2.3	5.2	3.3	4.6	2.6	6.4	3.0
Correct solutions transfer items	0.7	0.7	0.9	1.0	0.9	0.8	1.1	1.1
Proportional calculations learning items	2.4	2.2	2.9	3.1	2.9	3.1	4.5	3.7
Proportional calculations transfer items	0.3	0.5	0.5	0.8	0.5	0.8	0.8	1.2

Table 2
Calculations on domain knowledge pretest by condition.

Calculations pretest	Control		Worked example		*t*-test
	M	SD	M	SD	
Missing	9.1	4.3	8.5	4.7	$t\,(91) = 0.67$, $p = 0.504$, $d = 0.13$
Incomplete	2.2	2.7	1.7	1.9	$t\,(91) = 0.96$, $p = 0.338$, $d = 0.21$
Qualitative	0.7	1.3	0.8	1.4	$t\,(91) = -0.33$, $p = 0.742$, $d = 0.07$
Additional approach	1.3	2.0	1.6	2.4	$t\,(91) = -0.65$, $p = 0.515$, $d = 0.14$
Proportional	2.7	2.4	3.4	3.7	$t\,(91) = -1.15$, $p = 0.261$, $d = 0.22$

Table 3
Univariate effects of the mixed model MANCOVA.

Effect	Dependent variable	df_1	df_2	F	P	η_p^2
Time	Correct learning items	1	90	0.56	0.457	0.006
	Correct transfer items	1	90	1.70	0.196	0.019
	Proportional calculation learning items	1	90	0.00	0.997	0.000
	Proportional calculations transfer items	1	90	0.58	0.811	0.001
Time × Condition	Correct learning items	1	90	10.45	0.002	0.104
	Correct transfer items	1	90	0.22	0.639	0.002
	Proportional calculation learning items	1	90	4.12	0.045	0.044
	Proportional calculations transfer items	1	90	0.24	0.624	0.003

items on the posttest, but not on the transfer items. Students in the worked example condition were more able to solve the learning items correctly and wrote down more proportional procedures with these items, than students from the control condition.

To test whether students' game performance differed between conditions after controlling for computational fluency and prior knowledge a MANCOVA with game performance (time, attempts, correct solutions) as dependent, and condition (control, faded worked example) as independent variables was conducted. Computational fluency and proportional reasoning (i.e., pretest score) were included as covariates. Results of the multivariate test showed no significant effect of the covariate computational fluency, $F\,(3,85) = 0.34$, $p = 0.795$, $\eta_p^2 = 0.012$, a significant effect of the covariate proportional reasoning $F\,(3,85) = 10.80$, $p < 0.001$, $\eta_p^2 = 0.276$, and a significant multivariate effect of condition, $F\,(3,85) = 3.92$, $p = 0.011$, $\eta_p^2 = 0.121$. Further analysis showed a significant univariate effect for the average number of attempts, $F\,(1,87) = 6.57$, $p = 0.012$, $\eta_p^2 = 0.070$, a univariate effect for the average time, $F\,(1,89) = 4.60$, $p = 0.035$, $\eta_p^2 = 0.050$, and no univariate effect for the percentage correct, $F\,(1,87) = 3.03$, $p = 0.085$, $\eta_p^2 = 0.032$. Students who played the game with the faded worked examples seemed to be more efficient; they needed less attempts and less time to solve a challenge in the game (see Table 4 for descriptive statistics).

To evaluate students' interaction with the worked examples and its effects on students' performance on the posttest a stepwise regression analysis was conducted, with computational fluency (TTR), proportional reasoning (pretest scores), and worked examples interaction measures (number of challenges in which students interacted with the worked examples by typing, number of challenges in which students interacted with worked examples by accessing the textual information, and number of times students provided correct ratio's in the worked examples) as predictors. All predictors were entered simultaneously. Multicollinearity was not an issue, see Table 5 for the correlations of the variables. The results of the analysis indicated that two of the predictors (pretest score and number of challenges in which students interacted with the worked examples by typing) explained 47% of the variance in posttest performance, $R^2 = 0.47$, $F\,(2, 46) = 20.22$, $p < 0.001$. It was found that pretest performance significantly predicted posttest scores, $\beta = 0.498$, $p < 0.001$, as did the number of challenges in which students interacted with the worked examples by typing, $\beta = 0.280$, $p = 0.030$. Number of challenges in which students interacted with worked examples by accessing the textual information and number of times students provided correct ratio's in the worked examples did not contribute to the prediction of posttest performance.

6. Discussion and conclusion

Results from the current study show that instructional support in the form of faded worked examples can help improve computer game-based learning. Students who received faded worked examples in the computer game-based learning environment improved their proportional reasoning skills more than students who did not receive the faded worked examples. This improvement generated a Cohen's d effect size of 0.62 which can be deemed a medium effect and is greater than the average effect size of 0.37 for

Table 4
Descriptive statistics for game measures per condition.

Game measures	Control condition		Worked example condition	
	M	SD	M	SD
Average number of attempts per challenge (range 1–3)	1.5	0.3	1.4	0.3
Average time per challenge (s)	97.6	43.7	84.9	25.2
Percentage correct solutions (range 0–100)	70.0	19.3	75.2	16.1

Table 5
Correlations means and standard deviations of regression variables.

Worked Example Condition (n = 49)	Range	M	SD	1.	2.	3.	4.	5.
1. Total correct answers proportional reasoning posttest	0–16	7.5	3.6					
2. Total correct answers proportional reasoning pretest	0–16	5.4	2.8	0.64**				
3. Computational fluency	0–200	112.4	30.5	0.56**	0.59**			
4. Number of challenges in which students interacted with the worked examples by typing	0–24	19.9	7.7	0.53**	0.51**	0.42**		
5. Number of challenges in which students accessed textual information of the worked example	0–24	15.4	4.7	0.23	0.25*	0.14	0.74**	
6. Number of times students provided correct ratio's in the worked examples	0–16	8.0	7.4	0.26*	0.28*	0.28*	0.73**	0.66**

worked examples as reported by Hattie (2015). The difference in improvement between the worked example and the control condition resulted in a Cohen's *d* effect size of 0.60 (and a partial eta squared of 0.123). Compared to Mayer (2014, p. 140), who reports the median effect sizes of value added comparisons of computer game based learning environments, this is in line with the effect size of 0.68 for the added value of providing advice or explanations (i.e., coaching) but lower than the effect size of 0.81 for the added value of prompting self-explanations.

Students who received the faded worked examples improved their accuracy of both the answers and calculations they provided. This could indicate that students in the faded worked example condition were not only more able to apply their knowledge (provide a correct answer to a proportional problem), but were also more able to represent this knowledge (i.e., provide a correct calculation to a proportional problem). Results indicate that (in the worked example condition) quantity of interaction with the worked example positively affected posttest performance when students prior proportional reasoning skills were controlled. However, the quantity in which students accessed the textual explanations did not explain any further variance. The textual explanations show a strong positive correlation with students' interaction with the worked examples by typing and with the accuracy of their interaction. The reason the textual explanations did not explain any further variance on posttest performance (over prior knowledge and interaction by typing) might be due to the level of explanations given. The explanations were product oriented and, therefore, did not provide deeper knowledge than the knowledge that could be gained through interaction with the worked example by typing. The interaction by typing, however, means that students were completing the worked example, filling in the faded steps. We carefully conjecture that this could be a sign of students attempting to self-explain and/or actively process the information. Which would explain the positive effect on learning.

Though the positive effects of faded worked examples are in line with our expectations, which were based on research on instructional support in game-based learning environments (Moreno & Mayer, 2005; Wouters & van Oostendorp, 2013) and complex multimedia environments (Mayer & Moreno, 2003), we want to stress the fact that designing effective instructional support for game-based learning environments is difficult. Many studies point out that though support should be effective in theory, experimentation proves otherwise (Mayer, 2014; ter Vrugte & de Jong, 2017; Vandercruysse et al., 2016). In addition, designing support that helps prevocational students' game-based learning can be a challenge (ter Vrugte, de Jong, Vandercruysse, et al., 2015; ter Vrugte, de Jong, Wouters, et al., 2015). The population is very diverse and the students are often dealing with motivational issues and attention issues which makes it difficult to stimulate (self-directed) active participation in instructional activities.

It should be pointed out that students in both conditions had access to information about proportional reasoning during the experiment, that both conditions received an instruction with worked examples before they started and both conditions had access to complete worked examples in the environment (in the handbook), but it was only the students in the experimental group who received faded worked examples simultaneous with the challenges in the game. Therefore, it can be ruled out that the effect occurred because of a difference in access to information. The faded worked examples presented the relevant information for the problems that were embedded in the environment and, due to the gradual fading of worked-out solutions, stimulated active processing of the provided information. Based on the finding that simultaneous presentation positively affects learning (Sweller et al., 1998), and because students in both conditions received equal information and had equal access to this information, we carefully conjecture that the effect of the worked examples could be attributed to the simultaneous representation of both the practice problem and worked example and that the alignment between the two is essential (meaning that the presented worked example contains information that fits the presented problem).

Aside from effects on learning, process measures that were derived from logging showed that students also benefited from the faded worked examples while working in the game-based environment. Although the percentage of correctly solved challenges indicated no univariate difference, students who worked with the worked examples did need fewer attempts and less time per challenge. This could indicate that their strategy use was more effective. This is in line with our expectation and previous research (Carroll, 1994; Cooper & Sweller, 1987; Tarmizi & Sweller, 1988).

Overall effects were positive; nevertheless, it should be noted that univariate effects show that the faded worked examples in the current study specifically seemed to affect performance on the learning problems, and not on the transfer problems of the posttest. We speculate that the lack of transfer could be due to the level of students' self-explanation which might not have exceeded the procedural level. Though valuable, knowing how to solve something is not sufficient to understand it, and understanding is essential for transfer (Ohlsson & Rees, 1991; van Gog et al., 2008). It might be that the students in the current study were not able to provide self-explanations on this level (as also argued by Chi, Bassok, Lewis, Reimann, & Glaser, 1989), or that the textual explanations provided with the worked examples affected the students' tendency to provide explanations on this level. Meaning that their self-explanations did not exceed the procedural level (in line with the provided explanations) and, therefore, did not reach the conceptual level that is necessary to foster transfer. It would be interesting to see how different levels of explanation (combined with worked examples) would affect students' game based learning. A way to stimulate deeper explanations could be with prompts following Atkinson and Renkl (2007) who found positive effects of a combination of worked examples with self-explanation prompts.

In light of the current results, it is noteworthy that this study involved students from prevocational education. This population generally contains a large number of at-risk students who experience difficulty with searching, identifying, and processing of information. Faded worked examples are likely to specifically help students overcome these issues. Therefore, it would be interesting to evaluate to what extent ability (or level of education) affects the effectiveness of worked examples. Future research might also compare the effectiveness of different forms of support for students with different levels of ability.

In addition, specifically for game-like environments, it would be interesting to investigate whether integration of worked examples in game context affects the effectiveness. As Vandercruysse et al. (2016, p. 1) note: "support, and the way it is integrated in the game-based learning environment, are decisive for its effectivity". In the current study the faded worked examples were basically integrated in the background of the environment when students needed them. However, the discovery of the worked examples could also be made part of the gameplay, for instance by enabling students to discover this information themselves. More general, it would be interesting to find out whether characteristics of the worked examples affected the results. For instance, whether fading of the worked-out steps is essential for these effects and whether the positive effects are affected by representation mode (text or diagram) and represented information (domain).

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