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

Judith ter Vrugte [a,*], Ton de Jong [a], Sylke Vandercruysse [b], Pieter Wouters [c], Herre van Oostendorp [c], Jan Elen [b]

[a] Department of Instructional Technology, University of Twente, Postbus 217, 7500 AE, Enschede, The Netherlands
[b] Center for Instructional Psychology & Technology, KU Leuven, Etienne Sabbelaan 53, 8500, Kortrijk, Belgium
[c] Institute of Information and Computing Sciences, Utrecht University, Princetonplein 5, 3584 CC, Utrecht, The Netherlands

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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.

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.

* Corresponding author. GW - IST, Postbus 217, 7500 AE Enschede, The Netherlands.
E-mail address: j.tervrugte@utwente.nl (J. ter Vrugte).

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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).

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