Serious Support
for
Serious Gaming

Enhancing Knowledge Acquisition in a Game

for Prevocational Mathematics Education

Judith ter Vrugte

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Judith

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I

General Introduction

Game-Based Learning: Instructional Approaches to Enhance Knowledge Acquisition

This chapter is based on:
ter Vrugte, J., & de Jong, T. (2012). How to adapt games for learning: The potential role of instructional support. In S. Wannemacker, S. Vandercruysse & G. Clarebout (Eds.), *Serious games: The challenge* (Vol. 280, pp. 1-5). Berlin Germany: Springer.
ter Vrugte, J., & de Jong, T. (in press). Self-explanations in game-based learning: From tacit to transferable knowledge. In P. Wouters & H. van Oostendorp (Eds.), *Instructional techniques to facilitate learning and motivation of serious games.* New York, NY: Springer.

Educational Games

As society developed, education also developed. The quill pen was replaced by the ballpoint, and slates have been replaced by spiral notebooks. And today, smartphones, tablets, and laptops with touchscreen, keyboard, and mouse are common sights in everyday education. This introduction of technology into the classroom opened up opportunities for implementation of alternative teaching strategies in education. That, in turn, stimulated the introduction of computer games as an educational tool, and increased the relevance, significance, and influence of computer game-based learning research.

Games (board-, card- or computer-) can be defined as playful activities that have essential characteristics (Charsky, 2010; Dempsey, Lucassen, Haynes, & Maryann, 1996). These characteristics are used to formalize play; they provide a platform upon which play can be structured and organized and can be used in a variety of ways and combinations to design a variety of different games (Charsky, 2010; Koster, 2013). The focus of this dissertation is on computer games. Computer games can be defined as being interactive (Vogel et al., 2006), based on a set of agreed-upon rules and constraints (Dempsey, et al., 1996; Garris, Ahlers, & Driskell, 2002), and with a specific goal (Alessi & Trollip, 2001; Dempsey, et al., 1996). In addition, they contain challenging activities (Hannafin & Peck, 1988; Malone, 1981; Malone & Lepper, 1987), choices (Hannafin & Peck, 1988), and fantasy elements (Lepper & Cordova, 1992), and provide constant feedback to enable players to monitor their progress. This definition is in line with the definition of games as stated by Dempsey, et al. (1996) and with the definition of computer games as stated by Wouters, van Nimwegen, van Oostendorp, and van der Spek (2013, p. 250) for their meta-analysis on the effectiveness of serious games.

Serious games (or educational games) are games that are created not for mere entertainment, but with the objective of teaching, training, informing, or persuading (Annetta, Minogue, Holmes, & Cheng, 2009; Susi, Johannesson, & Backlund, 2007). These games combine game-characteristics with instructional elements. They seem to have promise for bringing about cognitive learning, achieving attitudinal changes, and enhancing motor skills (Kebritchi & Hirumi, 2008; Wouters, van der Spek, & van Oostendorp, 2009). Serious computer games potentially provide a medium for high quality cognitive learning (Ke, 2008; Kebritchi & Hirumi, 2008; Kiili, 2005), because they provide an interactive decision-making context in which the player is stimulated to analyze the situation and evaluate the effects of decisions made. By providing learners with control (Vogel, et al., 2006), feelings of competency (Ryan, Rigby, & Przybylski, 2006) and situatedness (Habgood & Ainsworth, 2011) games arrange engaging environments that stimulate personal motivation which, in turn, facilitates learning (Annetta, et al., 2009; Squire, 2005). Aside from these qualities, researchers have identified other benefits that add to their usefulness: they can support learning when traditional teaching methods are too boring (Annetta, et al., 2009; Girard, Ecalle, & Magnan, 2013; Wrzesien & Raya, 2010), they permit relatively affordable and risk-free interaction with phenomena and situations that would otherwise be inaccessible or unsafe (Farrington, 2011; Girard, et al., 2013; Westera, Nadolski, Hummel, & Wopereis, 2008), and they can give concrete form to certain abstract subjects such as mathematical equations (Girard, et al., 2013).

However, overviews of the effectiveness of game-based learning show that game-based learning has promise but that the outcomes of the research are ambivalent (Kebritchi, Hirumi, & Bai, 2010; Vandercruysse, Vandewaetere, & Clarebout, 2012; Vogel, et al., 2006; Wouters, et al., 2009). Inconsistencies between the results of game-based learning studies may have arisen due to various differences among the studies performed. Studies addressed different populations, as well as using computers differently, teaching different skills, and having different instructional designs (Johnson & Mayer, 2010; Wu, Hsiao, Wu, Lin, & Huang, 2012). To optimize game-based learning, it is therefore important to examine the effects of each of these elements (Boyle et al., 2014; DeLeeuw & Mayer, 2011). One of the elements that seems to affect the effectiveness of game-based learning is the presence and use of different kinds of instructional support (Ke, 2009; Wouters & van Oostendorp, 2013). In light of these findings, the research documented in this dissertation adopted a value-added approach and sought to identify the effects of combining instructional support with game-based learning. In this dissertation, instructional support was defined as any type of guidance, assistance or instruction that helps the players learn (Tobias & Fletcher, 2011). The following sections provide justification for the selection of the specific forms of instructional support that were the focus of these studies.

Game-Based Learning

In a nutshell, serious or educational games combine game characteristics and instructional elements with the objective of creating learning environments that facilitate students' learning processes. In theory, game characteristics can facilitate these processes in two ways: by affecting cognitive processes, such as experiential and active learning, and by affecting affective processes, such as students' motivation (Wouters, et al., 2013). Motivation is a highly valued characteristic of educational games; for this reason, most game developers design games in which students feel as though they are playing instead of learning. This can influence the students' learning mode (i.e., their level of intentionality): instead of a state of deliberative learning (i.e., intentional and conscious learning (Eraut, 2000)) they adopt a state in which learning is reactive (i.e., near-spontaneous and unplanned (Eraut, 2000)), or even implicit (i.e., 'in the absence of explicit knowledge about what was learned'(Reber, 1993, p. 5)). The 'learning mode' can affect specific features of the knowledge that is developed. In general, it seems that when the learning mode becomes less intentional, the development of explicit knowledge (knowledge that can be articulated) becomes less likely (Eraut, 2000; Reber, 1993).

In addition, most games capitalize on experiential learning; they promise to engage and motivate students through direct experiences with the game environment (Kiili, 2005). While students would typically learn in a top-down approach—receiving explicit knowledge through instruction and proceduralizing this knowledge through practice—experiential learning generally follows a bottom-up approach: students acquire knowledge through experience and practice (Eraut, 2000; Sun, Merrill, & Peterson, 2001). As a consequence of this experiential approach to learning, the learning becomes more intuitive and implicit.

Research on implicit learning has demonstrated that implicit skills are not always accompanied by explicit knowledge and vice versa (Berry & Broadbent, 1984). In implicit and reactive learning modes, students are more likely to obtain implicit knowledge and skills; the knowledge gathered is therefore often tacit, rather than explicit (Eraut, 2000; Reber, 1993). 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 gained implicit skills (improved performance during the game), but this gain did not translate into a gain in explicit knowledge (i.e., improved performance on knowledge tasks/transfer tasks).

Though implicit knowledge is valuable and measurable, explicit knowledge is generally our goal, because it is this explicit knowledge that increases recall and accessibility and promotes transfer (Wouters, Paas, & van Merriënboer, 2008). This, in turn, enables students to deploy their knowledge in more than one context, and fosters the ability to communicate it to others (Sun, et al., 2001). In addition, school tests are commonly designed to evaluate explicit knowledge, and only occasionally directly measure implicit knowledge. Therefore, when a game relies on implicit learning and as a result improves mainly implicit knowledge, students and teachers might fail to see the value of playing the educational game. And in some cases, because learning content is so intertwined with game-content, students and teachers even fail to see the connection between the game activities and the curricular content (Barzilai & Blau, 2014).

From the discussion thus far, we can identify several problems that arise with the introduction of game-based learning in formal education. The problems seem to derive from the learning mode and learning process that can be associated with game-based learning, which are more likely to stimulate the development of implicit knowledge rather than explicit knowledge (Leemkuil & de Jong, 2012). Finding a way to stimulate the development of explicit knowledge in game-based learning would make educational games more useful, because the connection between the game activities and the educational curriculum and learning objectives of the school would be more evident. And, most importantly, explicit knowledge fosters transfer, enabling students to reproduce the knowledge and put it into practice.

Self-Explanations to Foster Game-Based Learning

In order to construct explicit knowledge, students must be aware of what they are doing and how they are doing it. This awareness can be facilitated by self-explanation. Self-explanation is “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). It is a process of conscious reflection on, and analysis of, the output generated by implicit knowledge (Boud, Keogh, & Walker, 1985; Jordi, 2010). Self-explanation has been found to be an essential element in learning (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Ke, 2008), and more specifically, in experiential learning (Jordi, 2010). It has been demonstrated that the more students self-explain, the more they learn. In studies that focus on learning from worked examples, this is referred to as ‘the self-explanation effect’ (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chi, De Leeuw, Chiu, & Lavancher, 1994). In a review, Roy and Chi (2005) report that self-explanation results in learning gains as much as 44% higher than gains for control conditions without self-explanations. However, when playing a game students can be reluctant to take the time to think about their actions and reflect on the outcomes, due to the phenomenon of game flow (Ke, 2008). Students keep experimenting until their scores improve, but this trial-and-error behavior rarely enhances explicit knowledge (Kiili, 2005). Therefore, the addition of support that elicits self-explanations could optimize the effectiveness of educational games.

This is easier said than done. As mentioned before, games capitalize on their motivational appeal. Any alteration can affect the experience of game flow and diminish motivational effects. Therefore, any modification that is designed to turn playing into learning needs to be implemented with great care. As Killingsworth, Clark, and Adams (2015, p. 62) justly point out, “implementing self-explanation in educational games requires careful consideration of the specific affordances and constraints of digital games as a medium, and careful evaluation of the relationship between individual abilities, gameplay, and learning outcomes.”

This dissertation investigates how to optimize game-based learning by introducing instructional approaches that, in theory, can initiate self-explanation and, as a result, are likely to stimulate knowledge acquisition and the generation of explicit knowledge. The focus will be on three promising instructional approaches (i.e., self-explanation prompts, collaboration, and worked examples) that are briefly discussed in the following section.

Eliciting Self-Explanations

Self-Explanation Prompts

Research shows that self-explanation is effective in many learning domains (see Wylie and Chi (2014) for an overview). And though most students are likely to engage in some form of spontaneous self-explanation, the quality and quantity of these explanations vary. For this reason, studies have investigated ways to prompt self-explanations (to increase their quantity) and also to support them (to increase their quality). Wylie and Chi (2014, p. 420) introduced the 'continuum of different forms of self-explanation' by which they categorize different forms of prompted self-explanations. The categorization is based on the level of structure that the prompts and scaffolds provide, and is therefore related to the level of cognitive processing elicited. Prompts can be open, meaning that they indicate that the student should self-explain, but give no information about the content/focus of the self-explanation. Alternatively, prompts can be directive (focused), meaning that the prompts contain information about the focus/content of the self-explanation.

Both directive and open self-explanation prompts have advantages and disadvantages. While open prompts do not restrict students' thinking and might maximize learning opportunities, directive prompts are restrictive (Chi, 2000). And while directive prompts provide direction that might reduce the chances of erroneous responses, open prompts provide no direction, which could be too demanding and result in extraneous processing (O'Neil et al., 2014).

Self-Explanation through Collaboration

Instead of trying to get students to explain their thoughts to themselves (self-explanation), we could also trigger a similar process by having them explain their thoughts to someone else. Any situation where students must collaborate can induce these kinds of explanations. During collaboration, explanations can occur when students ask and answer questions. When students ask questions, they outline what they know and/or identify what they need to know. When students answer these kind of questions they are likely to consciously revisit their actions and verbalize what they know. Beyond simply encouraging verbalization and explanation, collaboration can induce discussion. Discussion about conflicting information can complete existing mental models or induce their reconstruction, and the quality of the knowledge might improve correspondingly.

Collaborative learning is a well-defined and thoroughly explored domain. Collaboration can be defined as a situation in which two or more people engage in problem solving and co-construct knowledge. A considerable number of studies have shown that both learning processes and learning outcomes can benefit from collaboration (e.g., Cohen, 1994; Kyndt et al., 2013; Webb, 1982). In addition, interaction in a collaborative setting is a highly engaging activity.

Self-Explanation through Worked Examples

Moreno and Mayer (2005) discovered that self-explanation prompts were effective in interactive environments when students were asked to self-explain program-provided solutions rather than their own solutions. Presenting students with solutions is a more controlled way to initiate self-explanations, in that it provides the possibility of controlling the information the students are reflecting on. One way to provide this information is by means of worked examples. Worked examples are step-by-step expert explanations of how to solve a problem (Anderson, Fincham, & Douglass, 1997). Research indicates that exposure to worked examples can be very effective for skill acquisition in well-structured domains such as mathematics (Anderson, et al., 1997; Carroll, 1994). In addition, worked examples provide expert models and therefore can be used as prompts to guide students and increase their efficiency, feelings of competence, and success (Carroll, 1994; Cooper & Sweller, 1987; Tarmizi & Sweller, 1988).

Research has shown that students who interact with worked examples learn more when they explain the examples to themselves: the self-explanation effect (Chi, et al., 1989; Chi, et al., 1994). Although most students are likely to engage in some form of spontaneous self-explanation, the quality of these explanations varies, and most students are likely to use inadequate self-explanation strategies (i.e., passive or superficial) while studying worked examples (Renkl, 1997). Atkinson, Derry, Renkl, and Wortham (2000) found that the structure of the worked example can encourage students to actively self-explain. In a follow-up article, Atkinson and Renkl (2007) suggested fading (providing a series of partially worked examples with gradual removal of worked-out steps) as a possible means of inducing self-explanations. Other research on partial and faded worked examples has endorsed their positive effects on learning (Richey & Nokes-Malach, 2013): students process these worked examples more actively (Atkinson & Renkl, 2007; Paas,1992; van Merriënboer & de Croock, 1992), and they are more encouraged to participate in self-explanation (Renkl, Atkinson, & Große, 2004).

Problem Statement and Dissertation Outline

At the beginning of the chapter we introduced game-based learning as a potentially effective instructional approach, but also pointed out that the effects of game-based learning are varied and far from optimal. Aside from the many features and characteristics that might affect the results of game-based learning, we conjectured that games are likely to increase knowledge, but that this knowledge is at risk of being implicit and tacit. We noted that although implicit knowledge is certainly valuable, explicit knowledge is generally considered more desirable in education, because it is more easily accessible and promotes transfer. It is suggested that explicit knowledge does not always automatically follow from the development of implicit knowledge, but that this process can be supported through self-explanations. Because self-explanations rarely occur automatically in game-based learning environments, we proposed that self-explanations in game-based learning environments can be elicited by specific forms of instructional support. Three possible forms of instructional support that could elicit self-explanations were briefly discussed: self-explanation prompts, collaboration, and partial worked examples. The studies reported in this dissertation sought to establish the effects of these three forms of instructional support on prevocational students' acquisition of knowledge about proportional reasoning in a computer game-based learning environment. The general research question that guided these studies was:

How can we support prevocational students' acquisition of knowledge about proportional reasoning in a game-based learning environment?

The general research question was addressed in three empirical studies that all targeted the same population (i.e., prevocational students), addressed the same domain (i.e., proportional reasoning), and employed the same game (i.e., 'Zeldenrust').

The Population

Participants in the studies that are reported in this dissertation were all secondary school students from the prevocational track (approximately 11-17 years of age). Prevocational education (in Dutch: VMBO) is a specific secondary school track in the Dutch educational system. It prepares students for intermediate vocational education (community college), and is the least advanced of the three Dutch educational tracks, followed by HAVO (preparing students for higher vocational education: university of applied sciences) and VWO (preparing students for scientific education: university of science). The prevocational population shows a wide variety in cognitive abilities and potential.

This population was chosen because this group includes a significant number of at-risk students with a history of poor learning. These students often encounter numerous unsuccessful instructional interventions and have grown resistant to the traditional educational material. Educational games can create an alternative approach that might motivate such learners to reengage with the educational material. In addition, the interactive multimodal features might provide them with new insights they would have missed with more traditional methods of instruction.

The Domain

Math was chosen because it is a fundamental skill for future school achievement, and prevocational students' math skills are often inadequate (CvE, 2014). More specifically, the math sub-domain of proportional reasoning was selected. Besides the fact that recent reports from the Cito show that prevocational students are severely deficient in proportional reasoning skill (Cito, 2011), the selection of proportional reasoning was driven by the following reasons. First, proportional reasoning is a fundamental skill for future math achievement and mathematical understanding (Rick, Bejan, Roche, & Weinberger, 2012). Second, proportional reasoning is a well-defined domain with concrete operationalization. And third, traditional instructional methods for proportional reasoning are often ineffective (Rick, et al., 2012), and therefore students regularly lack proportional reasoning skills (Cito, 2011; Lawton, 1993; Tourniaire & Pulos, 1985).

Difficulties with proportional reasoning seem to emerge from students' possession of fragile domain-specific concepts. Proportional reasoning problems vary in structure and this can create difficulty in applying these already fragile concepts (Lawton, 1993; Tourniaire & Pulos, 1985). Instruction of proportional reasoning is likely to benefit from game-based learning because, in addition to the traditional word problems, a game can provide students with a variety of motivational and vivid contexts and opportunities to interact with the material. The active, multimodal nature of the environment can help students to develop a more solid and concrete understanding of the normally abstract proportions and ratios that make up the core of proportional problems.

The Game

The game was developed in collaboration with prevocational students and their teachers. The process roughly involved the following stages: prototype development and testing, revision of prototype and testing, revision of prototype (control-version) and design of instructional support, experimental versions (control-versions with instructional support).

To foster immersive and engaged gameplay and create context for the educational content, a storyline was created. The theme of the storyline was tailored to fit prevocational students' interests and world. The storyline places the players in a hotel setting where they have to earn as much money as possible to finance their upcoming holiday abroad. The game consists of a lead game and different subgames and has four levels that can be completed. The lead game starts with the opportunity to select an avatar and introduces the storyline, after which it functions as a central point in the game where students can keep track of their progress (e.g., money, level) and from which students can enter the subgames. There are three subgames. These subgames present challenges that have to be solved to earn money. These challenges require proportional reasoning to come to a solution, and a correct solution will increase the player's amount of money. Each subgame includes four challenges and can be played once per level. When the players finish the three subgames (12 challenges), they automatically continue on to the next level. The challenges get more difficult as the game progresses. After four levels (48 challenges) the game ends. A more extensive description of the game is presented when reporting on the three studies in this dissertation, or can be found in 'Zeldenrust: a mathematical game-based learning environment for prevocational education' by Vandercruysse et al. (2015).

The Studies

The study that is discussed in Chapter 2 concerns an experimental study in which the effects of embedded self-explanation prompts were assessed in a factorial 2x2 design. The two factors were: self-explanation prompts and procedural information. The study that is discussed in Chapter 3 concerns a quasi-experimental study in which the effects of face-to-face collaboration were assessed in a factorial 2x2 design. The two factors were: collaboration and competition. Lastly, the study in Chapter 4 concerns an experimental study that compared the effects of embedded faded worked examples to a control condition who played the game without worked examples.

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2

Self-Explanation Prompts

A Study of the Effects of Self-Explanation Prompts and Procedural Information

This chapter is based on:
ter Vrugte, J., de Jong, T., Wouters, P., Vandercruysse, S., Elen, J., & van Oostendorp, H. (2015). When a game supports prevocational math education but integrated reflection does not. *Journal of Computer Assisted Learning*, *31*, 462-480.

Introduction

Games seem to offer an ideal circumstance for high quality learning (Girard, Ecalle, & Magnan, 2013), because they provide students with an interactive decision-making context in which students are stimulated to analyze a situation and evaluate the effects of their decisions (Kebritchi & Hirumi, 2008). By providing students with control (Vogel et al., 2006), feelings of competency (Ryan, Rigby, & Przybylski, 2006), and situatedness (Habgood & Ainsworth, 2011), games also create engaging environments that stimulate personal motivation (Kebritchi, Hirumi, & Bai, 2010; Wrzesien & Raya, 2010), which is then thought to facilitate learning (Squire, 2005).

The motivational and engaging nature of computer games makes them particularly attractive for educating students who have lower levels of intrinsic motivation, such as, prevocational students. Prevocational education (in Dutch: VMBO) is a specific secondary school track in the Dutch educational system where students are prepared for intermediate vocational education. It is the least advanced of three tracks that are offered in secondary education in the Netherlands, and it brings together students who vary highly in their cognitive capability and potential. Quite a few prevocational students are dealing with motivational and/or cognitive issues and many prevocational students have struggled with subjects such as mathematics for years. As a result, their teachers often face students who show educational resistance. These students could especially benefit from an alternative instructional method to keep them interested, motivated, and engaged.

However, recent overviews of the effects of game-based learning show that although educational games have potential, the use of computer games for education is not always effective in terms of knowledge acquisition (e.g., Kebritchi, et al., 2010; Li & Tsai, 2013; O'Neil, Wainess, & Baker, 2005; Vandercruysse, Vandewaetere, & Clarebout, 2012). One overall conclusion is that support is necessary in order to facilitate learning in game-based education (Garris, Ahlers, & Driskell, 2002; Leemkuil & de Jong, 2011; ter Vrugte & de Jong, 2012). The current study discusses games as an educational tool for prevocational students, and specifically focuses on the effects of incorporating support in the form of prompts that elicit self-explanation in an educational math game.

Motivation and Learning from Games

Motivation is one of the core aspects that makes games appealing for education (Papastergiou, 2009). Motivation can be described as the willingness and desire to engage in a task (Garris, et al., 2002). It refers to the individual's choice to engage in an activity and the individual's intensity of effort or persistence during the activity (Wolters, 1998). Garris, et al. (2002) describe the motivated learner as enthusiastic, focused, and engaged. Games and motivation seem to coincide, which means that games should offer a viable means of generating motivated learners. Motivational aspects of educational games that have been identified in prior research include enjoyment, task persistence, and engagement (Garris, et al., 2002; Lepper & Cordova, 1992). Paras and Bizzocchi (2005, p. 1) explain that 'games foster play, which produces a state of flow, which increases motivation, which supports the learning process'. A recent study by Liu, Horton, Olmanson, and Toprac (2011) demonstrated the positive relationship between motivation and learning in a digital learning environment. However, although motivation and engagement support the learning process, computer games that are engaging and motivational are not guaranteed to result in learning gains (Garris, et al., 2002).

Support in Games

From prior research in the field of open inquiry-flavored media environments it can be concluded that these environments generally need support structures in order to create an effective learning situation (Alfieri, Brooks, Aldrich, & Tenenbaum, 2010; ter Vrugte & de Jong, 2012; Wouters & van Oostendorp, 2013). Research shows that educational games can promote learning, provided that they include features that prompt students to process the educational content actively (Erhel & Jamet, 2013; Wouters & van Oostendorp, 2013). These findings are confirmed by the observation that students who play educational games often have difficulty with representing, reproducing, and generalizing the knowledge they have learned in the game. This demonstrates that the knowledge that students gain from gameplay is often more intuitive and implicit rather than explicit. This lack of explication can be partially attributed to game flow: for actual in-depth learning to take place, we need the students to be conscious of the educational material in the game and how to work with it, but game flow inhibits students from thinking about this content explicitly during game play (Johnson & Mayer, 2010; Ke, 2008; Leemkuil & de Jong, 2011; Paras & Bizzocchi, 2005; Sweetser & Wyeth, 2005). Therefore, integration of support that encourages thoughtful information processing during gameplay, could ensure better learning effects (Ke, 2008; Wouters, Paas, & van Merriënboer, 2008).

Self-explanation is an activity that is associated with thoughtful information processing and sense making and is therefore often thought of as essential element of the learning process (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Nokes, Hausmann, VanLehn, & Gershman, 2010; Roy & Chi, 2005). Self-explanation activities help students to become aware of processes that are normally experienced as self-evident, and help them to critically evaluate the effects of decisions they have made. In addition, self-explanations can encourage the students to integrate newly learned information with prior knowledge, which makes for stronger knowledge structures with increased accessibility (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Nokes, et al., 2010). Johnson and Mayer (2010) found that adding self-explanation components to an educational computer game furthers knowledge acquisition.

Incorporation of prompts that make students aware of the educational material can turn players into learners, but is also likely to disturb the game flow and thus interfere with students' engagement and motivation (Johnson & Mayer, 2010; Sweetser & Wyeth, 2005). Loss of engagement and motivation can, in turn, disrupt learning effects. The way self-explanation is initiated is therefore important.

One of the most salient differences between the various ways to elicit self-explanation is that between open and directed self-explanation. Open self-explanation means that a student is simply prompted to explain. An open prompt can take the form of a direct question or an action that requires explanation. Directed explanation is when students are not only prompted to explain, but are additionally guided or assisted in completing the explanation (Davis, 2003; Wylie & Chi, 2014). Directive prompts can consist of a series of questions to scaffold the explanation process or to direct attention to specific areas of learning. Both open and directive prompts have advantages and disadvantages. For example, Berthold, Eysink, and Renkl (2009) concluded that students are not always capable of responding appropriately to open self-explanation prompts. On the other hand, it is also likely that directive prompts restrict students' explanations and can thus limit their opportunities to learn (Chi, 2000).

Johnson and Mayer (2010) compared the effects of providing open, directive, and no self-explanation prompts within a computer game environment. They found that the directive condition yielded significantly better results (students showed more progress on a domain knowledge test) than the open and no prompt conditions, and that there were no differences between the open and no prompt conditions. They offered several explanations for these results: the open self-explanation prompts could have been too difficult or too disruptive to the game flow, or it might not have been the self-explanation in the directive condition that caused the effects, but the information that was provided through the multiple choice answers in the directive prompts. Expanding on these findings of Johnson and Mayer (2010), and taking into account the findings of Berthold, et al. (2009) about the fact that open prompts are often too demanding for students, the current study implemented directive prompts to support prevocational students when learning in the context of an educational computer game.

Current Study

The current study evaluates prevocational students' learning with an educational mathematics game. Mathematics was chosen because it is a fundamental skill for future school achievement, and prevocational students' mathematics skills are often inadequate (CvE, 2014). More specifically, the mathematics sub-domain of proportional reasoning was selected. Besides the fact that recent reports of the Cito show a severe deficiency of prevocational students in proportional reasoning skill (Cito, 2011), the selection of proportional reasoning was driven by the following reasons: first, proportional reasoning is a fundamental skill for future mathematics achievement and mathematical understanding (Rick, Bejan, Roche, & Weinberger, 2012). Second, proportional reasoning is a well-defined domain. And third, traditional instructional methods for proportional reasoning are often ineffective Rick, et al. (2012), and therefore students regularly lack proportional reasoning skills (Lawton, 1993; Tourniaire & Pulos, 1985). Difficulties with proportional reasoning seem to emerge from students' possession of fragile domain-specific concepts. Proportional reasoning problems vary in structure and this can create difficulty in applying these already fragile concepts (Lawton, 1993; Tourniaire & Pulos, 1985). Instruction of proportional reasoning is likely to benefit from game-based learning because, in addition to the traditional word problems, a game can provide students with a variety of motivational and vivid contexts and opportunities to interact with the material. The active, multimodal nature of the environment can help students to develop a more solid and concrete understanding of the normally abstract rules and relations that make up the core of proportional problems.

The population of this study is a specific group of secondary school students: prevocational students. This group includes a significant number of at-risk students with a history of poor learning. These students often encounter numerous unsuccessful instructional interventions and have grown resistant to the traditional educational material. Educational games can create an alternative approach that might motivate such learners to reengage with the educational material. In addition, the interactive multimodal features may provide them with new insights they would have missed with more traditional methods of instruction.

It is investigated whether prevocational students can benefit from an educational game and whether in-game self-explanation prompts could foster their learning. It is expected that students in this study do not possess the metacognitive skill and content knowledge that is necessary for successful open self-explanation (Berthold, et al., 2009; Johnson & Mayer, 2010). For this reason, we used directive self-explanation prompts that focused students' explanations toward specific aspects of domain knowledge. These prompts took the form of a series of multiple choice questions. Though the questions and possible answers would already provide direction to the students, we took into account the possibility that the students would not possess sufficient skill and prior knowledge to come to an explicit realization of the knowledge they acquired during the self-explanation. Therefore, procedural information that was designed to help students to structure this knowledge, was added to the study. This information was a visual representation of the information that was the focus of the self-explanation prompts.

In summary, this study employed a 2x2 factorial design to investigate the effects of directive self-explanation prompts and/or procedural information in an educational math game. Four conditions were compared: the game with self-explanation prompts, the game with procedural information, the game with a combination, and the game with no support.

Based on aforementioned literature it was expected that playing the game would help students to improve their proportional reasoning skills and that the self-explanation prompts would advance students' knowledge acquisition. It was expected that students would benefit most from a condition where they received both self-explanation prompts and procedural information, because the procedural information would help students to come to an explicit realization of the knowledge acquired during the self-explanation. In addition it was investigated whether students prior knowledge and computational fluency affected the effectiveness of the game and whether the addition of support influenced students' perceptions of the game, in particular whether it affected the way students perceived the usefulness and playfulness.

Method

Participants and Design

The study was conducted in two schools for prevocational education in the Netherlands. The sample involved 145 students, 78 boys and 67 girls, aged 13.3 to 17.5 years old (M = 14.88, and SD = 0.79). The students participated in the second (59 students) or third year (86 students) of the program of study. All students possessed basic computer skills, which are part of the national Dutch curriculum. Students were familiar with educational software, but new to the game that was used in the current study.

The study utilized a 2x2 factorial design. The four conditions involved were identical in terms of embedded learning objectives (proportional reasoning) and learning material (game environment), and differed on two variables: the presence or absence of self-explanation prompts and the presence or absence of procedural information.

Materials

Domain. The domain involved in this study is proportional reasoning. Three types of proportional problems were identified: comparison problems, missing value problems, and transformation problems (e.g., Harel & Behr, 1989; Kaput & West, 1994; Tourniaire & Pulos, 1985).

Comparison problems always involve two ratios. Students must determine the relationship between two ratios. Possible answers to these problems are that the first ratio is 'more than', 'less than' or 'equal to' the second ratio. Comparison problems can be divided into three levels of difficulty. The *first* level (the easiest level) includes problems that can be solved directly by qualitative reasoning. The answer to these problems can be achieved by reasoning because either the values of the antecedents or consequents in both ratios are equal (e.g., 1:4 vs. 3:4), or the comparison involves ratios that are obviously quite small and quite large (e.g., 100:31 vs. 42:100). The *second* level includes problems that can be solved by estimation. In this case, the answer can be estimated because the internal or external terms of the proportion show an easy multiplication (e.g., 2:4 vs. 4:6) or the internal or external terms of the proportion match a simple reference point (e.g., 1/2, 1/3, 1/4, or 1/10). The *third*, and hardest, level must be solved using full calculation. The answer cannot be determined directly by reasoning or estimation, but must be computed (e.g., 14:63 vs. 18:81).

The other two problem types are missing value and transformation problems. *Missing value problems* concern a proportion in which one value is missing. Students must calculate the missing value, assuming that both ratios are in proportion (e.g., 3:6 = ?:12). *Transformation problems* concern two ratios that are not (yet) in proportion (e.g., 3:6 ≠ 4:12). Students must calculate how much has to be added to one ratio to make both ratios equal. Both missing value and transformation problems can be divided over four levels of difficulty depending on whether the multiplicative relations between the internal and/or external ratios of the proportion are integer or not (e.g., Kaput & West, 1994; Tourniaire & Pulos, 1985; van Dooren, de Bock, Evers, & Verschaffel, 2009). The educational game intervention focused on practice and knowledge gains on all three problem types. An example of each type of problem as implemented in the game can be found in Table 2.1.

Game. The intervention consisted of a newly developed computer-game application: 'Zeldenrust', in which students take on the role of a hotel employee. The goal of the game is to gather as much money as possible (to spend on a holiday) and this can be achieved by completing challenges around the hotel. All challenges require efficient and effective use of proportional reasoning. The amount of money earned for completing a challenge increases in relation to the accuracy of the response, and the accuracy of the actions taken, while it decreases with the use of the calculator, and the number of attempts used to solve the problem. The more money students earn, the farther they can travel on their virtual holiday.

The game consists of:

- *the game center* where students keep track of their progress and receive directions
- *four levels* of progressively increasing difficulty, each level targets a specific level of proportional reasoning, students get to practice all the proportional problem types in every level
- *three subgames* that are designed to practice specific types of proportional reasoning problems, the subgames have dedicated features for performing specific assignments
- *48 challenges* that represent problems that require proportional reasoning, the student must complete four challenges at every level for every subgame

Table 2.1

Overview of level structure per subgame

Subgame	Problem type	Attempts per challenge	Example of problem	Game level 1	Game level 2	Game level 3	Game level 4
Jugs	Comparison	one	*"There are two pitchers of juice on the counter. A customer asks for the sweetest juice mix. Which juice mix will you give to the customer?"* The ratios of water/fruit were presented on the pitchers. The question was presented on a virtual blackboard. The student had to click on the correct pitcher to answer.	Qualitative reasoning	Estimation	Calculation	Mix of levels 1, 2, and 3
Fridges	Missing value	three	*"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."* A virtual blackboard presented the ratio of 3/1 next to the ratio with the missing value 9/?. The student had to answer the question by dragging and dropping the correct amount of juice bottles into the refrigerator.	Internal ratio and external ratio integer	Internal ratio integer and external ratio not integer Or vice versa	Internal ratio and external ratio not integer	Mix of levels 1, 2, and 3
Blender	Transformation	three	*"A fruit cocktail recipe prescribes 10 berries for every 100 ml of yoghurt. Somebody already mixed 20 berries and 500 ml of yoghurt. Can you complete the recipe?"* The ratio from the recipe (10/100) was presented on a virtual blackboard and the blender already contained 20 berries and 500 ml of yoghurt. The student had to answer the question by dragging and dropping the correct amount of berries and yoghurt into the blender.	Internal ratio and external ratio integer	Internal ratio integer and external ratio not integer Or vice versa	Internal ratio and external ratio not integer	Mix of levels 1, 2, and 3

Table 2.1 provides an overview of the subgames, levels and challenges (including the number of attempts that students are allowed to use, to solve a challenge in a subgame). Figure 2.1 provides an illustration of the game center and the three subgames.

Figure 2.1. Game center screen (upper left) and subgame screens.

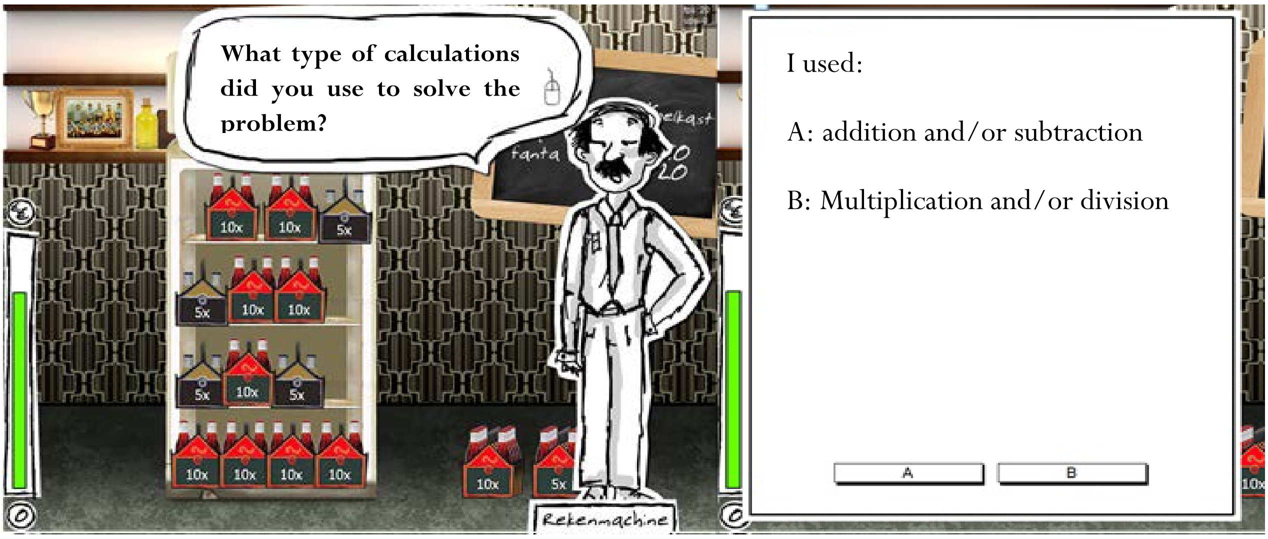
When the game starts, students see a short animation that introduces them to the storyline and the goal of the game. After this, they can choose an avatar (out of four options) and enter the game center, where they meet the hotel owners (non-playable characters) and are taken to their virtual room. This room (Figure 2.1, upper left illustration) is the game center, from here subgames can be entered. Students automatically return to this game center when a subgame is finished. In the subgames the hotel owners give the students tasks: fill the fridges, mix cocktails, and serve drinks. Only when all tasks are completed students can exit the subgame.

When a student enters a subgame (by clicking one of the paintings on the wall), the owners introduce the challenge that has to be accomplished. In addition, the first level of each subgame starts with a tutorial. After this, the first challenge is introduced. Students can solve the challenges by dragging and dropping the correct number of objects to the correct place. Once they have given their solution, feedback is provided. Feedback depends on the number of attempts students have made at solving the challenge and whether their solution is correct. After one attempt, the feedback states whether the solution is right or wrong. After a second attempt, the feedback states either that the answer is correct or that the answer is less or more than the expected answer (e.g., "This number is not correct. You have used too many berries."). After a third attempt the feedback states whether the answer is right or wrong and the game proceeds to the next challenge. After four challenges, students receive the cash they earned and return to their room. Here they can keep track of their holiday destination on a geographical map, or start a new subgame. Every subgame can be opened only once per level. After completion of all three subgames at one level, students get access to the next level. This structure fosters maximum variation (in context and problem type) in combination with progressive difficulty, which promotes the experience of challenge and reduces feelings of frustration.

The goal of 'Zeldenrust' is to encourage active learning within a game environment. Students have the opportunity to search for and discover information in an interactive environment, to engage in problem solving, to think about concepts presented and to test their understanding of those concepts. Papastergiou (2009) identified a series of elements that can promote student involvement within an instructional gaming environment. In the current game, the following elements were adopted: clear but challenging goals, fantasy linked to the student activity, progressive difficulty elements, and immediate and constructive feedback. In Zeldenrust goals are introduced in the narrative and intertwined with the gameplay and storyline of the game to assure *clear goals*. Clear goals stimulate engagement and engage players' self-esteem (Malone, 1981). Because games where the learning content and game content are fully – or intrinsically – integrated are expected to be superior with respect to learning outcomes (Habgood & Ainsworth, 2011), the storyline and the gameplay of Zeldenrust were designed to *integrate* the educational content seamlessly. As advised by Malone (1981), the goal and the theme of the storyline (earning money for a holiday) were tailored so that the students could identify with it, and could link the virtual (*fantasy*) world to their daily activity. And finally, to assure *progressive difficulty* and minimize frustration, a level-based structure was incorporated and *feedback* was provided. To promote greater retention and a greater correction of inaccurate strategies, feedback was provided immediately upon response, and was both corrective and constructive (Dihoff, Brosvic, & Epstein, 2003).

To overcome societal issues, the game depicted a gender-neutral and violence-free setting and storyline, and all references to alcohol or other drugs were avoided. Moreover, the following practical conditions were considered: the available computer hardware at schools, the total time needed to complete the game, and the intuitiveness of the game controls. These practical implications led to some design restrictions: 2D graphics were used instead of 3D, audio fragments were limited, the storyline was kept relatively simple, and all game controls were mouse-operated.

Variants of the game for the different conditions. To create the research conditions two additions to the game were designed: self-explanation prompts and procedural information. *Self-explanation prompts* were presented in the form of multiple choice questions. These questions directed students' attention to the steps that are the most important when solving a proportional problem, such as: 'what type of calculations did I use?', 'how did I apply these calculations?' 'what would happen if one quantity changed?' (see Figure 2.2 for an example of a prompt). After answering a multiple choice question (prompt), students received feedback on whether their answer was correct or incorrect.



What type of calculations did you use to solve the problem?

I used:

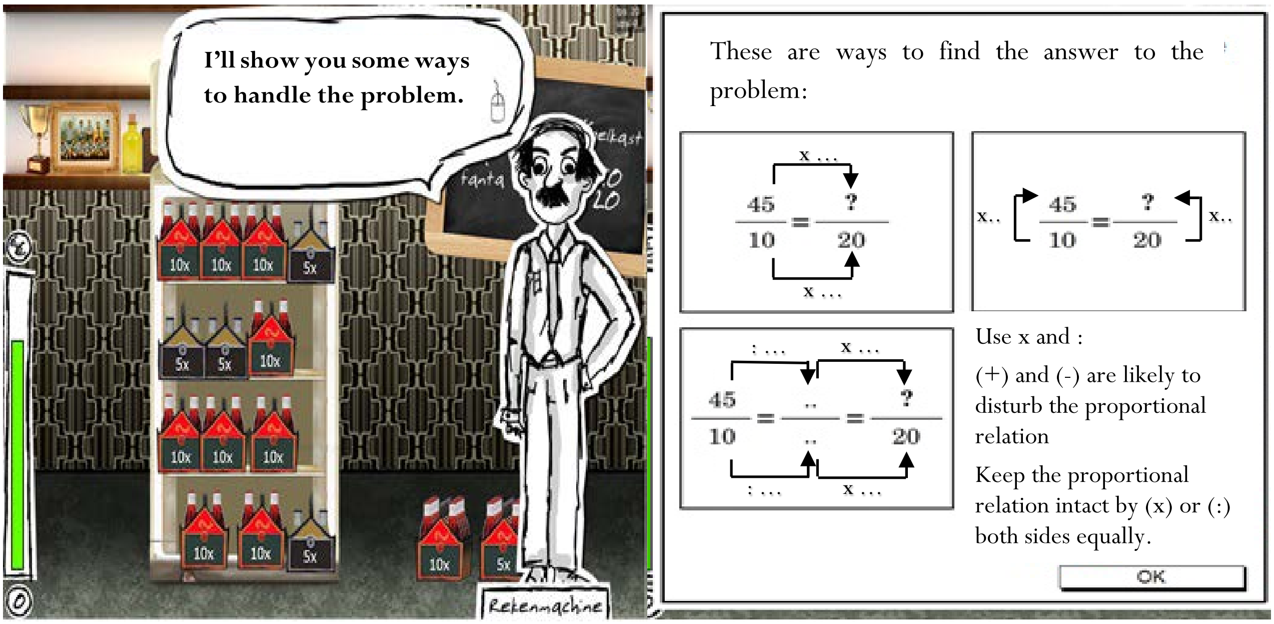
A: addition and/or subtraction

B: Multiplication and/or division

Figure 2.2. Self-explanation question screen (left) and answer screen (right).

Procedural information provided students with possible procedures and the corresponding rules necessary to tackle the problems that were presented in the game (see Figure 2.3 for an example of procedural information). When *self-explanation and procedural information* were combined the students would select a procedure that seemed to best fit the problem, after this they received the multiple choice questions. The picture of the procedure remained visible during the questions. The rules of the procedural information were provided to the students as feedback on students' answers to the questions. So the feedback in the combined condition did not only state whether the answer was right or wrong (as in the only self-explanation condition), but it also stated the corresponding rule.

The self-explanation prompts and procedural information appeared at pre-determined points; students received the support eight times during the game. They received it twice per level: after the first attempt for the second challenge during both the refrigerator and blender subgames. In this way, students could first practice the first challenge for each level, then receive self-explanation prompts and/or procedural information, and could apply the knowledge they had gained in the following problem. To keep disruption of the game flow to a minimum, all the information and questions were embedded in the storyline of the game and were presented in an interactive conversation with a non-playable character (i.e., one of the hotel owners).



These are ways to find the answer to the problem:

Use x and :

(+) and (-) are likely to disturb the proportional relation

Keep the proportional relation intact by (x) or (:) both sides equally.

Figure 2.3. Information introduction screen (left) and information screen (right).

Test materials. To evaluate computational skills, students completed an arithmetic tempo test, the *TTR (Tempo Test Rekenen)*. This is a validated test developed in the Netherlands and Flanders which aims to measure students' computational skills in fundamental arithmetic computations: addition, subtraction, multiplication, and division (de Vos, 1992). The test consists of the four types of arithmetic computations distributed over five sheets, one sheet for each type of computation and one with all types in mixed order. There were 40 arithmetic problems per sheet, presented in an order of increasing difficulty. The students had one minute per sheet to solve as many arithmetic problems as possible. The more arithmetic problems the students solved correctly, the better their computational skills.

TTR scores in the current study represent the sum of all the correct answers, with a possible range from 0 to 200. These scores were used to identify whether the students' were computationally fluent; a score was calculated based on the principle of automation which states that when a student is able to process the calculation and provide the answer within three seconds, the student has adequate mastery of learned facts and strategies (van de Bosch, Jager, Langstraat, Versteeg, & de Vries, 2009). Applying this principle to the TTR scores meant that students were computationally fluent when they were able to provide 100 or more correct answers within the 5 minutes (300 seconds) of the test.

Domain knowledge of proportional reasoning was assessed with a *domain knowledge test.* This test was used to measure domain knowledge prior to and after the intervention. Therefore, two parallel versions of this test were developed. Both had the same structure and text, but the numbers in the problems were changed. Both tests were equally difficult and they were administered in a counterbalanced order. Reliability analyses of the test scores shows a Cronbach's Alpha of .78.

The domain knowledge tests consisted of 15 open-ended questions: four questions for each type of proportional reasoning problem (i.e., missing value, comparison and transformation) and three transfer questions. The proportional problems of each type were presented in order of increasing difficulty. Every question presented a proportional problem that was similar in context and structure to the problems posed in the game. The three transfer questions were math problems from adjacent domains (i.e., fractions, measurements, and geometry).

For each question, the students had to write down a calculation (procedure) and an answer. Both answers and calculations were coded for the missing value and transformation problems. Because of the nature of the comparison (subject to guessing) and transfer problems (no identifiable procedures), only the answers were coded for these. Answers could be coded as correct, incorrect, or missing. The score for domain knowledge represented the sum of all the correct answers, with a range from 0 to 12. Scores on transfer represented the sum of all the correct answers on the transfer questions, with a range from 0 to 3. In addition, the number of adequate procedures was identified based on the calculations the students had provided at the missing value and transformation problems. Calculations were coded as adequate procedures when they could be identified as known proportional procedures (i.e., proportional procedures that are taught, or that are known to be effective). Table 2.2 provides an overview of the different procedures combined with an example per proportional problem type. If the calculation did not fit one of these procedures, it was coded as inadequate. The score on the adequate procedures could range from 0 to 8.

Furthermore, students' overall perception of the game was assessed with a perception questionnaire. This questionnaire measured students' perceived playfulness and perceived usefulness of the game. The questionnaire consisted of nine 6-point Likert scale items; five items to measure playfulness and four items to measure usefulness. The items that measured playfulness are all based on the 'direct play assessment' subscale from the play experience scale (Pavlas, Jentsch, Salas, Fiore, & Sims, 2012). The items that measured usefulness are all based on the 'usefulness' subscale of the Intrinsic Motivation Inventory (McAuley, Duncan, & Tammen, 1989).

Table 2.2

Scheme for coding calculations in the domain knowledge test

Adequate procedure	Example procedure missing value problem	Example procedure transformation problem
	Question: ***If a recipe for a smoothie prescribes that per 4 strawberries you should add 8 raspberries.*** ***How many strawberries do you need when you want to use 16 raspberries?***	**Question:** ***The recipe for a smoothie prescribes that per 4 strawberries you should add 8 raspberries.*** ***But someone already mixed 6 strawberries with 16 raspberries.*** ***How many strawberries do you need to add to complete the smoothie?***
Internal rationalization based on the internal ratio of the proportion	*4/8 = ?/16* 8 became twice as big (*or* 16 is 2 times 8) Therefore 4 should also be multiplied by 2 2 times 4 is 8 The answer is 8	*4/8 ≠ 6/16 thus 4/8 = 6+?/16* 8 became twice as big (*or* 16 is 2 times 8) Therefore 4 should also be multiplied by 2 2 times 4 is 8 So it should be 8/16 not 6/16 So I need to add two
External rationalization based on the external ratio of the proportion	*4/8 = ?/16* 4 is half of 8 (*or* 8 divided by 2 is 4) Therefore ? should also be half of 16 16 divided by 2 is 8 The answer is 8	*4/8 ≠ 6/16 thus 4/8 = 6+?/16* 4 is half of 8 (*or* 8 divided by 2 is 4) Therefore ? should also be half of 16 16 divided by 2 is 8 So it should be 8/16 not 6/16 So I need to add two
Simplifying first simplifying the first ratio of the proportion before expanding it	*4/8 = ?/16* 4/8 = 2/4 = 8/16 The answer is 8	*4/8 ≠ 6/16 thus 4/8 = 6+?/16* 4/8 = 2/4 = 8/16 So it should be 8/16 not 6/16 So I need to add two
Simplifying to one first simplifying the first ratio of the proportion to a 'something-to-one' ratio	*4/8 = ?/16* How many strawberries do I need for every single raspberry? 4/8 = 0,5/1 I need half a strawberry for every raspberry. There are 16 raspberries. 16 times 0,5 is 8 The answer is 8	*4/8 ≠ 6/16 thus 4/8 = 6+?/16* How many strawberries do I need for every single raspberry? 4/8 = 0,5/1 I need half a strawberry for every raspberry. There are 16 raspberries. 16 times 0,5 is 8 So it should be 8/16 not 6/16 So I need to add two
Correct additive reasoning calculating one or more equivalent ratios and adding it to the first ratio	*4/8 = ?/16* 8 plus 8 is 16 4 plus 4 is 8 The answer is 8	*4/8 ≠ 6/16 thus 4/8 = 6+?/16* 8 plus 8 is 16 4 plus 4 is 8 So it should be 8/16 not 6/16 So I need to add two

All items represented perceptions of the students in regard to the game and its potential for learning, for example: 'the use of this game is beneficial for me (when I am studying proportional problem solving)', and 'the game felt more like 'playing' instead of 'studying''. Reliability analyses of the test scores in the current study showed a Cronbach's Alpha of .68 for the items that measured perceived playfulness, and a Cronbach's Alpha of .90 for the items that measured perceived usefulness.

The students received this questionnaire after they finished the game and had to indicate the extent to which they agreed with the given perceptions (where higher scores equal greater agreement). Scores in the current study are the sum of the scores of all the items per construct, ranging from 0 to 30 for playfulness, and 0 to 24 for usefulness.

Procedure

The total time spent on this study was 200 minutes, spread evenly over four sessions. The first session started with a short introduction. In this introduction the students were informed about the organization of the upcoming lessons and what was expected from them. After the introduction the students completed the TTR and the domain knowledge test. Before starting the game in the second session the students were assigned to the four conditions. Due to large differences in performance between the students the distribution of the students over the conditions was based on their level of performance on the domain knowledge pretest. The students and the teachers received no information on the different conditions and their content and were not aware of any different groups that were made.

The second session started with a short introduction (approximately ten minutes) on how to play the game and on the math problems addressed in the game. The goal was to inform the students and to activate their prior knowledge on proportional reasoning so that they would be able to work independently on the game. Again, expectations were made clear: work individually, no help during the game, keep calm and quiet, and only pay attention to your own screen. Next, the students received codes so they could log in on a version of the game that matched the group they were assigned to. In the third session, the students could resume the game where they left off the previous time. When the students finished the game, the perception questionnaire was administered. In the fourth session, the students completed a parallel version of the domain knowledge test.

Data Analyses

A total of 145 students participated in the study. However, due to the duration of the study, and because it was spread across four sessions, drop-out occurred: two students failed to attend the pretests session, nine failed to attend the posttest session, eight failed to attend both the pre- and posttest sessions, ten failed to complete the game, and six failed to attend both the game and either the pre- or posttest sessions. In total 35 students did not complete the study (24%). Drop-out was evenly spread across conditions. Results of the performance measures are based on the analyses of data from the 110 students who completed all sessions (pretests, game, and posttest). For the results of the perception data eight additional students were left out of analyses, because these students failed to complete the perception questionnaire. For the results of the process data three additional students were left out of the analyses, because these three students loggings during the game were not saved properly.

Several variables were required to answer the research questions. Game generated loggings were consulted to derive in-game performance measures: number of attempts needed to solve challenges, correctly solved challenges, time on task. Time on task is taken as the total amount of time the students actually spent on all the challenges; time spent navigating around the environment was not recorded. A high score for time on task could have been caused by the student requiring more attempts (and thus more time), performing more calculations while solving a challenge, being slower with his or her calculations, or being distracted during the game. A higher score for time on task could therefore represent a weaker math student and/or a less engaged student. Table 2.3 provides an overview of all the variables that were derived from the game generated loggings.

Table 2.3

Coding scheme of in-game performance

Variable	Logging	Coding	Range per level	Range per game
Time-on-task	Time spent on a single challenge	Summation of all the loggings of time	N/A	N/A
Correct answers	Correct answer on a challenge	Summation of all the correct answers	0 - 12	0 - 48
Number of attempts	Attempts needed to complete a challenge	Summation of all the attempts	12 - 28	48 - 112

Results

Table 2.4 summarizes the descriptive statistics for the participants' test-scores and game performance per experimental condition. The overall mean of the pretest score was 6.37 (range = 13, *SD* = 3.00) out of a maximum of 15, which was considered to be sufficiently low to assume that the test could be used to register a development in knowledge. Univariate analysis of variance (ANOVA) revealed no differences in computational skills as measured with the TTR, $F(3, 106) = 1.33$, $p = .269$ (with effect size $\eta_p^2 = .036$), and no significant differences in prior knowledge, $F(3, 106) = 0.12$, $p = .949$ (with effect size $\eta_p^2 = .003$) between conditions. This proves that even after drop-out conditions are comparable with respect to students prior knowledge and skills.

Table 2.4

Summary of students' scores by condition

	Experimental condition							
	Self-explanation and procedural information (*n*= 28)		Self-explanation (*n*= 29)		Procedural information (*n*= 28)		Control (*n*= 25)	
	M	SD	M	SD	M	SD	M	SD
Test scores								
Computational skills (TTR)	115.8	18.2	122.6	23.8	127.7	24.9	118.5	27.5
Domain knowledge pretest	5.2	2.5	5.4	2.1	5.2	2.8	5.4	2.7
Domain knowledge posttest	6.0	3.1	6.7	2.6	7.2	2.8	6.5	2.6
Adequate procedures pretest	3.7	2.6	4.4	2.2	3.9	2.5	4.0	2.5
Adequate procedures posttest	4.8	2.6	5.5	2.4	4.5	2.9	5.0	2.5
Transfer pretest	1.3	1.0	1.0	0.9	1.1	1.0	1.3	1.0
Transfer posttest	1.2	1.0	1.2	0.9	1.5	1.0	1.2	1.0
Perceived usefulness	18.4	6.0	19.5	5.3	17.9	7.4	19.4	8.0
Perceived playfulness	11.0	4.5	14.1	4.4	12.7	4.8	13.3	4.4
In-game performance scores								
Time on task (seconds)	2350	606.1	2056	580.7	2221	688.2	2335	702.9
Number of correct solutions	31.4	7.6	31.2	8.9	33.8	7.7	35.9	8.5
Number of attempts	62.9	13.1	60.9	13.2	64.5	12.3	65.6	15.7

Effects of the Game

A paired sample t-test across all participants indicated a significant difference between total pretest and posttest scores, $t(109) = -5.23$, $p < .001$, with effect size $d = 0.44$. Further analysis indicated a significant difference between the number of adequate procedures on the pretest and the number of adequate procedures on the posttest, $t(109) = -4.47$, $p < .001$, with effect size $d = 0.34$. These results demonstrate that students not only learned to work with proportions implicitly (ability to solve the problem correctly), but also gained explicit knowledge (ability to provide the related procedure).

To evaluate whether playing the game affected students' posttest performance, a stepwise regression analysis was conducted, with computational skills (TTR), pretest domain knowledge score, and game measures (time-on-task and number of correct solutions) as predictors. All predictors were entered simultaneously. Tests to see if the data met the assumption of collinearity indicated that multicollinearity was not a concern (TTR Tolerance = .772, *VIF* = 1.30; pretest Tolerance = .737, *VIF* = 1.36, time-on-task Tolerance = .833, *VIF* = 1.20; and number of correct solutions Tolerance = .736, *VIF* = 1.36). Statistics on the correlations between the variables that were entered in the regression analyses, can be found in Table 2.5.

Table 2.5

Correlations, means, and standard deviations of regression variables

Measure	M	SD	1.	2.	3.	4.
1. Domain knowledge posttest	7	2.8				
2. Domain knowledge pretest	5	2.5	.577**			
3. Computational skills (TTR)	121	23.8	.462**	.374**		
4. Number of correct solutions in game	33	8.3	.486**	.366**	.335**	
5. Time-on-task in game (seconds)	2234	647.0	-.103	-.230*	.208*	.173

*** p <.05, ** p <.01**

The results of the regression indicated that three of the predictors (pretest score, computational skills, and number of correct solutions during the game) explained 52% of the variance in posttest performance, $R^2 = .52$, $F(3,106) = 37.20$, $p < 001$. It was found that pretest scores significantly predicted posttest scores, $\beta = .426$, $p < .001$, as did computational skills, $\beta = .247$, $p = .002$, and the number of correct solutions in the game, $\beta = .237$, $p = .003$. Time spent on challenges within the game did not contribute to the prediction of posttest performance, $p = .779$. These outcomes concur with the expectation that playing the game fosters knowledge acquisition; not only did the students perform significantly better on the posttest, how well they performed on the posttest is partially predicted by how well they performed during the game (when controlling for the effects of prior knowledge and mathematic skills).

Effects of Self-Explanation and Procedural Information on Knowledge Acquisition

The second and third hypotheses were, that self-explanation during the game would foster learning and that the combination of self-explanation and procedural information would produce the best results. A mixed-design ANOVA with time (domain knowledge pretest to posttest) as a within-subject factor and self-explanation and procedural information as between-subject factors revealed a main effect of time, $F(1, 106) = 27.40$, $p < .001$, $\eta_p^2 = .205$. This effect was not qualified by an interaction between time and self-explanation, $F(1,106) = 1.30$, $p = .257$, $\eta_p^2 = .205$, nor was there an interaction between time and procedural information, $F(1,106) = 0.28$, $p = .600$, $\eta_p^2 = .003$. The hypothesized interaction of time, self-explanation and procedural information was not significant, $F(1,106) = 3.01$, $p = .085$, $\eta_p^2 = .028$.

In addition, a mixed-design ANOVA with time (adequate procedures pretest to posttest) as a within-subject factor and self-explanation and procedural information as between-subject factors revealed a main effect of time, $F(1,106) = 19.74$, $p = .000$, $\eta_p^2 = .157$, and no effect of self-explanation, $F(1,106) = 0.09$, $p = .765$, $\eta_p^2 = .001$, or procedural information, *F*(1,106) = 0.01, $p = .920$, $\eta_p^2 = .000$, on the number of adequate procedures from pretest to posttest.

Furthermore, whether self-explanation and procedural information supported transfer was investigated. Hence, scores on transfer problems were analyzed. A mixed-design ANOVA with time (transfer pretest to posttest) as a within-subject factor and self-explanation and procedural information as between-subject factors revealed no main effect of time, *F*(1,106) = 2.76, $p = .100$, $\eta_p^2=.025$, no interaction between time and self-explanation, F(1,106) = 0.10, $p = .759$, $\eta_p^2=.001$, no interaction between time and procedural information, *F*(1,106) = 0.53, $p = .467$, $\eta_p^2=.005$, and no three-way interaction, *F*(1,106) = 2.84, $p = .095$, $\eta_p^2=.026$. These outcomes, though they support the previous finding that students learnt from the game, do not support the hypotheses that self-explanation prompts, procedural information, or a combination of both, support students' knowledge acquisition during game play.

Effects of Computational Fluency on Knowledge Acquisition

To evaluate whether computational fluency affected students' ability to learn from the game and their ability to benefit from the support, a mixed-design ANOVA with time (domain knowledge pretest to posttest) as a within-subject factor and self-explanation, procedural information, and computational fluency as between-subject factors, revealed a main effect of time, F(1,102) = 7.64, p = .007, $\eta_p^2 = .070$, and an interaction between computational fluency and time, F(1,102) = 4.96, p = .028, $\eta_p^2 = .046$, with the students who were computationally fluent outperforming the students who were not. There was no interaction between time, self-explanation and computational fluency, F(1,102) = 0.39, p = .535, $\eta_p^2 = .004$, and no interaction between time, procedural information and computational fluency, F(1,102) = 0.03, p = .868, $\eta_p^2 = .000$. All other effects were non-significant.

Effects of Prior Knowledge on Knowledge Acquisition

To evaluate whether prior knowledge affected students' ability to learn from the game and their ability to benefit from the support, students were grouped as performing either below average or above average based on their domain knowledge pretest scores. Then a mixed-design ANOVA with time (domain knowledge pretest to posttest) as a within-subject factor and self-explanation, procedural information and prior knowledge as between-subject factors revealed a main effect of time, *F*(1,102) = 24.14, $p < .001$, $\eta_p^2 = .191$, and an interaction effect from prior knowledge and time, *F*(1,102) = 27.27, $p = .009$, $\eta_p^2 = .065$, with the below-average students outperforming the above-average students. There was no interaction between time, self-explanation, and prior knowledge, *F*(1,102) = 3.35, $p = .070$, $\eta_p^2 = .032$, and no interaction between time, procedural information, and prior knowledge, $F(1,102) = 0.12$, $p = .731$, $\eta_p^2 = .001$. All other effects were non-significant.

These outcomes support the assumption that students with different levels of computational fluency, or prior knowledge are affected differently by playing the game, but do not support the hypothesis that these students are affected differently by the added support (i.e. self-explanation prompts, and procedural information).

Effects of Self-Explanation on Perception

In accordance with our last research question, differences in perception between conditions were investigated. To evaluate whether support in the game affected students' perception of the game, multivariate analysis of variance (MANOVA) with support (self-explanation and procedural information) as independent factors and perception (playfulness and usefulness) as dependent factors was conducted. The results of Pillai's Trace multivariate test showed no main effect from self-explanation, $F(1,98) = 0.18$, $p = .839$, $\eta_p^2 = .004$, no main effect from procedural information, $F(1,98) = 2.76$, $p = .068$, $\eta_p^2 = .054$, and no interaction between self-explanation and procedural information, $F(1,98) = 0.99$, $p = .375$, $\eta_p^2 = .020$. These outcomes indicate that there was no effect of the support (i.e., self-explanation prompts, and procedural information) on students perception of the playfulness and usefulness of the game.

Further Exploration

Results from the analyses of the effects of prior knowledge and computational fluency led us to believe that students' basic arithmetic abilities and prior domain knowledge influence whether they are able to learn from the game. Therefore, we evaluated which groups were able to benefit from the game and explored how they differed on in-game performance. For this evaluation/exploration we differentiated between students who were computationally fluent, and students who were not (based on the automation principle of van de Bosch, et al. (2009), as described earlier). In addition, because the results from analyses showed that students' prior knowledge affects the effect of the game, we also differentiated in students with above and below average prior knowledge (on condition that the students were computationally fluent).

First, we evaluated whether playing the game would help the different groups of students to learn about proportional reasoning. A paired sample t-test for the three groups showed a significant difference between total pretest and posttest scores for the computationally fluent students with below average prior knowledge, $t(42) = -7.25$, $p < .001$, $d = -1.16$, and the computationally fluent students with above average prior knowledge, $t(43) = -2.20$, $p = .034$, $d = 0.40$. However, the paired sample t-test results revealed no significant difference between total pretest and posttest scores for students who were not computationally fluent, $t(22) =$ -

0.57, $p = .573$, $d = -0.14$. This indicates that computational fluency is a prerequisite for learning from the game, and that when students are computationally fluent, all students, regardless of their prior knowledge, can benefit from the game.

Discussion and Conclusion

Overall Learning and Perception

One of the principal outcomes of this study is that students' ability to solve proportional problems increased significantly after playing the game, and that, despite the high density of educational content in the game, students generally perceive the games' playfulness as average and usefulness as slightly above average. These were not obvious outcomes, because the topic of proportional reasoning is quite demanding for prevocational students, and these students have built up some resistance to learning in general.

Further analyses revealed that students' posttest scores could be predicted by students' computational skills and domain knowledge, and that in-game performance showed an additional (unique) predictive value. This finding suggests that game play does indeed matter for acquiring proportional reasoning skills. Though students showed progress on proportional reasoning, analysis of transfer problems showed that there was no transfer. This is in line with previous findings on game-based learning that indicate that game-based learning does facilitate knowledge acquisition, but that students often experience difficulty in making this knowledge explicit which results in poor performance on transfer tasks (Chi, et al., 1989; Wouters, et al., 2008). Nonetheless, in the current study, students did show some attainment of explicit knowledge representations; students did gain competence in providing explicit representations of the employed procedures. That transfer failed to happen might be because these students were not able to disconnect what they had learned from the context that it was learned in, and therefore were not able to identify how they could use this newly obtained knowledge to help them solve the transfer problems.

Effects of Self-Explanation and Procedural Information

The current study evaluated the usefulness of support (self-explanation prompts and procedural information) for stimulating knowledge acquisition from an educational mathematics game. Results showed that support in the form of self-explanation prompts did not affect performance on proportional reasoning and transfer. The procedural information had no additional value as well. This indicates that the provision of procedural information did not serve as an aid for self-explanation, or knowledge acquisition. These findings contrast with work by Johnson and Mayer (2010), who found an effect of a similar implementation of self-explanation prompts. In the study by Johnson and Mayer (2010), however, participants were university college students, whereas in this study prevocational students were involved.

These groups of students have substantially different cognitive capacities and study skills, that may explain the difference in findings. We cautiously conjecture that—based on the cognitive demands self-explanation requires—our students lacked the capacity to engage in a productive self-explanation. In addition, it should be taken into account that the support was restricted and was fixed and did not necessarily match students' performance or experience. The number of prompts, the timing, and the interval could have influenced the effectiveness. Though the game rewarded students who actively participated in the support measures, it might still be that students were reluctant to respond to the prompts and therefore effects of support could have been diminished.

Analysis of students' perception of the game showed that the addition of the support did not affect their opinion on the usefulness or playfulness of the game. Thus, the current implementation of instructional support (in the form of self-explanation prompts and procedural information) to the serious game did not affect how students perceived the game. However, the current intensity of support in the game did not facilitate learning. A higher density of instructional support might be necessary to facilitate students' learning, but could also negatively influence students' perception of the game, and thus disrupt their motivation. Research is needed to explore the balance between instructional content, perception/motivation, and how these affect game-based learning.

Prior Knowledge and Computational Fluency

Our data suggest that students' capabilities are a decisive factor in the effects of the game. The results of the current study indicate that both students with below average and above average prior knowledge were able to learn from the game. Indicating that students who had not previously been able to meet their potential were able to learn successfully about proportional reasoning when using the game. However, computational fluency seemed to be a prerequisite for this learning. Students who are computationally fluent outperformed students who were not. Only the first group showed significant growth in domain knowledge. Several factors might explain the fact that the students who were not computationally fluent failed to learn from the game.

First, computational skills are necessary when solving proportional problems. Research has shown a clear link between students' understanding of the concept of multiplication and their proportional reasoning skills (Tourniaire, 1986). The game is not designed to teach the students computational skills. Though the students are challenged to work on them, and may improve them, their deficit can still create a threshold for actually improving their proportional reasoning.

Second, a lack of computational skills makes the students vulnerable for frustration when the game does not adapt to their level. The current game was designed to progress in difficulty at a fixed pace. Though this progression was designed to fit the pace of prevocational students learning proportional reasoning, students who could not keep up with this pace, could fall behind which could induce frustration and loss of engagement.

And third, students who have not reached computational fluency by the time they are in secondary school, are more likely to suffer from severe learning deficits or even didactic resistance. Computational skills are taught in primary school and make up the basis for all future math problem solving (Calhoon, Emerson, Flores, & Houchins, 2007). This means that the group of prevocational students who, despite age, education and remediation, have not mastered these skills, is likely to contain a large population of at-risk/low level students. Also, severe deficits in the development of computational skills has been linked to mathematical disabilities (Calhoon, et al., 2007; Warner, Schumaker, Alley, & Deshler, 1980). It could be that specifically this group is less susceptible for game based learning, because the game creates a setting where the relevant information is clouded by irrelevant additions (e.g. storyline, decorative representations). Mayer (2005) states that decorative representations induce unnecessary processing demands and can distract from learning. Recent findings from Magner, Schwonke, Aleven, Popescu, and Renkl (2014) imply that this extra processing load can be specifically disturbing for low-level students.

Conclusion

Overall, the results of the current study point toward the fact that game-based learning can help improve prevocational students' proportional reasoning, but that computational skills can influence the effectiveness. Our results showed that, although most students from our specific target group are able to learn from the game environment, there is also the risk that a number of students will fail to learn. It should be noted that when working with prevocational students, there will be students who fall behind but who do have the potential to grow and have just missed out on the ideal opportunity, and there will also be students who have already reached their potential, or who have deeper problems—such as learning deficits— that are preventing them from living up to their potential. In the current study, the learning process was stimulated for the students who were computationally fluent, but the students who were not were not able to learn from the game. This translates to the conclusion that the game was able to stimulate the students who failed to grasp proportional reasoning when working with other educational material but do have the potential to comprehend the subject matter, but that the game could not help the students who seem to have a severe deficit when it comes to mathematics. The high processing load of game-based learning environments might provide an explanation for these results.

The current study set-out to research whether support in the form of directive self-explanation prompts and procedural information could help students' game based learning. Results indicated no positive effects of self-explanation prompts or procedural information. We must, however, interpret these results carefully due to the number of participants. Nonetheless, in line with the focus of this study, it might be interesting to see how adaptive rather than fixed support can affect these students' game-based learning. Providing students with the just-in-time support is likely to be more effective than a fixed type of support (Berry & Broadbent, 1987; Gee, 2003; Hulshof & de Jong, 2006; Sweetser & Wyeth, 2005). Adaptive feedback, adaptive instructional support or even (heterogeneous) collaborative implementation of game-based learning could help accomplish this. In addition, it might be beneficial to compare motivational and learning effects of game-based learning to those of more traditional education in order to consider the practical implementations of game-based learning within an educational perspective.

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3

Collaboration

A Study of the Effects of Heterogeneous Collaboration and In-Class Competition

This chapter is based on:
ter Vrugte, J., de Jong, T., Vandercruysse, S., Wouters, P., van Oostendorp, H., & Elen, J. (2015). How competition and heterogeneous collaboration interact in prevocational game-based mathematics education. *Computers & Education*, *89*, 42-52.

Introduction

Computer Games as a Mathematical Tool for Prevocational Students

In the United States of America and Europe government has set goals regarding students' expected level of proficiency in mathematics, such as the American 'no child left behind act' (Commissie voor onderwijs cultuur en wetenschapsbeleid, 2010; Heinrich, 2015). But reports show that students and schools fail to meet these goals (CvE, 2014; Heinrich, 2015). Therefore, it is important to find methods of improving students' academic achievement in mathematics. Research shows that mathematical training significantly improves the performance of higher and average-performing students, but that the needs of lower achievers are not always addressed successfully (Jitendra et al., 2007; Schoenfeld, 2002). Furthermore, most research on mathematical education addresses primary school or university students, or specific groups of learning-disabled students. Research addressing other levels of education, such as prevocational education, seems scarce.

Prevocational education is a track in secondary education in which students are specifically prepared for intermediate vocational education. Students who attend the prevocational track show wide variety in their cognitive abilities and potential. Underachieving prevocational students have often struggled with subjects such as mathematics for years, and teachers in the prevocational track are therefore dealing with demotivated or apprehensive students who are unwilling to participate in education. Kramarski (2013) emphasizes the need for alternative training programs to help this group of students (from less-advanced levels of education) to conceptualize mathematical topics and to increase their engagement and experiences of success. Based on recent findings on the affordances of educational mathematics games (Kebritchi, Hirumi, & Bai, 2010; Shin, Sutherland, Norris, & Soloway, 2012; ter Vrugte et al., 2015; Young et al., 2012), we assume that computer game-based learning has the potential to meet this need.

Educational computer games are not just attractive for education because of their motivational components (e.g., Papastergiou, 2009; Paras & Bizzocchi, 2005; Squire, 2003); the interactive representations that games encompass can directly enhance learning outcomes (Habgood & Ainsworth, 2011). Computer games also make a diversity of vivid, comprehensive, and realistic problem-solving contexts easily accessible. This can help teachers to create settings in which otherwise abstract educational subjects can be made concrete, without needing to take field-trips, gather hands-on material, or rely on language to simulate context. All of this can support the accessibility of the mathematical subject matter for students who are not well equipped to learn mathematics topics, as is often the case for students such as those in prevocational education.

Competition as Motivator

The motivational component of games, as indicated above, makes them an appealing alternative instructional approach for prevocational students. A key element that is assumed to foster motivation during gameplay is competition. Competition makes games feel like play and stimulates engagement and persistence in the learning activity (Malone & Lepper, 1987). Though competition seems to be a key motivational element, there is limited research that addresses the empirical effectiveness of competition in games (Van Eck & Dempsey, 2002; Vandercruysse, Vandewaetere, Cornillie, & Clarebout, 2013).

Competition comes in many forms. One can compete against the system, against oneself, or against others (Alessi & Trollip, 2001). Computer games incorporate one or more of these forms in a variety of ways. For example, players can compete against time, improve on previous high scores, acquire high scores that give them access to higher levels or special features, and beat other players. Positive effects of competition that, in turn, can facilitate learning, are held to arise from the creation of an additional challenge, generating excitement, engagement and motivation (Cheng, Wu, Liao, & Chan, 2009; Malone & Lepper, 1987).

Competition during game-based learning has been found to positively affect game performance (Plass et al., 2013), learning (Kollöffel & de Jong, in press), and the quality of learning (DeLeeuw & Mayer, 2011). However, we must bear in mind that making competitive elements more salient can also lead to negative effects. Social comparison during competition can cause less secure learners' performance to be undermined, and could induce tension, anxiety and feelings of frustration and inferiority in these learners, all of which can diminish their performance (Cheng, et al., 2009). In addition, Van Eck and Dempsey (2002) found that the addition of competition affected the otherwise positive effects of contextualized advisement, demonstrating that competition can distract students from otherwise beneficial learning content and support.

Collaboration as Support

When designing educational games, it must be kept in mind that empirical evidence on the educational value of serious games is ambiguous, and that evidence supporting their expected effectiveness remains limited (Girard, Ecalle, & Magnan, 2013; Young, et al., 2012). Researchers and designers experience difficulties designing educational games that maintain motivational integrity, and even when researchers succeed in designing a motivational educational game, learning is not guaranteed (Garris, Ahlers, & Driskell, 2002). To be effective, educational games need to include support that can help to make explicit the knowledge involved (Leemkuil & de Jong, 2012) and, when necessary, can help students to acquire the relevant information (Leemkuil, de Jong, de Hoog, & Christoph, 2003; O'Neil, Wainess, & Baker, 2005).

The diversity of the population in prevocational education, may create a particular challenge for the design of an effective learning environment. Even support structures that have proven to be successful in other contexts, domains, or levels of education do not guarantee the success of an educational game in prevocational education. This has been demonstrated in the study by ter Vrugte, et al. (2015), which investigated whether the addition of reflection prompts and procedural information could enhance prevocational students' knowledge acquisition during game play. Even though reflection is often mentioned as a successful measure for stimulating knowledge acquisition and making knowledge explicit (e.g., Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Ke, 2008; Wouters, Paas, & van Merriënboer, 2008), and it has been proven to be successful when integrated in game-based learning (Johnson & Mayer, 2010), results from the study by ter Vrugte, et al. (2015) did not demonstrate any added value of reflection prompts or procedural information in a mathematics game for prevocational students. They explain that this might be due to the cognitive skills that reflection requires, or that the support might not have been provided frequently enough or at the right moments. We suggest collaboration as a continuous and adaptive form of support that can help students to extend and make explicit their knowledge during game-based learning.

Research in non-computer settings suggests that students often learn more effectively in groups than alone (Lou et al., 1996). Alessi and Trollip (2001) describe how collaborative multimedia environments have several advantages over non-collaborative multimedia environments: participants play the roles of both teacher and student, social skills are fostered, and metacognitive skills may be improved. Though not all educational content might benefit from a collaborative approach, Lou, et al. (1996) indicate that the hierarchical nature of mathematical tasks makes them suitable for successful implementation of collaborative learning. Overall, research concludes that collaborative learning in mathematics helps to eliminate students' frustration, because collaboration offers an adaptive support network (Davidson & Kroll, 1991; Whicker, Bol, & Nunnery, 1997).

Explanation in collaborative settings has been shown to foster knowledge acquisition (Gijlers, Saab, van Joolingen, de Jong, & van Hout-Wolters, 2009). And when collaboration is implemented in heterogeneous groups, students not only benefit from the effect of their explanations to others, fostering the creation of more explicit knowledge structures that aid generalization, but less able students also benefit from an adaptive source of support, receiving information when needed (Webb, 1982, 1984). Though research on collaboration in game-based learning seems limited, and results thus far do not always favor collaborative game play over individual game play (Chen, Wang, & Lin, 2015; Ke & Grabowski, 2007; Meluso, Zheng, Spires, & Lester, 2012; Plass, et al., 2013; van der Meij, Albers, & Leemkuil, 2011), some studies did report positive effects of collaboration on students' learning (Chen & Law, 2016), attitude towards the learning domain (Ke & Grabowski, 2007), and students' gameplay (Inkpen, Booth, Klawe, & Upitis, 1995), motivation and engagement (Inkpen, et al., 1995; Plass, et al., 2013). Therefore collaboration seems an attractive approach to support game-based learning.

Combining Competition and Collaboration

At first glance competition and collaboration may appear contradictory because collaborative learning means that students will be working together, while competition would imply that students are working 'against each other'. However, some models of collaborative learning suggest that the two can positively affect each other. Two of the most well-known competitive collaborative models are the 'Teams-Game-Tournament'(TGT) model and the 'Student-Teams-Achievement-Design'(STAD). Both can be considered as competitive designs because teams of students are competing against each-other. In TGT small heterogeneous teams of students work together. The primary function of the team is to make sure that each individual member can perform well in an instructional tournament. The design is as follows: teams receive instructional content, work together to maximize each individuals knowledge, and play individually during an instructional tournament. Individual scores will be summed up to a total team score. Team scores are compared. In STAD small heterogeneous teams of students work together. The primary function of the team is to get a high score on a collaborative task and to make sure that each individual member can perform well on an individual instructional task afterwards. The design is as follows: students complete an individual assessment, students receive instructional content, teams work together on a collaborative task and try to maximize each individuals knowledge during this task, students complete an individual assessment. Individual scores (progress in performance on individual assessment) and team score (performance on collaborative task) will be summed up to a total team score. Team scores are compared. In a review study on collaborative techniques Slavin (1980) concludes that the use of group competition has a positive effects on achievement. In both TGT and STAD group competition is used as an incentive for students interactions. In addition, in STAD the team scores represent both individual and team efforts, thus accounting for individual accountability and positive interdependence. Two elements that have been identified as essential in successful collaborative learning (Davidson & Kroll, 1991; Kyndt et al., 2013).

Plass, et al. (2013) addressed the effects of collaboration and competition in an educational game. They compared individual, competitive and collaborative gameplay and found no differences between conditions on learning, but did find that competition increased in-game performance, while collaboration decreased in game performance. Another example of research that addressed the combination of collaboration and competition in an educational (math) game, is the study published by Ke and Grabowski (2007). They explored whether computer games and collaborative learning could be used together to enrich mathematics education. They designed their collaborative condition in accordance with the TGT and found that, though gameplay promoted mathematical performance, there was no difference between collaborative or individual competitive gameplay on student achievement.

Current Study

In the current study, two factors that might contribute to the effectiveness of game-based learning in prevocational education are investigated: competition and collaboration. Based on the literature, the following conclusions can be drawn: educational games have potential for prevocational education; competition can foster motivation and engagement, but can also distract learners from educational content; and, in theory, game-based learning could benefit from collaboration, because it creates a setting that aids adaptive and continuous support and has the potential to foster both acquiring knowledge and making it explicit, but empirical research thus far does not favor collaborative gameplay over individual gameplay. Nonetheless, because working together at the computer is an integral part of prevocational education nowadays, implementing collaboration in a prevocational computer game-based learning setting seems like a non-intrusive step for supporting game-based learning. The current study employed a 2x2 factorial design with four conditions: the game with collaboration, the game with collaboration and competition, the game with competition only, and, as a control condition, the game without collaborative and competitive facilities. Therefore we not only explored main effects of collaboration and competition on learning, but we also investigated possible interactions between collaboration and competition.

Our first expectation was that the conditions in which students collaborated would result in greater learning compared to the solitary conditions. This is based on the assumptions that collaboration can lessen frustration and stimulate engagement (Davidson & Kroll, 1991; Whicker, et al., 1997) and that students who collaborate are more prone to externalize their knowledge, which in turn stimulates the formation of more explicit knowledge structures and deeper understanding of the material (Gijlers, et al., 2009; Webb, 1982).

Based on previously mentioned literature, our second expectation was that adding competition to a game would affect learning. Competition is likely to positively affect learning outcomes because it can stimulate game-performance and engagement. However, literature also shows that it could distract players from the educational content or can lead to feelings of frustration, and this could negatively affect learning outcomes.

Our third expectation was that the addition of competition would affect the effectiveness of collaboration. Competition in a collaborative setting can affect positive interdependence and individual accountability, two components that are considered to be crucial in effective collaborative learning. However, in a heterogeneous collaborative setting competition can also result in a disruption of the balance of the collaboration, causing one student (most likely the stronger student) to become more dominant.

Method

Participants and Design

The sample included 242 students, 118 boys and 124 girls, aged 11 to 15 years old (*M* = 13.3, *SD* = 0.748) from the first (*N* = 191) and second (*N* = 51) years in the program of study from three 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.

The study incorporated four conditions. Students were assigned to conditions based on their school class and school, ensuring that all schools were represented in all conditions. All of the conditions were identical in terms of embedded learning objectives (proportional reasoning) and learning material (the game environment) and differed only on two variables: the presence or absence of collaboration, and the presence or absence of competition.

Collaboration. The collaborative conditions employed unscripted, face-to-face, collaboration in dyads. The following design considerations from Davidson and Kroll (1991) and Kyndt, et al. (2013) were taken into account in designing the collaborative conditions: positive interdependence (group size was kept to a minimum, with only two students per group), promotive interaction (heterogeneous grouping was employed to maximize the benefits of collaborative learning), and individual accountability (individual testing).

Based on a meta-analysis by Lou, et al. (1996), in which it is concluded that grouping does not affect high ability students, but that heterogeneous grouping is most beneficial for low ability students, heterogeneous pairs were created. This was done using students' prior knowledge as measured with the domain knowledge pretest; above-average students were grouped with below-average students. Students were classed as above-average when their score was 6 or more on the proportional problems of the domain knowledge pretest (first 12 items: missing value, transformation, comparison problems), students were classed as below average when their score was 5 or less on the proportional problems of the domain knowledge pretest (on the same items). To create pairs with a substantial difference in prior knowledge but maintain comparability between pairs, the difference in prior knowledge between the below and above average students was controlled: the minimum difference was three points and the maximum difference was six points on pretest score. Students were not informed on the conditions of the grouping.

Competition. Students in the individual competitive conditions were told that they were competing against each other and students in the collaborative competitive conditions were told that they were competing against the other teams. Students were informed that their score would be a combination of their game score and their progress (percentage that presented the increase in correct answers on the posttest relative to the pretest), and that this meant that they would all have an equal opportunity to win because their prior knowledge was taken into account.

To fuel the experience of competition among the students, score overviews were provided at the start of the second game-session. In addition, during the game sessions (every ten minutes) the researcher checked the scores and told the class what the highest game score at that time was.

Collaboration and Competition. The condition where students both collaborated and competed was in line with the Student-Team-Achievement-Design (STAD). Students worked together in teams (two students) and competed with other teams in their classroom. Each team received one team score. This score derived from their team-performance during the game (game score) combined with each members' individual progress. This individual progress was a percentage that presented the increase in correct answers on the posttest relative to the pretest. Thus, team-score = game-score + progress team member one + progress team member two.

Materials

Domain. The current study focusses on the domain of mathematics because it is a fundamental skill for future school achievement, and prevocational students' mathematics skills are often inadequate (CvE, 2014). The game was designed to teach and practice the mathematics sub-domain 'proportional reasoning'. The selection of proportional reasoning was driven by the following reasons: first, it is a fundamental skill for future mathematical understanding and success (Rick, Bejan, Roche, & Weinberger, 2012). And second, traditional instructional methods for proportional reasoning are often ineffective (Rick et al., 2012), and therefore students regularly lack proportional reasoning skills (Lawton, 1993; Tourniaire & Pulos, 1985). Also, recent reports of the Cito (an international recognized *organization* for tests, assessments and examinations) show a severe deficiency of prevocational students in proportional reasoning skills (Cito, 2011).

Within the domain of proportional reasoning, three types of problems can be identified: comparison problems, missing value problems, and transformation problems. Table 3.1 provides a summary of these three types of problems.

Table 3.1

Summary of proportional problems and their levels

Problem type	Goal	Levels
Comparison	The student has to uncover the relationship between two proportions. Possible answers are: proportion one is 'more-than', 'less-than' or 'equal-to' proportion two	The difficulty of ***comparison problems*** is determined by the method that is required to solve the problem: 1. Can be solved by *qualitative reasoning*. The answer to these problems can be achieved by reasoning because either the values for two dimensions are equal (e.g., 1:4 vs. 3:4), or the comparison is between ratios that obviously differ in size (e.g., 100:31 vs. 42:100). 2. Can be solved by *estimation*. In this case, the answer can be estimated because the internal* or external** ratio allows for easy multiplication (e.g., 2:4 vs. 4:6) or the internal or external ratio matches a simple reference point (e.g., 1/2, 1/3, 1/4, or 1/10). 3. Has to be solved using *full calculation*. The answer cannot be reasoned or estimated, but has to be computed (e.g., 14:63 vs. 18:81).
Missing value	The students are provided with one complete proportion and a proportion with a missing value. The students have to calculate the value that is missing, assuming that both proportions have to be equal (e.g., 3:6 = ?:12).	The difficulty of ***both missing value and transformation problems*** is determined based on the multiplicative relations in the internal ratio and external ratio being integer*** or not (e.g., Kaput & West, 1994; Tourniaire & Pulos, 1985; van Dooren, de Bock, Evers, & Verschaffel, 2009): 1. Internal ratio integer, external ratio integer (e.g., 2 cups of milk per 1 spoon of fruit equals 4 cups of milk per 2 spoons of fruit) 2. Internal ratio integer, external ratio not integer (e.g., 4 cups of milk per 6 spoons of fruit equals 2 cups of milk per 3 spoons of fruit) 3. Internal ratio not integer, external ratio integer (e.g. 2 cups of milk per 4 spoons of fruit equals 3 cups of milk per 6 spoons of fruit) 4. Internal ratio not integer, external ratio not integer (e.g., 4 cups of milk per 6 spoons of fruit equals 6 cups of milk per 9 spoons of fruit)
Transformation	The students are provided with two unequal proportions (e.g., 3:6 ≠ 4:12). The students have to calculate how much has to be added to one proportion to make both proportions equal.	

* ***internal ratio***: ratio of two numbers of the same variable or term, ** ***external ratio***: ratio of two numbers of different variables or terms, *** ***integer***: a whole number (not a decimal)

Game. The intervention consisted of a fully mouse-operated computer game: 'Zeldenrust'. The game follows a number of design principles outlined by Papastergiou (2009). First, clear goals are introduced in the narrative and form an integral part of the storyline of the game: e.g., students are introduced to the goal of earning money at the start of the game, and are reminded how they can earn money at every subgame. Second, to ensure progressive levels of difficulty and minimize frustration, a level structure was adopted, and immediate and constructive feedback was provided. And third, the theme of the narrative (earn money) was designed specifically for teenagers, so that the game (fantasy) world could be linked to their daily activities.

The game narrative places the students in the role of a teenager who desperately wants to go on a holiday but has no money, and who therefore takes on a job as a hotel employee. The goal is to earn as much money as possible to be able to afford the most expensive holiday destination. To earn this money, the students have to complete challenges in the hotel, e.g., they have to fill the refrigerator and serve customers. These challenges all take place in a challenge-related game-environment (subgame). The more effectively and efficiently the students complete these subgames, the more money they can earn. However, inefficiency (e.g., dropping bottles from the fridge, inaccurate solutions) reduces the amount of money that can be earned upon completion of the subgame. In addition, students can trade money for support (i.e., calculator). This support can help them to solve the challenges more accurately.

When the game starts, students see a short animation that introduces them to the storyline and the goal of the game. After this, they can choose an avatar (from four options), they meet the hotel owners (non-playable characters), and are shown their virtual room. This room is a central point in the game. From here, students can navigate to various subgames. Figure 3.1 shows screencaptures of the different subgames.

Figure 3.1. Screendumps of subgames (translated). From left to right: fridges, blender, jugs.

In total, the game contains three types of subgames with four levels per subgame. Each subgame represents a proportional problem type (see Table 3.1) and the subgames are fully embedded in the storyline of the game. Comparison problems are presented in a subgame named ‘jugs’. In this subgame the player has to serve the required beverage mix. Missing value problems are presented in a subgame named ‘refrigerators’. In this subgame the student has to identify the missing number of bottles and refill the fridge. And last, transformation problems are represented in a subgame named ‘blender’. In this subgame the student has to ‘repair’ poorly executed recipes. Table 3.2 provides an overview of the subgames and examples of the challenges.

Table 3.2
Overview of level structure per subgame

Subgame	Problem type	Example of problem	Game level: difficulty
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: level 1 problems 2: level 2 problems 3: level 3 problems 4: mix of all levels
Fridges	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: level 1 problems 2: level 2 and 3 problems 3: level 4 problems 4: mix of all levels
Blender	Transformation	*“A fruit cocktail recipe prescribes 10 berries for every 100 ml of yoghurt. Somebody already mixed 10 berries and 500 ml of yoghurt. Can you complete the recipe?”* The given ratio of 10/100 is presented next to the incomplete ratio of 10/500. The student has to answer the question by dragging and dropping the berries into the blender.	1: level 1 problems 2: level 2 and 3 problems 3: level 4 problems 4: mix of all levels

When students enter a subgame, the owners introduces the challenge that must be completed, such as serving drinks, filling fridges, and mixing cocktails. In addition, in the first level, all of the subgames start 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 is correct. After the first trial, the feedback states whether the answer is right or wrong. After a second trial, the feedback either states that the answer is correct or whether the answer is more or less than the correct answer (e.g., “This number is not correct. You have used too much juice.”). After a third trial, the feedback states whether the answer is right or wrong and the game proceeds to the next challenge. After four challenges, the students receive the money they earned during the subgame, and return to their room. In their room, they can keep track of their holiday destination on a geographical map, or start a new subgame. Every subgame can be opened only once per level. After completion of all three subgames at one level, the students are given access to the next level. This structure fosters maximum variation (in context and problem type) in combination with progressive difficulty. The objective of this structure is to promote the experience of challenge and reduce feelings of frustration.

Test materials. To assess computational fluency, students completed an arithmetic tempo test, the *TTR (Tempo Test Rekenen)*. This is a validated test developed in the Netherlands and Flanders which aims to measure to what extent students are fluent in basic arithmetic computation, i.e., addition, subtraction, multiplication, and division (de Vos, 1992). The test consists of these four types of computation spread over five columns, one column for each type and one with all types mixed. There are 40 arithmetic problems per column. The students have one minute per column to solve as many arithmetic problems as possible. TTR scores in the current study represent the sum of all correct answers, with a possible range from zero to 200.

Domain knowledge was tested with a *domain knowledge test* (DK). The test consisted of 16 constructed response questions. Twelve questions presented a proportional problem similar in context and structure to the problems posed in the game: four questions for each type of proportional reasoning problem, presented in order of increasing difficulty within each type. Finally, to assess near transfer, four questions presented proportional problems that were similar in structure, but differed in context from the problems posed in the game. The score on domain knowledge represented the percentage of all correct answers (number correct divided by 16 times 100), with a range from 0 to 100. In addition students received a score that presented the percentage of correct answers on item 1-12 (similar problems: proportional problems that matched the context of the game) and a score that presented the percentage of correct answers on item 13-16 (transfer problems: proportional problems that did not match the context of the game).

This test was used to measure domain knowledge both before and after the intervention. Therefore, two parallel versions of this test were developed. Both consisted of the same structure and text, with only the numbers altered. The two versions were administered in a counterbalanced design, with approximately 50% of the students 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 Alpha of .698 on the pretest and .743 on the posttest.

Procedure

The total time of the experiment was 200 minutes spread evenly over four sessions. The first session started with a short introduction. During this introduction, students were informed about the organization of the forthcoming lessons and what was expected from them. Students received no information on the different conditions. After the introduction the students individually completed the TTR and the domain knowledge test.

Conditions were assigned per school class. Students in the collaborative condition were grouped heterogeneously. To prevent social problems during collaboration, the pairing of students in a collaborative group was assessed by the teacher and adapted as necessary.

The second session started with a short introduction of approximately ten minutes on how to play the game and on the mathematical problems addressed in 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. Again, expectations were made clear (work individually or with your partner, no help during the game, keep calm and quiet, and only pay attention to your own screen). In the collaborative conditions, students were informed who their teammate was, and in the competitive conditions students were informed that (and how) scores would be registered and that the ranking of scores within the class would be presented during the subsequent session. After this, students started the game. In the third session, all students could resume the game where they had left off the previous time, and the students in the competitive conditions were informed of their rankings and reminded that their final scores would be a combination of their game score and their (individual) progress. In the fourth session, students individually completed the domain knowledge test and the students in the competitive conditions received information about their rankings.

Results

Due to the fact that the study was spread across four separate sessions, some drop-out (10.2%) occurred. A total of 242 students began the study, but 25 failed to attend all research sessions (i.e., pretest, game session one, game session two, post-test). Results are based solely on analyses of data from students who attended all research sessions. In the case of students of collaborative pairs, when one of the students would not attend the posttest the other student would still be included in the analysis, when one of the students would miss one of the game sessions both of the students would be excluded from the analysis. An additional 49 students from the collaborative condition were excluded from analysis because they missed the pretest, or could not be grouped in accordance with the grouping terms, meaning that they could not be grouped in a pair, or could not be grouped in accordance with the heterogeneous terms ('a minimum difference of three points and a maximum difference of six points on pretest score').

Table 3.3 summarizes the descriptive statistics for the participants' test scores per condition. To aid interpretability the scores of the domain knowledge test are presented in percentage correct. The overall average pretest-score was 6.38 ($SD = 2.75$) out of 16, thus 40% correct, this was considered sufficiently low to allow room for growth. Univariate analyses of variance (ANOVA) revealed no differences between conditions in computational fluency, $F(3,164) = 1.900$, $p = .132$, with effect size $\eta_p^2 = .030$, no significant differences between conditions in prior domain knowledge, $F(3,164) = 0.240$, $p = .868$, with effect size $\eta_p^2 = .004$.

Table 3.3

Descriptive statistics for participants' test scores per condition

	Collaboration Competition		**Collaboration**		**Competition**		**Control**	
	(n = 45)		*(n = 53)*		*(n = 36)*		*(n = 34)*	
	M	SD	M	SD	M	SD	M	SD
Computational fluency	116.8	19.8	122.6	20.0	117.4	22.3	126.1	16.5
Domain knowledge pretest (%)	*39.6*	*16.7*	*40.6*	*17.7*	*41.0*	*18.5*	*38.1*	*16.2*
Missing value problems (%)	51.1	31.1	54.7	29.9	45.1	23.8	44.9	28.1
Comparison problems (%)	56.1	29.2	53.3	28.6	58.3	25.4	52.9	29.4
Transformation problems (%)	23.9	26.1	27.4	33.4	29.9	28.6	27.2	27.1
Transfer problems (%)	27.2	23.7	26.9	23.9	30.6	28.1	27.2	23.3
Domain knowledge posttest (%)	*42.1*	*20.7*	*44.1*	*21.1*	*45.1*	*18.8*	*43.8*	*21.1*
Missing value problems (%)	55.0	25.9	56.1	33.6	56.9	26.5	47.8	32.8
Comparison problems (%)	53.9	24.4	52.4	24.2	47.9	23.4	53.7	27.6
Transformation problems (%)	29.4	30.8	39.2	33.4	47.2	29.1	42.7	37.7
Transfer problems (%)	30.0	29.0	28.8	21.6	28.5	26.2	30.9	23.9

To test whether there were main effects for collaboration and competition and whether competition affects the effectiveness of collaboration, mixed model multivariate analysis of variance (MANOVA) with time (pretest to posttest) as within subject factor and collaboration and competition as between subject factors was conducted. The domain knowledge pre- and posttest measures on the four problemtypes (missing value, comparison, transformation, and transfer) were entered as dependent variables.

Results show a multivariate main effect for time, Pillai's trace = .142, $F(1,161) = 6.66$, $p < .001$, $\eta_p^2 = .142$. Univariate effects show a main effect for time for missing value problems, $F(1,164) = 4.41$, $p = .043$, $\eta_p^2 = .025$ and transformation problems $F(1,164) = 24.45$, $p < .001$, $\eta_p^2 = .130$, but no univariate main effect for time for comparison problems, $F(1,164) = 1.35$, $p = .248$, $\eta_p^2 = .008$ and transfer problems, $F(1,164) = 0.61$, $p = .436$, $\eta_p^2 = .004$. The multivariate main effect of time was not qualified by an interaction between time and competition, Pillai's trace = .022, $F(1,161) = 0.89$, $p = .470$, $\eta_p^2 = .022$, nor was there an interaction between time and collaboration, Pillai's trace = .022, $F(1,161) = 0.90$, $p = .456$, $\eta_p^2 = .022$. The hypothesized interaction between time, competition and collaboration was not significant, Pillai's trace = .017, $F(1,161) = 0.68$, $p = .605$, $\eta_p^2 = .017$.

Though the previous analysis does not demonstrate differences between conditions, condition differences may still exist for particular subgroups. In their meta-analyses Lou, et al. (1996) conclude that the effect of collaboration differs when addressing students with different relative abilities. Therefore, we explored whether there are effects of collaboration and competition when we differentiate between students with below average prior knowledge and students with above average prior knowledge.

Table 3.4

Descriptive statistics for participants' test scores per condition per ability level

	Collaboration Competition		**Collaboration**		**Competition**		**Control**	
Below average		*n = 26*		*n = 25*		*n = 21*		*n = 19*
	M	SD	M	SD	M	SD	M	SD
Computational fluency	117.2	22.6	118.4	22.8	113.2	23.4	125.1	16.4
Domain knowledge learning gain	3.4	13.3	9.3	16.1	11.9	19.3	5.9	17.6
Learning gain missing value	8.7	28.2	7.0	27.5	17.9	29.7	7.9	42.5
Learning gain comparison	5.8	34.1	3.0	29.2	-7.1	36.4	1.3	38.6
Learning gain transformation	5.8	32.1	24.0	29.3	33.3	32.9	11.8	36.7
Learning gain transfer	-6.7	32.1	3.0	23.2	3.6	26.6	2.6	20.2
Above average		*n = 19*		*n = 28*		*n = 15*		*n = 15*
	M	SD	M	SD	M	SD	M	SD
Computational fluency	116.3	15.7	126.4	16.7	123.3	19.7	127.4	17.1
Domain knowledge learning gain	1.3	14.5	-1.6	17.5	-6.7	12.8	5.4	18.1
Learning gain missing value	-2.6	26.2	-3.6	33.8	3.3	20.9	-3.3	36.4
Learning gain comparison	-13.2	29.3	-4.5	43.6	-15.0	24.6	0.0	39.0
Learning gain transformation	5.3	27.1	0.9	31.5	-5.0	30.2	20.0	35.6
Learning gain transfer	15.8	26.6	0.9	25.0	-10.0	18.4	5.0	17.1

Differentiation based on ability level was in-line with the rule applied in the creation of the heterogeneous groups, meaning that students were categorized as below average when the score on the domain knowledge pretest (transfer items not included) was 50% or below, and above average when the score was above 50%. This created two groups, Table 3.4 summarizes the descriptive statistics for the participants' test scores per condition per ability level. We would like to emphasize that the differentiation in ability level generates a reduction in sample size and therefore these results should be interpreted with caution.

Univariate analyses of variance (ANOVA) revealed no differences between conditions in computational fluency, $F(3,87) = 1.01$, $p = .391$ with effect size $\eta^2 = .034$ for below average students and $F(3,73) = 1.62$, $p = .191$ with effect size $\eta^2 = .062$ for above average students, and no significant differences between conditions in prior domain knowledge, $F(3,164) = 0.25$, $p = .858$ with effect size $\eta^2 = .018$ for below average students and $F(3,73) = 1.63$, $p = .191$ with effect size $\eta^2 = .028$ for above average students.

To test the effect of competition and collaboration on game based learning for students with below and above average ability, a MANOVA was conducted with competition and collaboration as independent variables and gain scores (difference between percentage correct pretest and percentage correct posttest) on the four different problem types of the domain knowledge test, as dependent variables. This analysis was performed for above and below average students separately.

Results for *below-average* students revealed no multivariate main effect for competition, Pillai's trace = .019, $F(1,84) = 0.41$, $p = .801$, $\eta_p^2 = .019$, no multivariate main effect for collaboration, Pillai's trace = .034, $F(1,84) = 0.75$, $p = .561$, $\eta_p^2 = .034$, but a significant interaction effect between collaboration and competition, Pillai's trace = .109, $F(1,84) = 2.56$, $p = .045$, $\eta_p^2 = .109$. This interaction was fully crossed (Figure 3.2). Univariate effects show this interaction effect is significant for transformation problems, $F(1,87) = 9.53$, $p = .003$, $\eta_p^2 = .099$, but not for missing value problems, $F(1,87) = 0.38$, $p = 539$, $\eta_p^2 = .004$, comparison problems, $F(1,87) = 60$, $p = .442$, $\eta_p^2 = .007$, and transfer problems, $F(1,87) = 0.92$, $p = .339$, $\eta_p^2 = .010$.

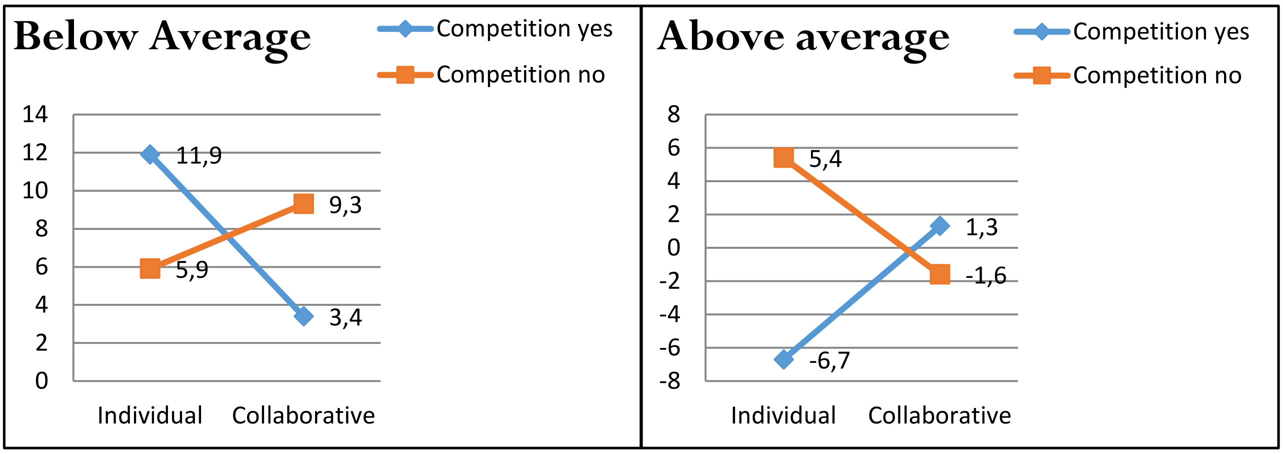

Figure 3.2. Illustration of multivariate interaction: learning gains per condition for students with below average and students with above average prior knowledge.

The multivariate interaction effect shows that the effect of collaboration is negatively influenced by the addition of competition, meaning that students with below-average prior knowledge benefit more from collaboration when competition is not present than when competition is present.

Results for *above-average* students revealed no main effect for competition, Pillai's trace = .069, $F(1,70) = 1.29$, $p = .282$, $\eta_p^2 = .069$, no main effect for collaboration, Pillai's trace = .072, $F(1,70) = 1.36$, $p = .258$, $\eta_p^2 = .072$, but a marginally significant interaction effect between collaboration and competition, Pillai's trace = .116, $F(1, 70) = 2.30$, $p = .068$, $\eta_p^2 =$ .116. This interaction was fully crossed (Figure 3.2). Univariate effects show this interaction effect is significant for transformation problems, $F(1,73) = 4.03$, $p = .049$, $\eta_p^2 = .052$, and transfer problems, $F(1,73) = 7.43$, $p = .092$, $\eta_p^2 = .010$, but not for missing value problems, $F(1,73) = 0.16$, $p = .691$, $\eta_p^2 = .002$, comparison problems, $F(1,73) = 0.71$, $p = .714$, $\eta_p^2 =$ .002.

The multivariate interaction effect is marginally significant and implies that the effect of collaboration is positively influenced by the addition of competition, meaning that students with above-average prior knowledge benefit more from collaboration when competition is present than when competition is not.

Discussion and Conclusion

Overall results of the current study confirm the expectation that prevocational students can benefit from a game-based mathematics learning environment. This is in line with previous findings of studies that employed the same game (ter Vrugte, et al., 2015), and in line with expectations based on prior research that underlined positive effects of game-based learning for mathematics education (e.g., Chang, Evans, Kim, Norton, & Samur, 2015; Kebritchi, et al., 2010).

The finding that there were no main effects of competition and collaboration on learning is also in line with previous findings from studies on collaborative learning (e.g., Chen, et al., 2015; van der Meij, et al., 2011). And studies from Ke and Grabowski (2007) and Plass, et al. (2013), who compared competition and collaboration. In line with most previous studies on collaboration in educational games, the current study employed a 'free' form of collaboration. Though we did not measure students' experience, or log their interactions, informal observation during the data-collection, and conversation with the students afterwards, indicates that students were collaborating in the collaborative condition. Students were having meaningful discussions about the game and the domain, and they valued the collaboration because as they claimed 'the other student could help you out'. In addition, both the researcher and the teachers involved, noted that the students who played collaboratively seemed more focused on the game, and had less questions than the students who played individually. Nonetheless, it might be that the quality and quantity of the discussions during the collaboration was not enough to foster substantial knowledge acquisition. Scripting is often suggested as a means to stimulate meaningful interaction in collaborative learning. Though scripting could improve the quantity and quality, Hamalainen (2008) conclude that it is difficult to script collaboration in a game-environment without over-scripting it. In a recent study Chen and Law (2016) successfully employed question prompts to scaffold the discussion in collaborative gameplay. In our opinion this could be equally effective and less obtrusive as scripting. It would be worthwhile to further look into this approach.

Though there was no overall effect of collaboration and competition, when differentiating between students with above-average and below-average prior knowledge, there was an interaction between the two. This interaction seems reversed when differentiating between students with below-average and above-average prior knowledge (see Figure 3.2), suggesting that below-average students would experience a 'positive effect' of collaboration on learning when competition is *not* present (and a negative effect when competition is present), while data suggests the reverse trend for the above-average students. They are likely to experience a 'positive effect' of collaboration on learning when competition *is* present (and a 'negative effect' when competition is not present). Due to smaller sample sizes caution is of the essence when interpreting these results. Nonetheless we will warily explore possible explanations for these findings.

It might be that the addition of competition changed the communication in the heterogeneous groups. It is plausible that when competition is added, the above-average students become more dominant in the group interaction. This is in line with Cohen (1994) observation that dominance of one student over another can prevent the dominated student from contributing to the collaborative process. In addition, the dominating student is less prone to provide feedback or help to the other student. In the current study, competition might have encouraged dominance of the above average students, leading to increased participation by these students and decreased participation by the below average students.

Though previous research has demonstrated that competition can have negative effects on learning (Van Eck & Dempsey, 2002), the finding of the current study, that competition might actually disrupt the collaborative process, seems counterintuitive. In the current study competition was carefully aligned with collaboration in such a way that it was more likely to foster positive interdependence and individual accountability than to disturb it. Nonetheless, it might be that the complexity of the team-scores in the current competitive collaboration was beyond prevocational students' comprehension. Possibly, the prevocational students were too focussed on the scores they collected as a team during gameplay, and failed to pay attention to the importance of the scores that would be generated by their own and their team-members' progress (posttest performance). This could have caused the competitive collaboration to lose its collaborative strength. More explicit instruction on score composition and a reduced focus on game-scores might affect the effect of competition.

In general, the results do not favor collaboration and/or competition over conditions where these are not incorporated. However, an issue to consider is that the current study only employed domain knowledge measures; informal observations from teachers and researchers in this study suggest that collaboration did have added value. During the data collection for the current study, the groups that collaborated seemed more manageable (this was noticed by the researcher and was stated by the teachers involved); students were calmer, asked fewer questions, and seemed more focused on the game. Also, as several other studies have shown, both collaboration and competition can foster situational interest, motivation, enjoyment and mastery-goal orientation (Van Eck & Dempsey, 2002). We would recommend further investigation of other possible effects of collaboration in combination with game-based learning, e.g., effects on student perceptions (e.g., motivation, experienced frustration), and teacher perceptions. In addition, future research might benefit from inclusion of a manipulation check, though collaboration is quite a salient element, it might be that students did not feel that they had to collaborate. The same goes for competition. Monitoring of students experience of the manipulation could provide insight that can help to structure the manipulation more effectively in future research and practice.

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4

Faded Worked Examples

A Study of the Effects of Embedded Faded Worked Examples

This chapter is based on:
ter Vrugte, J., de Jong, T., Vandercruysse, S., Wouters, P., Elen, J., & van Oostendorp, H. (in press). Game-based mathematics education: Embedded faded worked examples facilitate knowledge acquisition. *Learning & Instruction*.

Introduction

Despite the potential of educational games, 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).

Research shows that game-based learning environments with instructional support that helps players *select and represent relevant information* are more effective than game-based learning environments without this support (Wouters & van Oostendorp, 2013). 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. The current study briefly discusses instructional support in serious games and investigates worked examples as a means to foster students' problem solving and knowledge representations when learning from an educational mathematics game.

Instructional Support in Games

In a recent meta-analysis on instructional support in game-based learning environments, Wouters and van Oostendorp (2013) propose that effective instructional support should facilitate two types of learning processes. The first process is the *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. Consequently, students can easily get overwhelmed by the information presented. 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). 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) and prevent failure and feelings of frustration.

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). Support that helps students to actively process the educational content (i.e., relevant information) stimulates students to articulate and explain their new knowledge (Erhel & Jamet, 2013). This can help students to generate more explicit representations of their knowledge, and, in turn, can positively affect accessibility, recall and transfer of the knowledge (Wouters, et al., 2008).

In the following section, worked examples are discussed as a possible means of instructive support to foster these two learning processes: selection of relevant information and active organization of relevant information.

Worked Examples

Selection of relevant information. 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. A widely recognized method for modeling problem solving is by giving worked examples. 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.

Active organization of information. Besides the fact that worked examples provide expert models and therefore can guide students' selection of relevant information, worked examples can induce self-explanation, and self-explanation is known to foster the active organization of information (Wouters & van Oostendorp, 2013). Self-explanation is "a constructive activity that engages students in active learning, and ensures that learners attend to the material in a meaningful way" (Roy & Chi, 2005, p. 273). Though students are likely to generate some self-explanations when they work with a worked example, the quantity and quality of their explanations is diverse (Renkl, 1997). It has been found that the use of incomplete worked examples and the fading of worked out steps can prevent passive processing and encourage self-explanations (Atkinson, Derry, Renkl, & Wortham, 2000; Atkinson & Renkl, 2007).

Fading. 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 students' 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).

Current Study

Research on computer game-based learning shows that providing guidance (Moreno & Mayer, 2005), stimulating active processing of educational content (Erhel & Jamet, 2013), and prompting self-explanations that 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. The worked example can support students' selection of relevant information, the fading of worked-out steps can stimulate learners to actively process the educational content, and worked examples offer an explicit representation of the embedded learning content in the game, which can help players to successfully extract learning content and procedures and make a connection between game terminology and mathematics terminology.

In addition, because worked examples model expert strategies, there is less need for trial and error (often seen in experiential learning). Trial-and-error strategy in computer games is a type of non-systematic approach: knowledge of how to play is gathered through experience and observation, not by reading rules and instructions (Dempsey, Haynes, Lucassen, & Casey, 2002). Though trial and error is a natural approach and essential for discovery and experiential learning, reducing the degree to which students engage in trial and error is beneficial for education in general and for educational games in particular, because students are likely to accomplish more in less time (Jin & Low, 2011).

Despite the promising features of worked examples and their proven effectiveness in both multimedia learning and more conventional educational settings, little is known about the combination of games and worked examples. In the current study, the possibility that 'faded partial worked examples' can stimulate knowledge acquisition from game-based learning is investigated. To that end, two game-playing conditions are compared: an experimental condition in which students played the game with faded worked examples, and a control condition in which students played the game without worked examples.

The study focuses on knowledge measures as well as game-play measures 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 game performance (reducing the number of incorrect solutions) and knowledge acquisition. 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 that will support better performance on transfer problems and more correct carrying out of procedures (consistent with the worked examples).

Method

Participants and Design

The sample included 103 students, 47 boys and 56 girls, aged 12.3 to 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.

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.

Materials

Domain. The current study focuses on 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, et al., 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). This is despite the fact that in the Netherlands proportional reasoning is already taught in primary education and students are expected to master proportional reasoning by the end of primary school.

Within the domain of proportional reasoning, three types of problems can be identified: comparison problems, missing value problems, and transformation problems. Table 4.1 presents a summary of these three types of problems.

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. This strategy is most efficient when the multiplicative relationship expressed by the internal ratio of the proportion has an integer value. Students can also use the strategy of the 'external ratio', meaning that their calculations focus on the external ratio of the proportion. This strategy is most efficient when the multiplicative relationship expressed by the external ratio of the proportion has an integer value.

Table 4.1.

Summary of proportional reasoning problems and their levels

Problem type	Goal	Levels
Comparison	The student has to determine the relationship between two ratios. Possible answers are: ratio one is 'more than', 'less than' or 'equal to' ratio two	The difficulty of ***comparison problems*** is determined by the method that is required to solve the problem: 1. Can be solved by *qualitative reasoning*. The answer to these problems can be arrived at by reasoning, because either the values for two dimensions are equal (e.g., 1:4 vs. 3:4), or the comparison is between ratios that obviously differ in size (e.g., 100:31 vs. 42:100). 2. Can be solved by *estimation*. In this case, the answer can be estimated, because the internal* or external** ratio allows for easy multiplication (e.g., 2:4 vs. 4:6) or the internal or external ratio matches a simple reference point (e.g., 1/2, 1/3, 1/4, or 1/10). 3. Has to be solved using *full calculation*. The answer cannot be reasoned or estimated, but has to be computed (e.g., 14:63 vs. 18:81).
Missing value	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 difficulty of ***both missing value and transformation problems*** is determined based on whether the multiplicative relations within the internal ratio and external ratio have integer*** values or not (e.g., Kaput & West, 1994; Tourniaire & Pulos, 1985; van Dooren, de Bock, Evers, & Verschaffel, 2009): 1. Internal ratio integer, external ratio integer (e.g., 2 cups of milk per 1 spoon of fruit equals 4 cups of milk per 2 spoons of fruit) 2. Internal ratio integer, external ratio not integer (e.g., 4 cups of milk per 6 spoons of fruit equals 2 cups of milk per 3 spoons of fruit) 3. Internal ratio not integer, external ratio integer (e.g., 2 cups of milk per 4 spoons of fruit equals 3 cups of milk per 6 spoons of fruit) 4. Internal ratio not integer, external ratio not integer (e.g., 4 cups of milk per 6 spoons of fruit equals 6 cups of milk per 9 spoons of fruit)
Transformation	The students are provided with two unequal ratios (e.g., 3:6 ≠ 4:12). The students have to calculate how much needs to be added to one ratio to make the two ratios equal.	

* ***internal ratio***: ratio of quantities of the same variable, ** ***external ratio***: ratio of quantities of different variables, *** ***integer***: a positive or negative whole number (not a decimal)

A more elaborate and more universal strategy is the strategy of simplification. In this strategy, students first adjust a 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.

Game. The current study employed the educational game ‘Zeldenrust’, a two-dimensional, cartoon-like, educational computer game. It is designed for prevocational students (ages 12-16) and aims to teach and train proportional reasoning skills. Vandercruysse et al. (2015) provide a detailed description of the design principles of the game.

In the game, students are encouraged to earn as much money as possible. To earn this money, they have to complete challenges at the hotel ‘Zeldenrust’, such as filling the refrigerators and serving guests. These challenges all take place in a challenge-related game environment (subgame) that students can enter from a central point in the game (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 game 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). In the subgame ‘refrigerators’ students must refill the fridge (missing value problems). And last, in the subgame ‘blender’ students must ‘fix’ improperly executed recipes (transformation problems). Table 4.2 presents an overview of the subgames and examples of the challenges.

When students enter a subgame, the owners introduce the challenge that must be completed. 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 sub-games at one level, students move on to the next level.

Table 4.2.
Overview of level structure per subgame

Subgame	Problem type	Example of problem	Game level: difficulty
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: level 1 problems 2: level 2 problems 3: level 3 problems 4: a mix of all levels
Fridges	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 whiteboard shows the given ratio of 3/1 and the ratio with the missing value 9/?. The fridge contains the 9 bottles of water. The student has to answer the question by dragging and dropping the juice bottles inside the refrigerator.	1: level 2 problems 2: level 3 problems 3: level 4 problems 4: a mix of all levels
Blender	Transformation	*"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 would follow the recipe?"* The whiteboard shows the given ratio of 10/100 and the incomplete ratio of 10/500. The blender already contains 10 berries and 500 ml of yoghurt. The student has to answer the question by dragging and dropping the berries into the blender.	1: level 2 problems 2: level 3 problems 3: level 4 problems 4: a mix of all levels

In the current study two versions of the educational game 'Zeldenrust' were employed: one with partial worked examples that were faded and one with no worked examples. Both games were identical, but in the version with faded worked examples worked examples were presented during the fridges and blender subgame. Figure 4.1 shows an example of the fridges subgame with worked example (left) and the fridges subgame without worked example (right).

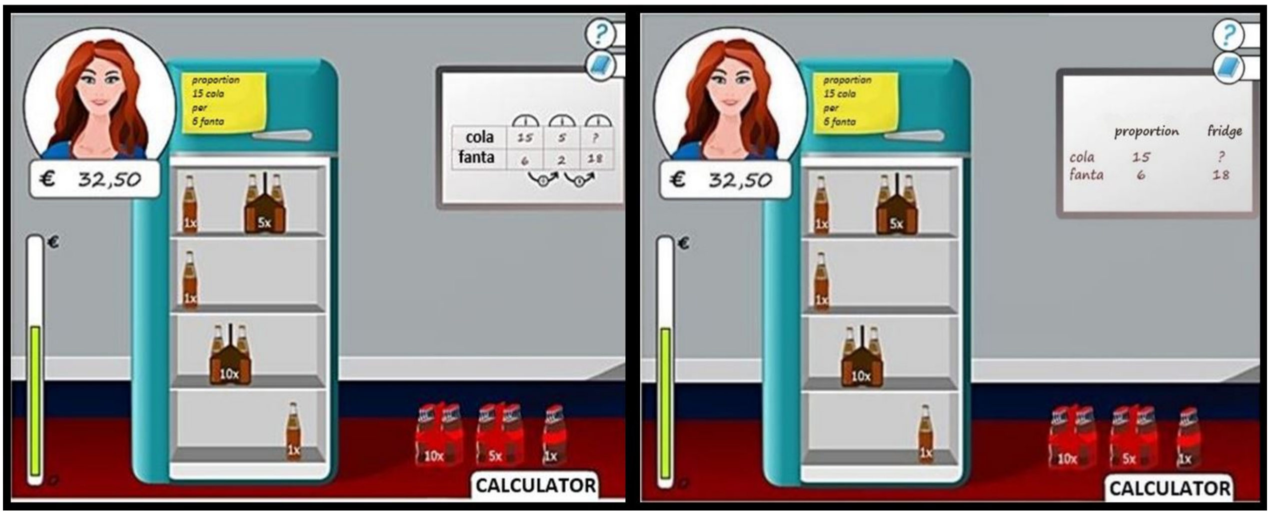
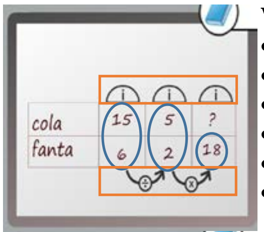


Figure 4.1. Fridges subgame faded worked example condition (left) and control condition (right).

Faded worked example. 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. Figure 4.2 presents examples of the worked examples in the different levels of the fridges sub-game. 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 with the given amounts of the first and final ratio filled out.



Worked example level 1:
- Table
- Information about column content
- Amounts of first ratio (column 1)
- Partial solution 1(column 2)
- Given amount of final ratio (column 3)
- Information about actions

Worked example level 2:
- Table
- Information about column content
- Amounts of first ratio
- ~~Partial solution 1~~
- Given amount of final ratio
- Information about actions

Worked example level 3:
- Table
- Information about column content
- Amounts of first ratio
- ~~Partial solution 1~~
- ~~Given amount of final ratio~~
- ~~Information about fractions~~

Worked example level 4:
- Table
- ~~Information about column content~~
- ~~Amounts of first ratio~~
- ~~Partial solution 1~~
- ~~Given amount of final ratio~~
- ~~Information about actions~~

Figure 4.2. Example of the worked examples as presented in the fridges subgame level 1 to 4.

Students could interact with the worked examples by clicking on them and filling out the blank 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.

Representation. Based on learner characteristics (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 & Renkl, 2007), these were made available on student demand. The textual information provided instructional explanations, informing players about the meaning of the parts of the worked example. Students received textual information about the content of the table (for each column) and each step of the solution (for each arrow). The amount of text was kept to a minimum.

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 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 primary-school domain), we chose to use product-oriented worked examples.

Content. As explained in the description of the domain, 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'. In the current study this meant that students were prompted to adapt the first ratio and to then solve the problem based on the strategy of the internal ratio. This strategy is in line with the most common proportional reasoning strategy taught at prevocational education. In addition, this is an 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.

Test Materials

Computational fluency. To assess computational fluency, students completed an arithmetic tempo test, the TTR (Tempo Test Rekenen). This is a validated test developed in the Netherlands and Flanders that aims to measure students' level of fluency in basic arithmetic computation (i.e., addition, subtraction, multiplication, and division) (de Vos, 1992). The four types of computations are spread over five columns, one column for each type and one with all types mixed, of 40 arithmetic problems each. The students have one minute per column to solve as many arithmetic problems as possible. TTR scores in the current study represent the sum of all correct answers, with a possible range from 0 to 200.

Domain knowledge. To assess students' level of proportional reasoning, a proportional reasoning test (paper and pencil) consisting of 16 constructed response questions was administered. Twelve questions presented a proportional problem similar in context and structure to the problems posed in the game: four questions for each type of proportional reasoning problem, presented in order of increasing difficulty within each type. Finally, to assess near transfer, four questions presented proportional problems that were similar in structure, but differed in context from the problems posed in the game. The domain knowledge test was scored for number of *correct answers* and coded for *type of calculation.* Totals for both were calculated separately for the 12 game-based proportional problems and the four transfer proportional problems. Where the correct answer score shows that students can successfully apply their knowledge, the calculation score provides insight in the ability of the students to articulate and represent their 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: 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, than it was assessed whether the calculation provided a complete line of reasoning for the answer. If not, than the calculation was coded as incomplete. If so, than 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 total range of this score was 0–16 distributed across the different categories. In addition, the proportional calculations were counted for the game-based problems and transfer problems separately, these scores could range from 0-12 for the game-based problems and from 0-4 for the transfer problems.

The domain knowledge test was used to measure domain knowledge 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 .68 on the pretest and a Cronbach's Alpha of .85 on the posttest.

Process measures. Logfiles were consulted to derive in-game performance measures for each student. The following actions were documented during the game: how many attempts students needed to complete a challenge, how much time they spent on an attempt, and whether they were able to find the correct answer for a challenge. These records were used to calculate the mean number of attempts used per challenge, the mean time per challenge, and the percentage correct of all provided solutions.

Procedure

The total time of the experiment was 200 minutes spread evenly over four sessions. Each session was planned during a math lesson and each class participated in their usual composition. 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.

The *first session* took place in the usual classroom and started with a short introduction in which students were informed about the organization of the forthcoming lessons. Students received no information on the different conditions. After the introduction the students individually completed the TTR and the domain knowledge test.

The *second session* took place in a computer lab and started with a short introduction (ten minutes) on how to play the game and on the type of mathematical problems addressed in the game. The introduction was supplemented with a hand-out to show students an example of each subgame and showed a screenshot of one challenge per subgame accompanied by a worked example that introduced the three strategies (internal ratio, external ratio, simplifying). The information on the hand-out was in-line with information offered in the hand-book 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 started the game. In the *third session*, also at a computer lab, all students could resume the game. In the *fourth session*, which took place in their usual classroom, students individually completed the domain knowledge test.

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 gameplay failed. These two cases were excluded from the logfile analyses, for which case data from 91 students were reported. Table 4.3 summarizes the descriptive statistics for the participants' test scores per condition.

Table 4.3.
Descriptive statistics for test scores by condition

	Control Condition (n = 44)		**Worked Example Condition (n = 49)**	
	M	**SD**	**M**	**SD**
Computational fluency	107.8	20.3	112.5	30.5
Domain-knowledge pretest				
Correct solutions game-based problems	5.0	2.3	4.6	2.6
Correct solutions transfer problems	0.7	0.7	0.9	0.8
Proportional calculations game-based problems	2.4	2.2	2.9	3.1
Proportional calculations transfer problems	0.3	0.5	0.5	0.8
Domain-knowledge posttest				
Correct solutions game-based problems	5.2	3.3	6.4	3.0
Correct solutions transfer problems	0.9	1.0	1.1	1.1
Proportional calculations game-based problems	2.9	3.1	4.5	3.7
Proportional calculations transfer problems	0.5	0.8	0.8	1.2

An independent samples t-test revealed no differences between conditions in the level of computational fluency, $t(84.2) = -.88$, $p = .383$ with effect size $d = 0.18$, and the level of prior domain knowledge (total correct solutions pretest), $t(91) = .44$, $p = .661$ with effect size $d = 0.09$, at the start of the study. When considering the students' calculations, an independent samples t-test indicated no difference between the two conditions in the number of missing, incomplete, qualitative, additive or proportional calculations on the pretest (see Table 4.4 for the results).

Table 4.4.
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	$t(91) = 0.67$, $p = .504$, $d = 0.13$
Incomplete	2.2	2.7	1.7	1.9	$t(91) = 0.96$, $p = .338$, $d = 0.21$
Qualitative	0.7	1.3	0.8	1.4	$t(91) = -0.33$, $p = .742$, $d = 0.07$
Additional approach	1.3	2.0	1.6	2.4	$t(91) = -0.65$, $p = .515$, $d = 0.14$
Proportional	2.7	2.4	3.4	3.7	$t(91) = -1.15$, $p = .261$, $d = 0.22$

To evaluate whether the prevocational students learned from the game, a paired samples t-test across all participants' pretest scores and posttest scores was performed. The results indicated a significant difference between the game-based problem pretest and posttest scores, $t(92) = -4.05$, $p < .001$, with effect size $d = 0.42$, and a significant difference between the transfer problem pretest and posttest scores $t(92) = -1.99$, $p = .049$, with effect size $d = .21$, demonstrating that students' domain knowledge increased significantly.

To test whether students' knowledge gain differed between conditions a mixed-design multivariate analyses of variance (MANOVA) with 'condition' (control and faded worked example) as between-subject factors, and 'time' (pretest to posttest) as within-subject variable, was conducted. The repeated measure 'time' included the number of correct solutions on the game-based and transfer problems on the pretest and posttest, and the number of proportional calculations that students included with their solutions for the game-based problems and transfer problems.

Results show a multivariate main effect for time, $F(1,88) = 5.13$, $p = .001$ (Wilk's $\Lambda = .811$, $\eta_p^2 = .189$), no multivariate main effect for condition $F(1,88) = 1.35$, $p = .260$ (Wilk's $\Lambda = .942$, $\eta_p^2 = .058$), and a significant multivariate interaction effect $F(1,88) = 3.23$, $p = .016$ (Wilk's $\Lambda = .872$, $\eta_p^2 = .128$). Given the significance of the multivariate interaction effect, the univariate effects were examined. Table 4.5 summarizes the output of the univariate analyses.

Table 4.5.

Univariate effects of the mixed model MANOVA

Effect	Dependent variable	*df*$_1$	*df*$_2$	*F*	*P*	η_p^2
Time	Correct game-based problems	1	91	16.70	<.001	.155
	Correct transfer problems	1	91	4.0	.049	.042
	Proportional calculation game-based problems	1	91	15.29	<.001	.144
	Proportional calculation transfer problems	1	91	7.09	.009	.072
Time * Condition	Correct game-based problems	1	91	11.32	.001	.111
	Correct transfer problems	1	91	0.09	.761	.001
	Proportional calculation game-based problems	1	91	4.51	.036	.047
	Proportional calculation transfer problems	1	91	0.28	.598	.003

The univariate effects indicate that students in the worked example condition specifically performed better on the game-based problems on the posttest, but not on the transfer problems. Students in the worked example condition were more able to solve the problems correctly and wrote down more proportional procedures, but these students were not more able to apply their knowledge on proportional transfer problems.

To test whether students' game performance differed between conditions a MANOVA with game performance (time, attempts, correct solutions) as dependent, and condition (control, faded worked example) as independent variables was conducted (see Table 4.6 for descriptive statistics). Results showed a significant multivariate effect of condition, $F(1,87) = 2.95$, $p = .037$, $\eta_p^2=.092$. Further analysis showed a significant univariate effect for the mean number of attempts, $F(1,89) = 5.31$, $p = .023$, $\eta_p^2=.056$, but no univariate effect for the mean time, $F(1,89) = 2.97$, $p = .088$, $\eta_p^2=.032$, and no univariate effect for the percentage correct, $F(1,89) = 1.99$, $p = .162$, $\eta_p^2=.022$. Thus, students who played the game with the faded worked examples seemed to be more efficient when it came down to the number of attempts they needed to solve a challenge problem.

Table 4.6.

Descriptive statistics for game measures per condition

Game measures	Control Condition		Worked Example Condition	
	M	**SD**	**M**	**SD**
Mean number of attempts per challenge	1.5	0.3	1.4	0.3
Mean time per challenge (sec.)	97.6	43.7	84.9	25.2
Percentage correct solutions	70.0	19.3	75.2	16.1

Discussion and Conclusion

The overall results of the current study confirm the expectation that prevocational students can benefit from a game-based learning environment. This is in line with previous studies that used the same game (ter Vrugte, de Jong, Vandercruysse, et al., 2015; ter Vrugte, de Jong, Wouters, et al., 2015; Wouters et al., 2015). Results also show that students benefit from additional support in the form of worked examples that were faded. Students who received faded worked examples during game play performed better on a domain knowledge posttest than students who played the game without worked examples. Students who played the game with faded worked examples were not only more accurate on the posttest, they were also likely to use the instructed proportional procedures (when taking into account accuracy). This could indicate that students in the faded worked example condition were not only more able to apply their knowledge, but were also more able to represent their knowledge.

Though this is 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. 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 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 the game and both conditions had access to complete worked examples during the game (in the game handbook), and that only the experimental group received faded worked examples embedded 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 game 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 example 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 during the game showed that students also benefited from the faded worked examples during game play. Although the mean time per challenge and the percentage of correctly solved challenges indicated no univariate difference, students who worked with the worked examples did need fewer attempts per challenge. This could indicate that their strategy use was more effective (less trial-and-error). This is in line with our expectation and previous research on the effects of worked examples (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 game-based problems, and not on the transfer problems. This indicates that although students gained knowledge and were more able to apply and represent this knowledge, the fading of worked examples did not assist construction of transferable knowledge. A possible explanation for this result can be found in prior research on worked examples. The current study employed product-oriented worked examples. This type of worked example supports knowledge of the procedure, but not the rationale behind the procedure. This can be problematic, because knowing how to solve something is not enough to understand it, and understanding is important for transfer (Ohlsson & Rees, 1991; van Gog, Paas, & van Merriënboer, 2008). Self-explanation could compensate for this lack of information, but students could fall short on their ability to provide explanations at this level (as also argued by Chi, Bassok, Lewis, Reimann, & Glaser, 1989). Although in the current study we encouraged students' self-explanations by fading of the worked examples, it might be that students' self-explanations were only on the procedural level and did not reach the conceptual level that is necessary to foster transfer.

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. Research shows that students' ability interacts with the effects of provided (instructional) support (ter Vrugte, de Jong, Vandercruysse, et al., 2015; van Gog, et al., 2008). Future research might evaluate to what extent ability level affects the effectiveness of worked examples and could compare the effects of different forms of support for students with different levels of ability.

In addition, it would be interesting to find out whether the fading of the worked examples is essential for these effects, and whether representation mode (text or diagram) and represented information (domain) matter. Therefore, we would suggest that future research on the use of worked examples in game-based learning focus on structural characteristics of worked examples. And we would encourage the use of worked examples with other domains than arithmetic.

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5

General Discussion

Introduction

This dissertation focused on evaluating game-based learning in prevocational education. Mayer (2011) distinguishes between media comparisons and value-added comparisons in educational evaluation. Applying this distinction to game-based learning a media-comparison study would entail a comparison of game conditions with non-game conditions, whereas a value-added study would entail a comparison of a standard version of a game to an enhanced version that is augmented to test a specific design proposition. Though many researchers seem convinced of the potential of game-based learning, researchers also acknowledge that the empirical evidence for games as learning tools is ambiguous (Clark, Tanner-Smith, & Killingsworth, 2016; Vandercruysse, Vandewaetere, & Clarebout, 2012; Young et al., 2012). Comparison between studies is difficult due to diversity in content, gameplay, and population (among other things). To distinguish between effective and ineffective practices and elements, and to optimize game-based learning, value-added comparison studies are required (Clark, et al., 2016; Wouters, van Nimwegen, van Oostendorp, & van der Spek, 2013). Therefore, studies in the current dissertation adopted a value-added approach: a standard version of the game was compared to versions that were enhanced with different forms of instructional support.

The different forms of instructional support that were evaluated were selected because of their potential to elicit self-explanations and because they had been proven to be effective in other educational settings. The potential to elicit self-explanations seemed beneficial for game-based learning because within games students often learn by doing (experiential learning), and the educational content is often intertwined with the game-content. The knowledge students develop is therefore likely to be tacit and implicit. Although this knowledge is valuable, explicit knowledge is generally considered more desirable in education, because it is more accessible and promotes transfer. Self-explanations can raise awareness of the educational content and can help students to develop explicit knowledge of what was learned. Three consecutive empirical studies investigated three different forms of instructional support: self-explanation prompts, collaboration, and faded worked examples.

Study 1 (see Chapter 2) investigated whether self-explanation prompts in the form of multiple choice questions and/or procedural information in the form of visual representations of proportional reasoning strategies could enhance learning. Neither form of support (nor a combination) positively affected learning. A possible reason for this could have been that the prompts were too difficult for students because their level of prior knowledge and/or their (meta)cognitive skills were too low to respond successfully and understand the explanations. In addition, there might have been too few prompts; prevocational students might possibly benefit from a more continuous form of support. Collaboration was assumed to offer a more continuous form of support and, in addition, could offer just-in-time support. Therefore, Study 2 (see Chapter 3) investigated whether collaboration could enhance game-based learning. Collaboration was implemented in accordance with the Student Teams Achievement Divisions (STAD) design, in which competition was used to create an incentive for the collaboration. The factors of competition and collaboration were investigated using a 2x2 factorial design. Neither factor nor a combination of both significantly increased knowledge acquisition. A possible explanation could be that there was little control over the content and quality of the information students received and discussed. Worked examples seemed to provide a solution to this. Worked examples are likely to elicit self-explanations, especially when partial or faded. Aside from controlling the information presented to the students, fading can help to direct students' attention to specific steps or information. Therefore, Study 3 (see Chapter 4) investigated whether faded worked examples could aid knowledge acquisition. A principal finding of this study was that worked examples positively affected students' in-game performance and knowledge acquisition. The use of process-oriented worked examples instead of the product-oriented worked examples that were used might help to enhance these already positive effects.

Before discussing these research results in a broader perspective, it is important to highlight the outcome that learning was significantly enhanced in all three studies. The overall pretest to posttest Cohen's *d* effect sizes for studies 1, 2 and 3 were 0.44, 0.46, and 0.46 respectively, which are regarded as medium-sized effects. These findings show that the intervention involving the educational game 'Zeldenrust' formed a solid foundation for learning about the domain of proportional reasoning. This intervention was carefully designed in accordance with the prevocational curriculum and specifically targeted prevocational students. The results of the three studies show that further improvement of this environment was difficult, but possible. The investigated implementations of self-explanation prompts and collaboration did not result in improved effectiveness, but the addition of faded worked examples did.

Comparison of Support

Though there were some minor differences between the baselines of the studies in terms of students, learning environment, and context, the value-added approach allows for a comparison of results across studies and speculation about characteristics that might have affected the effectiveness of the support. Aside from many other characteristics, the support that is investigated (i.e., prompts, collaboration, and worked examples) can be compared on the ***accuracy*** of the information students received or constructed, and on the ***availability*** and ***accessibility*** of the support.

Accuracy

Control over the accuracy of the information students receive and construct seems relevant because research in the field of self-directed learning and self-explanation shows that the degree to which self-explanations foster learning can be affected by the completeness and accuracy of the self-explanation (Chi & Bassok, 1989; Hsu, Tsai, & Wang, 2012).

In Study 1, students received specific questions that focused their self-explanation on specific relevant information in the field of proportional reasoning; students had to answer these questions and received (explanatory) feedback accordingly. In Study 2, students collaborated and received no extra information aside from the information presented to them in the game. Information shared during collaboration was not checked for accuracy. In Study 3, students received faded worked examples. The worked examples provided the students with accurate information. The extensiveness of the information that the worked examples contained slowly reduced as the game progressed.

In Study 2, there was the risk that students shared incomplete, inaccurate, or irrelevant information, while in Studies 1 and 3 the researchers controlled the information that students received. The information provided to the students in these two studies was therefore complete, accurate, and relevant. However, only Study 3 yielded a positive effect on learning. This could indicate that simply providing students with accurate information is not enough. Learning could be affected by other characteristics of the support, such as its availability and accessibility.

Availability

The availability of support appears relevant because explanations, information, and support seem to be most effective when they are provided to the students just-in-time (Berry & Broadbent, 1987; Gee, 2003; Hulshof & de Jong, 2006; Sweetser & Wyeth, 2005). When support is only available to students at fixed moments, students can experience difficulty in matching it to their experience or knowledge. When support is continuously available to students, students can use it when they most need it. Therefore, mismatches between the support and the students' experience and knowledge are less likely. Aside from the timing aspect of availability (fixed moment or continuous) of support, it matters whether the design allows for simultaneous availability of procedural information and a practice problem. A design in which practice problems and procedural information (such as a worked example) are presented simultaneously is likely to be more effective than a design in which procedural information and practice problem are presented non-simultaneously (Sweller, van Merrienboer, & Paas, 1998).

In Study 1, the support was available at fixed moments and had a non-simultaneous design; students received questions and feedback in-between practice problems at eight fixed moments during the game. In Study 2, the support was continuous and simultaneous; students could collaborate whenever they liked. In Study 3, the support was also continuous and simultaneous; the worked examples were presented with every challenge in the game, but the information that they presented slowly faded.

In Study 1, the support was non-continuous with a non-simultaneous design, which may have negatively affected its effectiveness, because this could have caused students to experience difficulty matching the support to their experience. In studies 2 and 3, the support was continuous with a simultaneous design, but only Study 3 yielded positive effects on knowledge acquisition. When comparing the two forms of continuous support (i.e., collaboration and faded worked examples) the most salient difference between the two seems to be the accessibility of support: the two forms of support, collaboration and worked-examples, seem to provide different conditions for successful use.

Accessibility

Accessibility of support seems relevant because in order to fully benefit from the support, students need to be able to successfully access and use it. When comparing different kinds of support, it can happen that the conditions for accessing the support are not equivalent. This seems to be the case with collaboration and worked-examples. In Study 2 (collaboration), students could obtain support through interaction with their peer; however, this meant that students had to be aware of their own and their peer's understanding and knowledge. To collaborate, students had to be able to identify that they were experiencing a problem, had to be aware of their difficulties and possible gaps in their knowledge, and had to be able to identify and verbalize relevant knowledge to provide support. Literature shows that awareness of understanding (metacognitive knowledge) affects learning, and that students often experience difficulty with this (e.g., Cao & Nietfeld, 2007; Pintrich, 2002). Thus, although collaboration (Study 2) offers a continuous form of support, students' lack of awareness might have formed a threshold; it could be that students were not able to access the support when it would have been helpful. This might have affected the learning outcomes in Study 2.

In Study 3, support was also continuous, but the conditions for successful use of the support (accessibility) seem less demanding. Because of the prominent and continuous visual schematic representation, access to the support did not depend on students' awareness of their own understanding or lack of it. Hence, more students were able to access and use the support. It is likely that the support that was provided to the students through the worked example was more accessible than the support provided through collaboration. In addition, the schematic nature of the representation in Study 3 might have increased its effectiveness. Schematic representations have been proven to be useful support for proportional reasoning because they allow students to look beyond the surface features of the problem and can help them to interpret and elaborate on the information that is specifically important for proportional problems (Jitendra, Star, Dupuis, & Rodriguez, 2013).

Conclusion

Based on the considerations above it, could be speculated that the faded worked examples yielded positive effects because they formed a continuous form of accessible support that provided (initially) a complete set of accurate schematically represented information, with a simultaneous availability of procedural information and practice problems. Further research should provide more insight into the significance of these support characteristics. In addition, it would be interesting to see whether these effects hold when the educational content, game genre, and population are different than those in the studies presented in this dissertation.

Food for Thought

There are some points of interest in the design of the studies in this dissertation that are relevant to consider when evaluating the full extent of the results of the research. In this section, a few points will be discussed, including the measurements, the game, the duration, the students, and the teachers.

The Measurements

In the current dissertation, the focus was on learning proportional reasoning and the use of game-based learning in education. The emphasis of the measurements was on performance success (game performance and post-test performance), because these measurements are considered most relevant for standard education. The method and form of testing students' domain knowledge was also comparable to the method and form of testing that is commonly used in education. These choices ensured that the outcomes of the studies would be meaningful for educational practice.

In the domain knowledge tests, a distinction is made between proportional problems (i.e., missing value, transformation and comparison with a context that is similar to the contexts presented in the game and that we called game-based knowledge) and transfer problems (math problems from adjacent domains, or proportional problems with other contexts than the ones that were introduced in the game). In retrospect, however, we could also consider the game-based problems on the posttest as a transfer measure. Students' learning occurred in the game, where the problems were embedded in the game and were represented visually with a minimum of text. The game-based domain knowledge test problems were text-based and no graphics were used. Therefore, we could say that there was already a significant difference between problems presented in the game and problems presented in the domain knowledge test. Hence, we could also consider the game-related problems on the domain knowledge test as a measure of transfer; thus, it might be that the learning measured by the posttest underestimates the learning that actually took place.

An alternative way of measuring knowledge gained would be to assess learning during the game. For instance, a specific level could be added to the game that could be used to assess domain knowledge. An example of this type of assessment can be found in Johnson and Mayer (2010). However, although this type of measurement would be a solution for the transfer issue, it could also create problems with identifying and separating domain knowledge from game experience (e.g., did the student learn, or did the student improve at playing the game?).

The research in this dissertation focuses on performance measures, but it might have been interesting to gain insight into the cognitive processes and mental behavior of students during game play and during interaction with the support as well. Although measurements during the game, such as thinking-aloud techniques, might have provided insight into these processes (Karsenty, 2001; Nielsen, Clemmensen, & Yssing, 2002) a conscious decision was made not to employ these in the current dissertation.

The first reason for this decision was that any interruption during game play can diminish game-flow and affect engagement and performance (Ke, 2008; Sweetser & Wyeth, 2005; Van Eck, 2006). Students' cognitive involvement is known to be required for thinking aloud, which therefore introduces cognitive load that in turn could interfere with performance on other cognitive tasks such as game performance. The second reason not to use think-aloud techniques had to do with characteristics of the implemented support. The expectation was that the functionality of the support would be partially due to elicited self-explanations. Think-aloud techniques are not only a successful method for assessment, but also often used as a metacognitive strategy to help students during learning, similar to self-explanation. Prompting students to think aloud (to verbalize and explain their thoughts) would probably interfere with the effects of the conditions, resulting in problematic interpretation of study outcomes.

The considerations above indicate that the outcome measures in the current dissertation, though already showing positive learning effects, might be an underestimation of the actual learning that took place. For future studies on game-based learning, it would be valuable to also consider alternative ways to assess game-based learning and cognitive performance during game play.

The Game

The game that was developed for this line of research was a simulation-like adventure game: 'Zeldenrust' (Vandercruysse et al., 2015). One of the focal points during the design of the game was to embed the educational content (proportional reasoning) in a natural non-invasive manner; representations used were therefore mainly visual and realistic. Representations can serve as tools for understanding, exploration, recording, and monitoring of problem solving in mathematics (Ainsworth, 1999; Moreno, 2002; Stylianou, 2011). Examples of representations in mathematics are: symbols and signs, text and numerals, drawings and pictures, and graphs and diagrams. When it comes to mathematics, representations are often limited: one representation cannot always convey all the information about a specific concept. Therefore, the use of multiple representation is often encouraged in instruction. The combined use of different representations is considered an effective tool for showing the different facets of a specific concept.

In the game that was used in the current dissertation, the problems are first presented in a text format, after which students see a realistic pictorial and textual/numerical representation of the problem. Although this provides students with multiple representations that contain the information necessary to solve the proportional problem, these representations do not convey all of the information that is relevant to the domain of proportional reasoning. For instance, they do not convey underlying structures that could help students to uncover fundamental definitions, rules and principles of the domain. It would be interesting to see whether varying the use of representation (which is also seen in textbook presentations of proportional reasoning) would improve the effectiveness of the game.

The Duration

The studies in the current dissertation employed an intervention with the game that lasted roughly 100 minutes, spread over two class sessions. Taking into account the time spent starting the class, giving instructions, and starting the game, the students' actual playing time averaged about 50 minutes (the time reported in the studies is the time on task, which is less than the time spent in the game). The duration of the intervention was a deliberate choice, and matched the time teachers generally spent teaching the content that was targeted with the game. However, game-based learning needs time to reach its potential, because aside from learning the educational content, students might need time to get used to playing the game (Clark, et al., 2016; Wouters, et al., 2013).

Although the studies in the current dissertation indicate that the intervention with the game was effective—students performed significantly better on the domain knowledge test after playing the game—the effects might have been stronger if students had more time to play with the game or played a trial level to familiarize themselves with the gameplay before starting the actual educational game.

The Students

Participants in the studies that are reported in this dissertation were all secondary school students from the prevocational track. The student population that attends the prevocational track shows wide variety in cognitive abilities and potential. Research in other domains indicates that prior knowledge can have a significant effect on the effectiveness of interventions and support. In Study 1, the effect of computational fluency on students' learning from the game was evident. In Study 2, differences were seen in the effect of competition combined with collaboration for students with below-average prior knowledge and those with above-average prior knowledge. These phenomena were not found in Study 3. Although effects of prior knowledge on the effectiveness of worked-examples have been reported, for example, the expertise reversal effect as described by van Gog, Paas, and van Merriënboer (2008), worked examples in this sample (Study 3) seemed to benefit students regardless of prior knowledge. It would be interesting to find out whether the fading of the worked examples played a role in making the support equally effective for students with below-average and above-average prior knowledge.

The Teachers

Teacher support during the studies was restricted to management of the class. This was a deliberate choice, because any teacher interventions could affect the comparability between conditions. However, this resulted in an artificial class setting: this level of individuality and self-directed learning is not usually encountered in prevocational education. In addition, game-based learning should not normally replace the teacher, but should support the teaching (and maybe occasionally substitute for a textbook). If teachers did help and assist, their efforts could strengthen the effects of game-based learning and the support implemented. It would be interesting to see whether training teachers to support game-based learning would increase the effectiveness of games or the effectiveness of the support that was the focus of this dissertation.

Conclusion

Though there seems to be some proof that game-based learning in general can be associated with higher learning gains than non-game instruction (Clark, et al., 2016; Vogel et al., 2006; Wouters, et al., 2013) it seems simplistic to state that games (as a medium) should be favored over more traditional or typical classroom approaches. Surely, variety is the spice of life, and games therefore offer a valuable alternative instructional approach that can complement traditional education. But it is not the use of the game per se that matters. The design of the game can have a significant effect on its educational utility. As Clark, et al. (2016, p. 110) justly point out in their meta-analysis about games, design, and learning: "the design of an intervention is associated with as large an effect as the medium of an intervention".

The content of this dissertation indicates that effective design is not easy, but that it is possible. Based on the results of these studies, it is carefully conjectured that the following characteristics should be kept in mind when designing game-based learning support: first, *accuracy* seems to matter. When designing support, the information students receive should be *accurate*. Second, *availability* is important. Support is most likely to be effective when it is available to the students when they most need it and when it best matches students' experience and knowledge. Therefore continuous or just-in-time support is preferable. In addition, to help students match the support to their experience, it is probably best to present practice problem and support/procedural information simultaneously. And last, *accessibility* affects effectiveness. Support can only be effective when students are able to access and use it. Support should be carefully designed to match students' competencies.

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6

English Summary

Introduction

Game-based learning is often considered to be an effective instructional approach, but the effects of game-based learning are varied and far from optimal. This could be because the knowledge gathered in game-based learning environments is at risk of being implicit and tacit. Though this knowledge is certainly valuable, explicit knowledge is generally considered more desirable in education, because it is more accessible and promotes transfer. Explicit knowledge does not always automatically follow from the development of implicit knowledge, but this process can be supported through self-explanations. Because self-explanations rarely occur automatically in game-based learning environments, the addition of support that is likely to elicit self-explanations could optimize the effectiveness of game-based learning.

This dissertation addressed how to optimize game-based learning with instructional approaches that, in theory, can initiate self-explanation and, as a result, are likely to stimulate knowledge acquisition. The focus was on three promising instructional approaches: self-explanation prompts, collaboration, and worked examples. The studies reported in this dissertation sought to establish the effects of these three instructional approaches on prevocational students' acquisition of knowledge about proportional reasoning in a computer game-based learning environment. The general research question that guided these studies was:

How can we support prevocational students' acquisition of knowledge about proportional reasoning in a game-based learning environment?

The general research question was addressed in three empirical studies. All studies targeted the same population (i.e., prevocational students), addressed the same domain (i.e., proportional reasoning), employed the same game (i.e., 'Zeldenrust'), and followed a similar procedure.

Population

Participants in the studies that are reported in this dissertation were all secondary school students from the prevocational track. This population was selected because this group includes a significant number of at-risk students with a history of poor learning. Many of these students have encountered various unsuccessful instructional interventions and have grown resistant to the traditional educational material. Educational games can provide an alternative approach that might motivate such students to reengage with the educational material. In addition, the interactive multimodal features might provide them with new insights they would have missed with more traditional methods of instruction.

Domain

Math was chosen because it is a fundamental skill for future school achievement, and prevocational students' math skills are often inadequate. More specifically, the math subdomain of proportional reasoning was selected. Besides the fact that recent reports show a severe deficiency in the proportional reasoning skills of prevocational students, proportional reasoning was selected because it is a fundamental skill for future math achievement and mathematical understanding, and it is a well-defined domain. In addition, instruction of proportional reasoning would be likely to benefit from game-based learning because, in addition to the traditional word problems, a game can provide students with a variety of motivational and vivid contexts and opportunities to interact with the material. The active, multimodal nature of the environment can help students to develop a more solid and concrete understanding of the normally abstract proportions and ratios that make up the core of proportional problems.

Game

The game was developed in collaboration with prevocational students and their teachers and the development process roughly involved the following stages: prototype development and testing, revision of prototype (base-version) and testing, revision (control version), and design of instructional support and experimental versions (control-versions with instructional support).

To foster immersive and engaged gameplay and create context for the educational content, a storyline was created. The theme of the storyline was tailored to fit prevocational students' interests and experiences. The storyline places the players in a hotel setting where they have to earn as much money as possible to finance their upcoming holiday abroad. The game consists of a lead game and different subgames, and has four levels that can be completed. The lead game introduces the storyline and functions as a central point where students can keep track of their progress (e.g., money, level) and from which students can enter the subgames. The game has three subgames that present challenges that have to be solved to earn money. These challenges require proportional reasoning for their solution. Each subgame contains four challenges and can be played once per level. When the players finish three subgames (12 challenges), they automatically continue on to the next level. The challenges get more difficult as the game progresses. After four levels (48 challenges), the game ends.

Procedure

A similar procedure was employed for every study. Data collection for each class took approximately 200 minutes, spread evenly over four sessions. Pretests were administered in the first session (computational fluency and domain knowledge). The second session started with a short introduction to the game, and the rest of the second session and the third session were spent working with the game. A posttest was administered in the final session (domain knowledge). An exception to this procedure was the game-experience questionnaire, which was administered after the game in the third session of study 1.

Studies

Study 1. Self-Explanation Prompts

The first study (see Chapter 2) focused on self-explanation prompts as a way to support prevocational students' knowledge acquisition in a game-based learning environment. Taking into account the students' metacognitive skills, directive self-explanation prompts were designed and implemented in the game to elicit self-explanation during gameplay. The prompts took the form of a series of multiple choice questions and were designed to direct students' explanations toward specific aspects of domain knowledge. Though the questions already provided direction to the students, we took into account the possibility that the students would not possess sufficient skill and prior knowledge to come to an explicit realization of the knowledge they acquired during their self-explanation. Therefore, procedural information that was designed to help students structure this knowledge was added to the study. This information was a visual representation of the information that was the focus of the self-explanation prompts.

The study followed a 2x2 design with two factors: self-explanation prompts and procedural information. Four conditions were compared: the game with self-explanation prompts, the game with procedural information, the game with self-explanation prompts and procedural information, and the game with no additional support. A total of 145 students from the third and fourth years of prevocational education participated in this study (mean age 14.9 years). Learning outcomes, game performance (logfile data), and students' perception of the game were assessed.

It was expected that the game would help improve students' proportional reasoning skills, but that this effect might depend on prior knowledge and computational fluency, and that students who receive self-explanation prompts during the game would outperform students who did not receive these prompts. In addition, it was expected that the effect of the self-explanation prompts would be stronger when students received the prompts combined with the procedural information, because the procedural information would help the students to come to an explicit realization of the knowledge that resulted from their self-explanation.

Results indicated that students' ability to solve proportional problems increased significantly after playing the game, and that, even with the high density of educational content in the game, students generally perceived the game's playfulness as average and usefulness as slightly above average. Further analyses revealed that students' posttest scores could be predicted by their initial computational skills and domain knowledge, and that in-game performance showed an additional (unique) predictive value. This finding suggests that game play did indeed matter for their progress in proportional reasoning.

Although students showed progress on proportional reasoning, analysis of transfer problems showed that there was no transfer. The support in the form of self-explanation did not affect performance on proportional reasoning and transfer. The procedural information also had no additional value. Analysis of students' perception of the game showed that the addition of the support did not affect their opinion about the usefulness and playfulness of the game.

The results of this study indicated that students with below-average prior knowledge and above-average prior knowledge were both able to learn from the game, which demonstrates that students who had not previously been able to meet their potential were able to learn successfully about proportional reasoning when using the game. However, computational fluency seemed to be a prerequisite for this learning. Students who were computationally fluent outperformed students who were not. Only the first group showed significant growth in domain knowledge.

Study 2. Collaboration and Competition

The second study (see Chapter 3) investigated whether collaboration and/or competition could foster prevocational students' knowledge acquisition in a game-based learning environment. In theory, collaboration can offer an adaptive and continuous form of support in which the interaction between students (e.g., questioning, explaining, and discussing educational content) can foster both acquiring knowledge and making this knowledge explicit. The addition of competition can foster active participation, motivation, and engagement. Therefore, competition is likely to enhance learning and can serve as an incentive for collaboration. Collaboration was implemented in accordance with the Student Teams Achievement Division design. The teams (dyads) were created by pairing students with above-average prior domain knowledge and students with below-average prior domain knowledge. In-class competition was simulated by providing score updates, top five rankings, and the promise of a prize.

The study followed a 2x2 design with two factors: heterogeneous collaboration and competition. Four game conditions were compared: collaboration and competition, collaboration control, competition control and control. A total of 242 students from the first and second years of prevocational education participated in the study (mean age 13.3 years). Learning outcomes were assessed.

Results of this study showed that prevocational students' domain knowledge improved after playing the game, but that there were no additional effects of collaboration and competition (nor a combination of both). However, when the dataset was divided in two groups–one with students with above-average prior knowledge and one with students with below-average prior knowledge–results indicated an interaction between collaboration and competition. This interaction was significant for the below-average students, suggesting that below-average students experienced a positive effect of collaboration on learning when competition was not present (and a negative effect when competition was present).

Study 3. Worked Examples

The third study (see chapter 4) investigated whether faded worked examples could foster prevocational students' knowledge acquisition from a game-based learning environment and their ability to represent this knowledge. A worked example can support students' selection of relevant information, and the fading of worked-out steps can stimulate learners to actively process the educational content, which are two seemingly essential elements of effective support for game-based learning. In addition, worked examples offer an explicit representation of the embedded learning content in the game, which can help players to successfully extract learning content and procedures, and to make a connection between game terminology and mathematics terminology.

This study compared two conditions: the game with faded worked examples and the game without worked examples. A total of 103 students from the first and second years of prevocational education participated in the study (mean age 13.8 years). Learning outcomes and game performance were assessed.

Results of this study showed that prevocational students' domain knowledge improved after playing the game. This progress could be seen on game-based problems as well as on transfer problems. In addition, faded worked examples positively affected this progress: students who played the game with faded worked examples performed better during the game and on the domain knowledge test afterwards. In addition, these students did better at providing correct calculations and solutions for proportional game-based problems, but did not perform better on proportional transfer problems. Performance on transfer problems might be improved by providing students with process-oriented worked examples instead of the product-oriented worked examples that were used in this study.

Conclusion

Based on the results of the above-mentioned studies, we can conclude that game-based learning can be beneficial for prevocational education, and that the design of effective support to enhance prevocational students' knowledge acquisition from a game-based learning environment is not easy, but it is possible. It could be speculated that faded worked examples are a promising approach to supporting acquisition of knowledge about proportional reasoning in a game for prevocational education.

7

Nederlandse Samenvatting

Inleiding

Computerspellen worden vaak gezien als een effectieve instructiemethode, maar de effecten van deze benadering blijken niet eenduidig en vaak verre van optimaal. Dat de effecten niet in lijn zijn met de verwachtingen zou kunnen komen doordat computerspellen meestal uitgaan van actief en ontdekkend leren, het leren door te ervaren, en de educatieve inhoud vaak is ingebed in het spel en de verhaallijn. Deze kenmerken (i.e., leren door te ervaren, 'verborgen' educatieve content) hebben als gevolg dat de kennis die tijdens het spelen opgedaan wordt vaak impliciet en context-gebonden is. Hoewel de leerlingen wel degelijk kennis opdoen en deze kennis ook meetbaar is, wordt er in het onderwijs over het algemeen gestreefd naar expliciete kennis omdat expliciete kennis toegankelijker is en in verband wordt gebracht met transfer. Expliciete kennis volgt niet automatisch uit impliciete kennis, maar dit proces kan wel ondersteund worden door bijvoorbeeld 'self-explanation'. Uit onderzoek blijkt echter dat self-explanation zelden spontaan voorkomen tijdens het spelen met computerspellen. Er is blijkbaar ondersteuning nodig om leerlingen tijdens het werken met een educatief spel aan te zetten tot self-explanation. Ondersteuning die self-explanation tijdens het spelen met een educatief spel stimuleert, zou, in theorie, de verwerving van expliciete kennis bevorderen en zo de bruikbaarheid en effectiviteit van educatieve computerspellen kunnen bevorderen.

Voor deze dissertatie werd onderzocht hoe de effectiviteit van educatieve computerspellen kan worden geoptimaliseerd door het toevoegen van ondersteuningsvormen die, in theorie, kansrijk zijn in het bevorderen van het verwerven en expliciteren van kennis doordat zij aanzetten tot self-explanation. Drie vormen van ondersteuning werden onderzocht: self-explanation prompts, samenwerking en deels-uitgewerkte voorbeelden. De onderzoeken in deze dissertatie beoogden de effecten van deze ondersteuningsbenaderingen op de kennisverwerving van VMBO leerlingen in een educatief spel over het rekendomein verhoudingen te meten. De algemene onderzoeksvraag die hierbij gesteld werd was:

Hoe kunnen we VMBO leerlingen tijdens een educatief spel ondersteunen bij hun kennisverwerving over het rekendomein verhoudingen?

De algemene onderzoeksvraag werd in drie empirische studies onderzocht. Alle studies richtten zich op dezelfde populatie (VMBO leerlingen), maakten gebruik van hetzelfde educatieve spel, behandelden het zelfde leerdomein (het rekendomein verhoudingen) en volgden een overeenkomstige procedure.

Populatie

Participanten in de onderzoeken die in deze dissertatie zijn beschreven, zijn allen leerlingen van het voorbereidend middelbaar beroepsonderwijs (VMBO). Het VMBO biedt praktijkopleidingen en meer theoretische opleidingen en bestrijkt vier leerjaren. In de onderbouw (1e en 2e leerjaar) volgen leerlingen algemene vakken en in de bovenbouw (3e en 4e leerjaar) kiezen leerlingen voor een sector. Daarnaast wordt er in het VMBO onderscheid gemaakt in vier leerwegen: theoretisch, gemengd, kaderberoepsgericht en basisberoepsgericht. Deze leerwegen worden soms in combinatievormen aangeboden, zoals: basiskader (BK) en gemengd theoretisch (GT). Aan Studie 1 (Hoofdstuk 2) hebben alleen leerlingen uit het 2^{e} en 3^{e} leerjaar (13 – 17 jaar) van de gemengde en theoretische leerweg deelgenomen, aan Studie 2 (Hoofdstuk 3) en Studie 3 (Hoofdstuk 4) hebben leerlingen uit het 1^{e} en 2^{e} leerjaar (11 – 15 jaar) van alle leerwegen deelgenomen. Voor alle leerwegen geldt dat de populatie van het VMBO erg divers is waardoor er een grote variatie in zowel cognitieve als affectieve vaardigheden en mogelijkheden zichtbaar is.

De populatie werd gekozen omdat deze een significant aantal risicoleerlingen kent. Risicoleerlingen hebben vaak te maken met een onderwijsverleden waarin veelvuldige herhaling en faalervaringen niet onbekend zijn. Hierdoor is er een vergroot risico op weerstand tegen bepaalde instructiematerialen en instructiebenaderingen. Daarom zouden educatieve computerspellen voor deze groep een waardevol alternatief kunnen bieden. Daarnaast zou de interactieve en multimodale aanpak de leerlingen tot nieuwe inzichten kunnen brengen waar ze met andere methoden nog niet toe waren gekomen.

Domein

Rekenen werd gekozen omdat het een fundamentele vaardigheid is voor toekomstig academisch functioneren. Daarnaast blijken de rekenvaardigheden van middelbare scholieren vaak ontoereikend. Meer specifiek werd er gekozen voor het rekendomein verhoudingen. Verhoudingen is één van de vier domeinen binnen het rekenen en bekleedt ongeveer 30% van het rekenonderwijs. Onderzoeksrapporten van Cito laten zien dat VMBO leerlingen met een ernstig tekort op het rekendomein verhoudingen kampen.

Problemen bij het oplossen van rekenkundige verhoudingsproblemen lijken te ontstaan doordat leerlingen vaak niet over expliciete kennis van domein-specifieke concepten beschikken; verhoudingsproblemen variëren in structuur en expliciete kennis is benodigd om effectief en efficiënt met deze variatie om te gaan. Het is waarschijnlijk dat onderwijs over verhoudingen baat heeft bij educatieve computerspellen omdat deze spellen op een relatief simpele manier een diversiteit aan motiverende en interactieve problemen en contexten binnen het bereik van de docent en leerling kunnen brengen. De actieve en multimodale aard van een educatief spel zou leerlingen kunnen helpen om een meer solide, concreet en expliciet beeld van het normaal gesproken abstracte gebied van verhoudingen te krijgen.

Spel

Het spel voor het onderzoek in de huidige dissertatie is ontwikkeld in samenwerking met leerkrachten en leerlingen van het VMBO. Grofweg werden de volgende fases doorlopen: ontwerp en toetsing van het prototype, aanpassingen en toetsing van prototype, ontwerp van ondersteuning en ontwerp van experimentele spelversies. Er werd één basis versie van het spel ontwikkeld en voor de verschillende experimenten werd deze basis versie vergeleken met experimentele versies (versies waarbij de basisversie werd uitgebreid met de te onderzoeken ondersteuning).

Om interactie en motivatie van de leerlingen met het spel te bevorderen werd er gekozen voor een verhaallijn die aan zou sluiten bij de belevingswereld van deze leerlingen: geld verdienen. In het spel speelt de leerling een tiener die op vakantie wil, maar geen geld heeft. Daarom moet de tiener een bijbaantje zoeken. De tiener komt in het hotel van familieleden terecht en gaat hier taken uitvoeren om zoveel mogelijk geld te verdienen en zo ver mogelijk op vakantie te kunnen gaan.

Het spel bestaat uit een ‘lead game’ en een drietal ‘subgames’. De lead game dient als centraal punt in het spel waar de leerling de vooruitgang kan monitoren (verdiende geld, vakantiebestemming) en naar de verschillende subgames kan navigeren. De verhaallijn wordt eveneens in de lead game geïntroduceerd. De subgames bevatten uitdagingen (vier per subgame). Om de uitdagingen op te lossen moeten de leerlingen gebruik maken van hun kennis over rekenkundige verhoudingen. Als een leerling een uitdaging goed oplost, wordt er uitbetaald. Als een leerling drie subgames heeft uitgespeeld (12 uitdagingen), opent automatisch een nieuw level. Hoe hoger het level, des te complexer de uitdagingen worden. In totaal bevat het spel vier levels (48 uitdagingen) waarna het automatisch afsluit.

Procedure

De beschreven studies volgden een vergelijkbare procedure. De dataverzameling werd klassikaal uitgevoerd en duurde per klas ongeveer 200 minuten evenredig verdeeld over vier sessies. De voormeting (i.e., rekenvaardigheid en domeinkennis) werd in de eerste sessie afgenomen. De tweede en derde sessie werden gebruikt om het spel te spelen en in de vierde sessie werd een nameting (domeinkennis) uitgevoerd. Een uitzondering hierop is studie 1 waar in toevoeging op de beschreven procedure een vragenlijst aan het eind van de derde sessie werd afgenomen.

Studies

Study 1. Self-Explanation Prompts

In de eerste studie (Hoofdstuk 2) is onderzocht in welke mate self-explanation prompts de kennisverwerving konden stimuleren. Er werd gekozen voor directieve prompts omdat er verwacht werd dat de leerlingen onvoldoende vaardigheden hadden om met open prompts tot succesvolle self-explanation te komen. De directieve prompts gaven structuur en richting aan de self-explanations en stuurden met behulp van multiple-choice vragen de self-explanations van de leerlingen richting essentiële informatie van het domein. Daarnaast werd er rekening gehouden met de mogelijkheid dat VMBO leerlingen ondanks de directieve aard van de prompts nog moeilijkheden konden ervaren om tot een expliciete representatie van de tijdens de self-explanations opgedane kennis te komen. Daarom werd er tevens ondersteuning geboden in de vorm van procedurele informatie: een visuele weergave van essentiële procedurele informatie van het rekendomein verhoudingen (deze informatie kwam overeen met de informatie waar de prompts de focus op legden).

Deze studie volgde een 2x2 design met twee factoren: self-explanation prompts en procedurele informatie. In totaal werden er vier condities vergeleken: het spel met prompts, het spel met procedurele informatie, het spel met beide vormen van ondersteuning en een controle conditie (spel zonder ondersteuning). Aan deze studie namen 145 leerlingen deel uit het derde en vierde jaar van het VMBO (gemiddelde leeftijd 14.9 jaar). Leeruitkomsten, prestatie tijdens het spel (loggegevens) en de perceptie (over de speelsheid en nut van het spel) van de leerlingen werden gemeten.

Eén van de uitkomsten van deze studie is dat leerlingen na het spelen van het spel significant beter presteerden op de domeinkennistoets dan voor die tijd. Daarnaast was hun perceptie over het algemeen positief, leerlingen gaven het 'nut' en de 'speelsheid' van het spel een score die gemiddeld tot iets bovengemiddeld was. Verdere analyse toonde aan dat de prestatie op de nameting niet alleen een product was van voorkennis en rekenvaardigheid, maar dat de prestatie tijdens het spel hier een significante unieke bijdrage op had. Dit suggereert dat het spelen van het spel daadwerkelijk bij heeft gedragen aan de toename in kennis. Wanneer de prestaties van ondergemiddelde en bovengemiddelde leerlingen vergeleken werden, bleek dat beide groepen significant vooruitgingen. Deze vooruitgang was alleen zichtbaar bij leerlingen die over een voldoende niveau van rekenvaardigheid beschikten.

Ondanks dat leerlingen een toename in kennis van verhoudingen lieten zien, bleek er geen effect op transferopgaven. Resultaten lieten daarnaast geen effect zien van de toegepaste support. De self-explanation prompts en de procedurele informatie, of een combinatie ervan, hadden geen significante invloed op de kennisverwerving noch op de perceptie van de leerlingen over de speelsheid en het nut van het spel.

Studie 2. Collaboratie en Competitie

In de tweede studie (Hoofdstuk 3) werd onderzocht in welke mate samenwerken wel/niet in combinatie met competitie kon bijdragen aan de kennisverwerving. Er werd verwacht dat collaboratie een continue adaptieve vorm van support zou bieden. Omdat leerlingen elkaar kunnen helpen, elkaar kunnen motiveren en voor succesvolle collaboratie genoodzaakt zijn om hun kennis en problemen te verwoorden werd verwacht dat collaboratie zou kunnen bijdragen in zowel het verwerven van als het expliciteren van kennis. Daarnaast werd verwacht dat competitie de motivatie en betrokkenheid van de leerlingen kon beïnvloeden, hetgeen een positief effect zou hebben op het leren in zowel de individuele als collaboratieve setting. De collaboratie werd geïmplementeerd aan de hand van het Students Teams Achievement Devisions (STAD) design. In de samenwerkingscondities werkten de leerlingen in heterogene tweetallen die samengesteld werden op basis van voorkennis (leerlingen met bovengemiddelde voorkennis werden gekoppeld aan leerlingen met ondergemiddelde voorkennis). Competitie werd binnen de klassen geïnitieerd waarbij leerlingen werden uitgedaagd om individueel of als team een zo hoog mogelijke score te halen. De score was een combinatie van individuele vooruitgang en spelscore, wat inhield dat de kans om te winnen in principe onafhankelijk was van voorkennis.

Deze studie volgde een 2x2 design met twee factoren: collaboratie en competitie. In totaal werden er vier condities gecreëerd: collaboratief, competitief, collaboratief en competitief en een controle conditie waarin leerlingen individueel werkten en waarbij er geen competitie werd geïnitieerd. Aan deze studie namen 242 leerlingen uit het eerste en tweede jaar van het VMBO deel (gemiddelde leeftijd 13.3 jaar). Alleen leeruitkomsten werden geëvalueerd.

Net als bij studie 1 toonde de uitkomsten van deze studie aan dat leerlingen na het spelen van het spel significant beter presteerden op de domeinkennistoets dan voor die tijd. Er bleken echter geen significante effecten van samenwerking, competitie of een combinatie van de twee op deze vooruitgang. Wanneer een onderscheid werd gemaakt tussen leerlingen met boven- en ondergemiddelde voorkennis bleek er wel een significante interactie tussen collaboratie en competitie voor de groep ondergemiddelde leerlingen. Hieruit viel af te leiden dat competitie voor deze leerlingen een negatief effect had op de effecten van de samenwerking.

Studie 3. Uitgewerkte Voorbeelden

In de derde studie (zie Hoofdstuk 4) werd onderzocht in welke mate uitgewerkte voorbeelden de kennisverwerving van de leerlingen konden bevorderen. Het ging hierbij om uitgewerkte voorbeelden die initieel bijna volledig uitgewerkt waren, maar gedurende het spel steeds minder uitgewerkte informatie bevatten (‘faded’). De uitgewerkte voorbeelden konden de leerlingen helpen om relevante informatie te herkennen en selecteren, en het vervagen van de informatie in het uitgewerkte voorbeeld kan de leerlingen aanzetten tot actieve verwerking van deze informatie. Daarnaast bieden de uitgewerkte voorbeelden een expliciete representatie van de educatieve content die in het spel ingebed is, hetgeen de leerlingen helpen om de educatieve inhoud en procedures succesvol uit het spel te filteren en een connectie te maken tussen de terminologie in het spel en de formele terminologie.

In deze studie werden twee condities vergeleken: het spel met uitgewerkte voorbeelden die langzaam werden vervaagd en het spel zonder uitgewerkte voorbeelden. In totaal namen 103 leerlingen uit het eerste en tweede leerjaar van het VMBO deel aan het onderzoek (gemiddelde leeftijd 13.8 jaar).

De resultaten van dit onderzoek laten, net als de resultaten van studie 1 en studie 2, zien dat leerlingen na het spelen van het spel significant beter presteerden op de domeinkennistoets dan voor die tijd. Deze vooruitgang was zichtbaar bij zowel op het spel gebaseerde opgaven als op transfer opgaven. Daarnaast bleek dat de uitgewerkte voorbeelden een significant effect hadden: leerlingen in de conditie met uitgewerkte voorbeelden bleken zowel tijdens het spel als op de nameting beter te presteren. Deze leerlingen hadden tijdens het spel gemiddeld minder pogingen nodig om opdrachten op te lossen en gaven bij de nameting meer correcte berekeningen en oplossingen voor de op het spel gebaseerde opgaven. Er bleek echter geen effect op de transfer opgaven van de nameting, dit zou verklaard kunnen worden door de oriëntatie van de uitgewerkte voorbeelden, deze was vooral product-georiënteerd. Procesgeoriënteerde uitgewerkte voorbeelden zouden mogelijkerwijs een beter effect op transfer bewerkstelligen.

Conclusie

Op basis van de resultaten van bovengenoemde studies kan de veronderstelling worden gemaakt dat educatieve computerspellen een positieve, effectieve bijdrage kunnen leveren aan het VMBO onderwijs, en dat het ontwerpen van effectieve ondersteuning om de positieve effecten te optimaliseren niet eenvoudig, maar wel mogelijk is. Er zou voorzichtig geconstateerd kunnen worden dat deels uitgewerkte voorbeelden een veelbelovende ondersteuningsvorm voor educatieve computerspellen bieden. Meer onderzoek naar de besproken ondersteuningsvormen, waarbij gevarieerd wordt in educatieve content, spelgenre en populatie, zal het bredere perspectief bieden dat nodig is om meer algemene conclusies te trekken.

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SERIOUS SUPPORT FOR SERIOUS GAMING

Enhancing Knowledge Acquisition in a Game for Prevocational Mathematics Education

Game-based learning is often considered to be an effective instructional approach, but the effects of game-based learning are varied and far from optimal. This dissertation addresses how to improve game-based learning with instructional support.

The series of empirical studies reported in this dissertation sought to establish the effects of three forms of instructional support (i.e., self-explanation prompts, collaboration, and faded worked examples) on prevocational students' knowledge acquisition in an educational game.

Results indicated that game-based learning can be beneficial for prevocational education and that the addition of faded worked examples can enhance the effectiveness of the educational game.