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How competition and heterogeneous collaboration interact in prevocational game-based mathematics education

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ABSTRACT

The present study addresses the effectiveness of an educational mathematics game for improving proportional reasoning in students from prevocational education. Though in theory game-based learning is promising, research shows that results are ambiguous and that we should look into ways to support game-based learning. The current study explored two factors (i.e., collaboration and competition) that have been associated with motivational and cognitive effects, and have potential to optimize game-based learning. In a fully crossed design, four conditions were examined: collaboration and competition, collaboration control, competition control, and control. It was found that, over all, gameplay did improve students' proportional reasoning skills but that learning effects did not differ between conditions. However, when students' ability levels were taken into account, an interaction between collaboration and competition was found. For below-average students, the effect of collaboration was modified by competition, showing a negative effect of competition on domain knowledge gains in a collaborative learning situation. In contrast, for above-average students, the data demonstrated a trend that suggests a positive effect of competition on domain knowledge gain in a collaborative learning situation.

1. 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 (e.g., the ‘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.

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Prevocational education is a less advanced level of 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.

2. 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.

3. 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 gameplay (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, in press), 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.

4. 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-Team-Achievement-Division' (STAD) design. 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 TGT and found that, though gameplay promoted mathematical performance, there was no difference between collaborative or individual competitive gameplay on student achievement.

5. 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 2×2 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.

6. Method

6.1. Participants and design

The sample included 242 students, 118 boys and 124 girls, aged 11–15 years old ($M = 13.3$, $SD = .748$) 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.

6.1.1. 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.

6.1.2. 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 10 min) the researcher checked the scores and told the class what the highest game score at that time was.

6.1.3. Collaboration and competition

The condition where students both collaborated and competed was in line with the Student-Team-Achievement-Division 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.

6.2. Materials

6.2.1. 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 1 provides a summary of these three types of problems.

6.2.2. 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

Table 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[a] or external[b] 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[c] 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.	

[a] **Internal ratio**: ratio of two numbers of the same variable or term.

[b] **External ratio**: ratio of two numbers of different variables or terms.

[c] **Integer**: a whole number (not a decimal).

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.

In total, the game contains three types of subgames with four levels per subgame. Each subgame represents a proportional problem type (see Table 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. Fig. 1 shows screencaptures of the different subgames. Table 2 provides an overview of the subgames and examples of the challenges.

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.

6.2.3. 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 1 min 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).

Fig. 1. Representation (translated) of subgames. From left to right: 'refrigerator', 'blender', 'jugs'.

Table 2
Overview of level structure per subgame.

Subgame	Problem type	Example of problem	Game level: Difficulty of proportional problem
Jugs	Comparison	“There are two jugs of juice on the counter. A customer asks for the sweetest juice mix. Which juice mix will you give to the customer?” The ratio of water/fruit is presented on the jugs. The student has to click on the correct jug to answer.	1 Contains level 1 problems 2 Contains level 2 problems 3 Contains level 3 problems 4 Contains a mix of all levels
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 Contains level 1 problems 2 Contains level 2 and 3 problems 3 Contains level 4 problems 4 Contains a mix of all levels
Blender	Transformation	“A fruit cocktail contains 10 berries for every 100 ml of yoghurt. How many berries should you add to 500 ml of yoghurt if you want to maintain the flavor?” The given ratio of 10/100 is presented and the student has to answer the question by dragging and dropping the berries into a blender that contained the 500 ml of yoghurt.	1 Contains level 1 problems 2 Contains level 2 and 3 problems 3 Contains level 4 problems 4 Contains a mix of all levels

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.

6.3. Procedure

The total time of the experiment was 200 min 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 10 min 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.

Table 3
Descriptive statistics for participants' test scores per condition.

	Collaboration competition *(n = 45)*		Collaboration *(n = 53)*		Competition *(n = 36)*		Control *(n = 34)*	
	M	SD	M	SD	M	SD	M	SD
Computational fluency (range: 0–200)	116.82	19.82	122.60	19.98	117.44	22.25	126.09	16.52
Domain knowledge pretest (% correct)	*39.58*	*16.70*	*40.57*	*17.66*	*40.97*	*18.45*	*38.05*	*16.24*
Missing value problems (%)	51.11	31.06	54.72	29.85	45.14	23.78	44.85	28.06
Comparison problems (%)	56.11	29.20	53.30	28.60	58.33	25.35	52.94	29.36
Transformation problems (%)	23.89	26.09	27.36	33.35	29.86	28.55	27.21	27.09
Transfer problems (%)	27.22	23.73	26.89	23.94	30.56	28.10	27.21	23.33
Domain knowledge posttest (% correct)	*42.08*	*20.66*	*44.10*	*21.14*	*45.14*	*18.79*	*43.75*	*21.10*
Missing value problems (%)	55.00	25.89	56.13	33.58	56.94	26.47	47.80	32.78
Comparison problems (%)	53.89	24.40	52.36	24.15	47.92	23.43	53.68	27.62
Transformation problems (%)	29.44	30.75	39.15	33.44	47.22	29.14	42.65	37.70
Transfer problems (%)	30.00	29.00	28.77	21.59	28.47	26.15	30.88	23.88

The values in italics represent the percentage correct of the total domain knowledge test.

7. 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, posttest). 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 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, $F(3,164) = 1.90$, $p = .132$, with effect size $\eta_p^2 = .030$, no significant differences between conditions in prior domain knowledge, $F(3,164) = .24$, $p = .868$, with effect size $\eta_p^2 = .004$.

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 problem types (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, $F(1,164) = .61$, $p = .436$, $\eta_p^2 = .004$. The multivariate main effect of time was not qualified by an interaction between time and competition, Pillai's trace = .022, $F(1,161) = .89$, $p = .470$, $\eta_p^2 = .022$, nor was there an interaction between time and collaboration, Pillai's trace = .022, $F(1,161) = .90$, $p = .456$, $\eta_p^2 = .022$. The hypothesized interaction between time, competition and collaboration was not significant Pillai's trace = .017, $F(1,161) = .68$, $p = .605$, $\eta_p^2 = .017$.

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.

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 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, $F(3,164) = .25$, $p = .858$ 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, $F(1,84) = .41$, $p = .801$, $\eta_p^2 = .019$, no multivariate main effect for collaboration Pillai's trace = .034, $F(1,84) = .75$, $p = .561$, $\eta_p^2 = .034$, 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 (Fig. 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, $F(1,87) = .38$, $p = 539$, $\eta_p^2 = .004$, comparison problems, $F(1,87) = 60$, $p = .442$, $\eta_p^2 = .007$, and transfer problems, $F(1,87) = .92$, $p = .339$, $\eta_p^2 = .010$.

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

Table 4
Descriptive statistics for participants' test scores per condition per ability level.

	Collaboration competition		Collaboration		Competition		Control	
	M	SD	M	SD	M	SD	M	SD
Below average	n = 26		n = 25		n = 21		n = 19	
Computational fluency	117.19	22.64	118.4	22.75	113.24	23.44	125.05	16.4
Domain knowledge learning gain	3.40	13.26	9.25	16.05	11.90	19.25	5.92	17.61
Learning gain missing value	8.65	28.23	7.00	27.50	17.86	29.73	7.89	42.53
Learning gain comparison	5.77	34.14	3.00	29.15	−7.14	36.35	1.31	38.62
Learning gain transformation	5.77	32.06	24.00	29.29	33.33	32.91	11.84	36.67
Learning gain transfer	−6.73	32.06	3.00	23.18	3.6	26.56	2.63	20.23
Above average	n = 19		n = 28		n = 15		n = 15	
Computational fluency	116.32	15.74	126.36	16.67	123.33	19.72	127.40	17.11
Domain knowledge learning gain	1.32	14.52	−1.56	17.48	−6.67	12.82	5.42	18.12
Learning gain missing value	−2.63	26.21	−3.57	33.83	3.33	20.85	−3.33	36.43
Learning gain comparison	−13.16	29.31	−4.46	43.60	−15.00	24.64	.00	38.96
Learning gain transformation	5.26	27.10	.89	31.54	−5.00	30.18	20.00	35.61
Learning gain transfer	15.79	26.63	.89	24.98	−10.00	18.42	5.00	17.12

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 (Fig. 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, $F(1,73) = .16$, $p = .691$, $\eta_p^2 = .002$, comparison problems, $F(1,73) = .71$, $p = .714$, $\eta_p^2 = .002$.

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.

8. 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 (in press) successfully

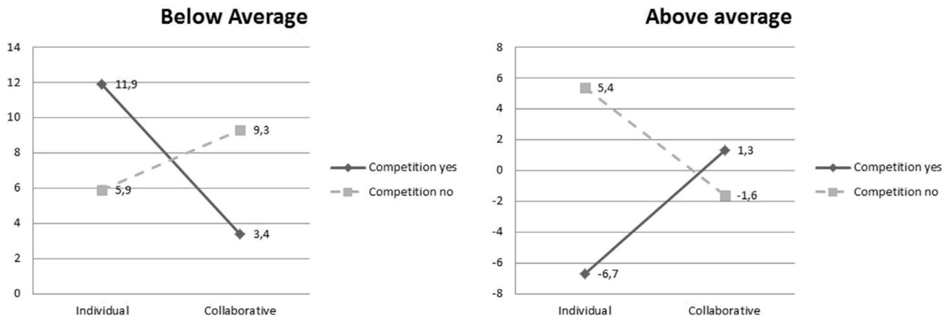

Fig. 2. Illustration of multivariate interaction: learning gains per condition for students with below average and students with above average prior knowledge.

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 Fig. 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 counter-intuitive. 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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