"Zeldenrust": A Mathematical Game-Based Learning Environment for Prevocational Students

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Abstract In this contribution, we present a game-based learning environment for 12–16-year-old vocational students in which they can practice proportional reasoning problems. The learning content and goals, as well as the specific game features are discussed. We can conclude that developing a serious game implies many choices and decisions led by theoretical foundations, as well as by practical limitations and pragmatic considerations.

Keywords Number sense • Game development • Educational game

Serious games have become a hot issue in educational technology and are considered as a potential instruction tool for effective and efficient delivery of complex subject matter (Ke, 2008). Despite the flourishing popularity of implementing games in education and the promising claims that arose, empirical research and evidence to support these claims remains scarce (Papastergiou, 2009). The absence

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of an univocal and generic definition of educational games, a shared framework to talk about educational games and clear methodological guidelines to evaluate their effectiveness, results in a gap between what is theoretically claimed and what has been empirically demonstrated as well as in insufficient guidance for game designers on how to develop effective serious games. In order to make a step forward with respect to this guidance, there is a need for rigorous scientific studies that pinpoint instructional design features that improve instructional effectiveness (Aldrich, 2005; DeLeeuw & Mayer, 2011). Also, to make sure scientific results are more generalizable and comparable, scientific research would benefit from more detailed and clear descriptions of the games that are implemented in scientific studies. Therefore, we provide a detailed description of the development of a game-based learning environment (GBLE) in which we focus on the learning content, the story line, game design, and other specific game features. The environment is developed for prevocational students (second grade) and aims at stimulating their proportional reasoning abilities.

Learning Content: Proportional Reasoning

When developing a game for educational purposes, two points considering learning content draw the attention. First, the learning content has to fit educational goals to make the game attractive for use in educational settings and second, the learning content has to be suitable for integration in a game context. The game we describe focuses on the content domain of mathematics, since math is particularly suited for game-based learning (Hays, 2005). More specifically, we focus on "number sense" because number sense is a central component in the curriculum of our target group. Number sense is defined in different ways in the mathematics education literature. We use the definition of McIntosh, Reys, and Reys (1992): "Number sense refers to a person's general understanding of number and operations along with the ability and inclination to use this understanding in flexible ways to make mathematical judgments and to develop useful strategies for handling numbers and operations." (p. 3).

In the game, number sense was operationalized by exercises on proportional reasoning, or "reasoning in a system of two variables between which there exists a linear functional relationship" (Karplus, Pulos, & Stage, 1983a, p. 219). This operationalization is in line with the abovementioned definition of number sense by McIntosh et al. (1992), since students, in order to advance in the game, need to understand proportional reasoning problems, be able to conduct operations with them and apply the provided strategies in a flexible way to handle the proportional reasoning problems and operations correctly and efficiently. As Berk, Taber, Gorowara, and Poetzl (2009) stated "proportional reasoning readily lends itself to the development of flexibility in that multiple methods are available for solving proportion problems, and for particular problems, particular methods are more efficient than others" (p. 116). According to Lamon (1999), there are six mathematical content areas that contribute to the development of proportional reasoning: relative thinking, partitioning, unitizing, attending to quantities and changes, ratio sense, and rational number interpretations. Consequently, playing the game might also strengthen these content areas that proportional reasoning encompasses.

Besides its relation to number sense, proportional reasoning was chosen because it is a well-defined domain with concrete applications (not too abstract). These characteristics make proportional reasoning suitable for implementation in an educational game and scientific evaluation. Additionally, proportional reasoning is seen as a crucial topic in school mathematics, and considering the tight connections of proportional reasoning with ratios, rational numbers, and other multiplicative concepts, it spans the entire curriculum—from elementary school through university level mathematics (Lamon, 2007). Also, in both the Flemish and Dutch prevocational curriculum, the math domain of proportional reasoning is relevant and the prevocational students are expected to understand the proportional reasoning language and be able to solve simple proportional reasoning problems. However, proportional reasoning is also considered as a frequent source of difficulty for students (Lamon, 2007) and teachers in (prevocational) math education mention that their students often experience difficulties with it because of its mathematical complexity and its cognitive challenge. For the target group of this GBLE, this is confirmed by the Flemish national assessment results (Vlaamse Overheid, 2009). The relevance of proportional reasoning in the curriculum, the shortage of proportional reasoning skills, and the search for alternative instructional approaches creates a setting where research on the topic is desirable.

Types of Problems

Three types of proportional problems were selected based on the literature: (1) missing value problems, (2) transformation problems, and (3) comparison problems (e.g., Harel & Behr, 1989; Kaput & West, 1994; Vergnaud, 1983). For the first type of problems, missing value problems, a missing value in one of two ratios needs to be found. These problems can be schematically presented as a/b = ?/d or as a/b = c/? (e.g., 3/4 = 12/?). The second type of problems, transformation problems, are problems in which two ratios are given but one (or two) values need to be adapted to create two equivalent ratios. For instance, the ratios 3/6 and 4/12. In the second ratio, 2 needs to be added to 4 to make this ratio equivalent to the first ratio (3/6 = 6/12). This latter type of problems is assumed to be more difficult than missing value problems because the student has to figure out independently how much has to be added and to what amount it has to be added. This in contrast to the missing value problems where it is clear what number is missing where. Next to this, the strategies that are used to solve transformation problems require more steps than the strategies involved when solving missing value problems. The third type of problems, comparison problems, are problems where the relationship between two ratios needs to be determined. One ratio can be "equal to," "less than," or "more than" the other ratio (e.g., is 1/2 equal to 11/20?). This third type of problems is different from the other two types of problems because in the former case no values are missing (type 1) or need to be adapted (type 2). The two ratios are given and the student has to compare them with each other (or with a simple reference point, e.g., 1/2) in order to solve the problems.

Difficulty Levels

Several task-related and subject-related factors influence performance of students on proportional reasoning problems (Tourniaire & Pulos, 1985) and thus influence the difficulty of these problems. For the missing value problems, two factors were used to divide the type of problems in different difficulty levels, namely (1) the presence or absence of integer or non-integer (internal or external) ratios and (2) numerical complexity (i.e., the value of the numbers and thus the value of the ratios). To explain the first factor (integer or non-integer internal or external ratio), an example is given: 1/2 = 3/6. The internal ratio is the "between ratio" or in this case the values 1 and 3 or the values 2 and 6. The external ratio is the "within ratio" or in this example value 1 and 2 and value 3 and 6. In ratios, the multiplicative relationship can be integer or non-integer. In our example, the problem has integer multiples for the internal ratio ($1 \times 3 = 3$ and $2 \times 3 = 6$) as well as for the external ratio ($1 \times 2 = 2$ and $3 \times 2 = 6$) because we can multiply the values of the ratios with a natural number (in this case respectively 3 and 2). In the following example: 2/6 = 3/9, the external ratio is non-integer because we need to multiply 2 and 6 with 1.5 to have 3 and 9. Taking this together, four combinations can be made. A rational task analysis (e.g., Kaput & West, 1994; Karplus et al., 1983a; Tourniaire & Pulos, 1985; Vergnaud, 1983), but also empirical validation (e.g., Van Dooren, De Bock, Evers, & Verschaffel, 2009), suggest the following difficulty hierarchy in the combinations (with increasing degree of difficulty): (1) two integer ratios, (2) integer internal ratio and non-integer external ratio, (3) non-integer internal ratio and integer external ratio, and (4) two non-integer ratios. For this game, this classification was combined with a second factor of difficulty: the numerical complexity of the ratios or the value of the number, that is, ratios bigger than 1 or not. It is assumed that a ratio bigger than 1 (in the example 39/3 and 13/1 both the internal (39/13) and the external (39/3) ratio are bigger than 1) leads more to deficiencies of reasoning than a ratio smaller than 1 (in the example 1/2 and 4/8 both the internal (1/4) and the external (1/2) ratio are smaller than 1) (Steinhorsdottir, 2006; Tourniaire & Pulos, 1985).

Also for the transformation problems two factors were used to divide this type of problems in different difficulty levels, namely (1) the presence or absence of integer or non-integer (internal or external) ratios and (2) the number of values (i.e., one or two) that must be adapted to become the correct answer. In the first difficulty level, both values can be adapted, but it is not compulsory. So if the two ratios that are given are 3/6 and 4/12, the player can add 2 to value 6 to make this ratio equivalent with the first ratio (3/6 = 6/12), but the player can also add 5 to 4 and 6 to 12 (3/6 = 9/18). All the equivalent answers (e.g., 10/20, 12/24) are also correct. In the second difficulty level, only one value must be adapted. For these exercises, it is not allowed to adapt both and multiply both numbers in the first ratio to obtain an equivalent ratio. Only one correct answer is possible. In the last difficulty level, both numbers must be adapted in the sense that the player cannot solve the problems by changing only one number. Take for example 3/6 and 4/13. Both numbers need to be adapted to be able to solve this task. In this example 5 needs to be added to 4 and 6 to 13 to obtain the correct sollution: 3/6 = 9/18. All other equivalent answers are also correct. Table 1 gives an overview of these difficulty levels for the missing value and transformation problems.

Because the third type of problems, the comparison problems, is—as abovementioned—different from the other two types of problems, the difficulty

Table 1 Overview of difficulty levels for missing value and transformation problems

Difficulty level	Sub-level	Internal ratio (IR)	IR <or> 1	External ratio (ER)	ER <or> 1	Amount of values that can/must be adapted
Missing value problems						
1	a	Integer	<1	Integer	<1	
	b	Integer	<1	Integer	>1	
	c	Integer	>1	Integer	<1	
	d	Integer	>1	Integer	>1	
2	a	Integer	<1	Non-integer	<1	
	b	Integer	<1	Non-integer	>1	
	c	Integer	>1	Non-integer	<1	
	d	Integer	>1	Non-integer	>1	
3	a	Non-integer	<1	Integer	<1	
	b	Non-integer	<1	Integer	>1	
	c	Non-integer	>1	Integer	<1	
	d	Non-integer	>1	Integer	>1	
4	a	Non-integer	<1	Non-integer	<1	
	b	Non-integer	<1	Non-integer	>1	
	c	Non-integer	>1	Non-integer	<1	
	d	Non-integer	>1	Non-integer	>1	
Transformation problems						
1	a	Integer		Integer		2 values can
	b	Integer		Integer		1 value must
	c	Integer		Integer		2 values must
2	a	Integer		Non-integer		2 values can
	b	Integer		Non-integer		1 value must
	c	Integer		Non-integer		2 values must
3	a	Non-integer		Integer		2 values can
	b	Non-integer		Integer		1 value must
	c	Non-integer		Integer		2 values must
4	a	Non-integer		Non-integer		2 values can
	b	Non-integer		Non-integer		1 value must
	c	Non-integer		Non-integer		2 values must

Table 2 Overview of difficulty levels for comparison problems

Difficulty level	Specification		Example
Comparison problems			
1	Quantitative reasoning	Equal values for ingredient 1	81/43 and 81/39
		Equal values for ingredient 2	80/43 and 83/43
		Extreme large and small ratios	1/36 and 42/4
2	Solved by estimation	Internal ratio easy multiplication	11/20 and 22/36
		External ratio easy multiplication	30/60 and 42/80
		External ratio matches simple reference point (1/2, 1/3, 1/4, 1/10)	17/36 and 21/41
3	Complete calculation		16/41 and 33/85

levels are based on another type of task analysis (e.g., Cramer, Post, & Currier, 1993; Karplus, Pulos, & Stage, 1983b; Spinillo & Bryant, 1999) and empirical validation (Hendrickx, 2013). Comparison problems are divided into three levels of difficulty, based on the procedure(s) that can be used to solve the problems (e.g., comparing both ratios with each other). The first level includes problems that can be solved directly by quantitative reasoning. These problems can be solved by reasoning because either the values for two dimensions are equal (e.g., 81/43 vs. 81/39) or the comparison involves ratios that are inversed (e.g., 1/36 vs. 42/4). In the second difficulty level, the problems can be solved by estimation because the internal or external ratio show an easy multiplication, and hence is integer (e.g., 11/20 vs. 22/36) or the external ratio matches a simple reference point (e.g., 1/2 in the example 17/36 and 21/41). In the third and final level, the answer cannot be determined directly by qualitative reasoning or estimation, but by using full calculation (e.g., 16/41 vs. 33/85). This level contains only non-integer multiplicative relationships. Table 2 gives an overview of the difficulty levels for the comparison problems. With the game we strive for practice and knowledge gains on all three types of problems by integrating the proportional reasoning problems into the story line of the game.

The Game

The development of the game involved an iteration process including: (1) a prototype showing how students could act in the game, (2) a base version, and (3) a revised base version. Each milestone was followed by an evaluation through small focus groups of teachers/students (prototype) and pilot studies (base/revised version). The iteration approach was chosen to allow modifications in the concept and specifications of the game.

The self-developed game we describe is designed for 12–16-year-old Flemish and Dutch prevocational students. The game is available in an online and standalone version. The online version requires an Internet connection and Adobe's FlashPlayer. The game can be started from a central Internet address and all player actions are logged (e.g., number of attempts for every exercise, number of correct answers on the tasks, the use of the calculator and handbook (tutorial), how many bottles are put in the refrigerator, timestamps). These extensive loggings create extra research opportunities, that is, to investigate players' game behavior, performance, and learning during game-play. The standalone version has to be installed on PCs, does not require a separate FlashPlayer, and does not support logging of player actions. Both the online and stand-alone version consist of a 2D cartoon-like environment. The choice in graphics (2D, 3D) and the level of detail were a compromise between the advice to make games as realistic as possible and the practical constraints with respect to development time and cost and capacity of school networks and available hardware.

Game Design

To foster immersive and engaged gameplay and create context for the educational content, a story line was created. The theme of the story line was tailored to fit the teenage students' interests and world. In the game the students take on a role as hotel employee, more specifically in the hotel of their uncle and aunt. They work there and complete several tasks to earn money for a summer journey. The destination of the holiday depends on the amount of money they can gather through playing the game. During this virtual career they encounter problems and fulfill tasks that help them to understand, practice and master the math domain of proportional reasoning.

Lead Game

The game consists of a lead game and different subgames. When players enter the (lead) game, they can activate an avatar with a choice for gender and origins (see Fig. 1). Choosing one's own avatar is assumed to increase players' arousal (Lim & Reeves, 2009) and intrinsic motivation (e.g., Cordova & Lepper, 1996). After having picked an avatar, the lead game continues and players are introduced (see Fig. 2) to the main story line and game goal (i.e., the wish to go on holiday, the need for money, the job in the hotel). This is done by an automatic tutorial in which text and images are combined with each other (see Fig. 2). After this short introduction, players are accompanied by the two non-playable characters (NPGs), being their

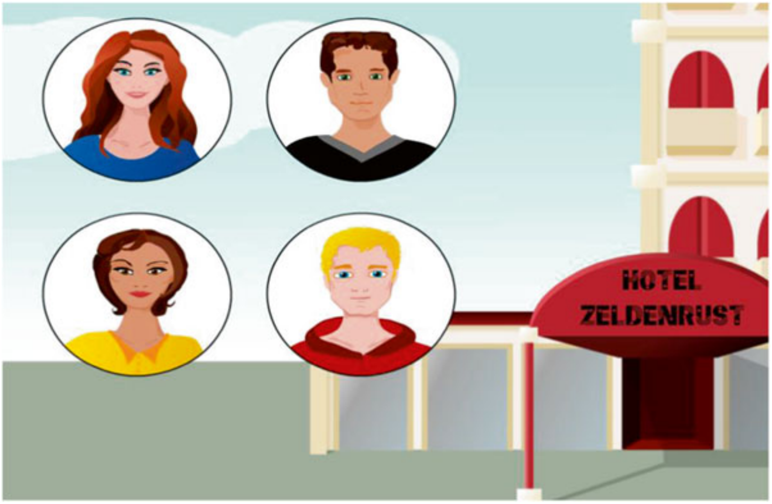

Fig. 1 Overview of the four avatars the players can choose based on gender and origin

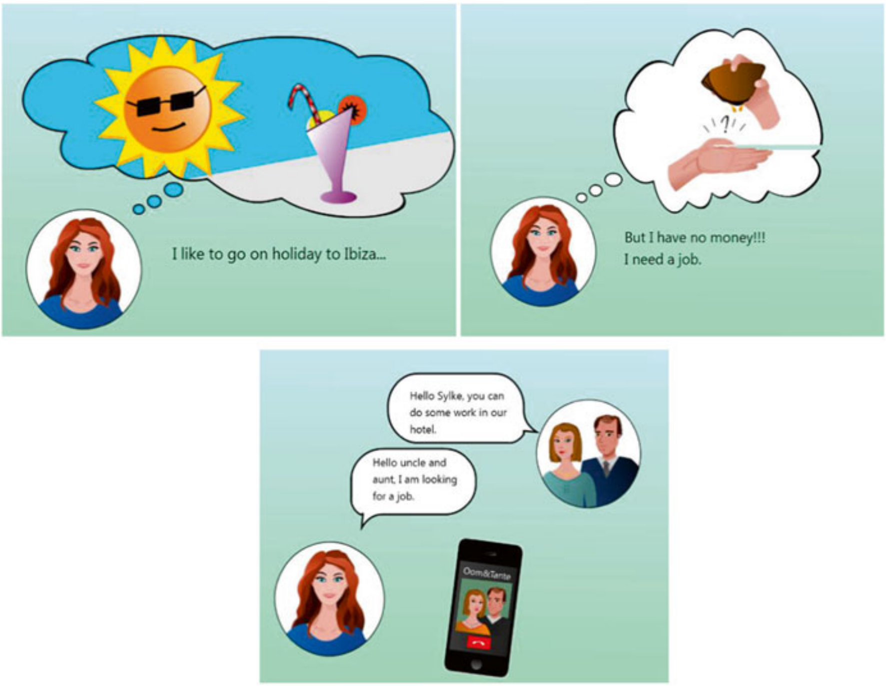

Fig. 2 Short introduction in which the story line and game goal are explained

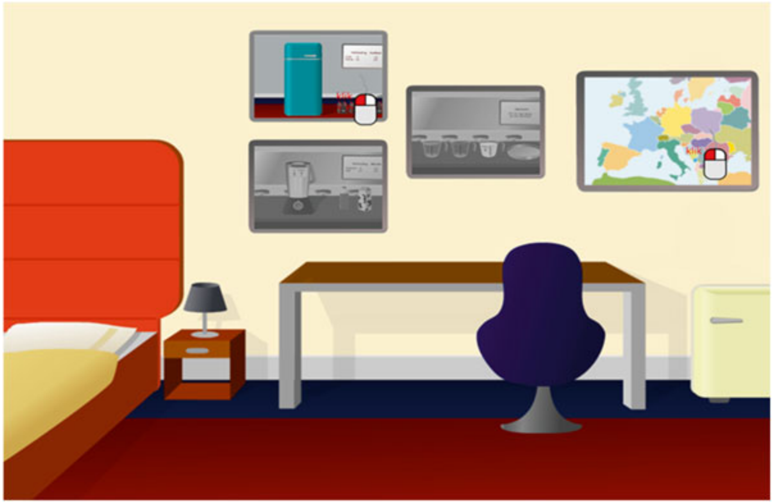

Fig. 3 The central room in the game. From this room, subgames can be activated by clicking on the paintings. The paintings that are highlighted and can be played. Because this is the start of the game, only the first refrigerator subgame is accessible. The map gives the player an overview of his score and the countries he can already visit

uncle and aunt, to their room where they can sleep during the stay. There, the NPGs give additional information about the importance of the room. The room is the central place of the game because from this point the players have to choose the tasks they want to execute (see Fig. 3) and they can consult their game score, that is, the money they already earned, and keep track of the destinations they can already visit with that amount of money (see further). Hence, from the lead game the players can navigate to each of the three different subgames. Each subgame represents a specific environment in which the player can complete a number of specific tasks, that is, (1) fill refrigerators, (2) mix/blender cocktails, and (3) serve drinks (see further). Successful completion of the tasks will lead to an increase in money (score). The amount of money earned depends on how well jobs are done. The more accurate and efficient the job is done, the higher the amount of money earned.

In total, the game consists of four levels. Every level equals one day of work in the hotel (i.e., day 1 = level 1, day 2 = level 2, day 3 = level 3, and day 4 = level 4) and all three subgames are available in every level. Only the first subgame in the first level (the refrigerator) is fixed. The player cannot choose to start with another subgame because this first subgame contains a tutorial which provides the player with useful information concerning the game mechanics. After all tasks in the first subgame are finished (four tasks in every subgame; see further), the players return to their room where they can activate a new subgame by clicking on the two remaining paintings: the serving subgame or the blender subgame.

Fig. 4 The refrigerator subgame. The task is presented on the board on the right side of the screen (i.e., 16/4 = ? /12). The player has to click or drag the correct amount of bottles in the refrigerator. When the player thinks he solved the task, he has to close the refrigerator by clicking on the door

When the players complete all three subgames of one level, the players finished the level and will automatically proceed to the consecutive level, which means that all the subgames will be available again. When players finish the complete game (four levels with 12 tasks each), 48 tasks are completed.

Subgames

As mentioned above, the first subgame is the refrigerator subgame. In this subgame, the players encounter missing value problems. Here, players need to fill the refrigerator in accordance with a given proportion (e.g., for every x bottles of lemonade, there need to be y bottles of cola in the refrigerator. If there are z bottles of lemonade in the refrigerator, how many bottles of cola do you need?). The task appears on the board which is located on the upper right corner of the screen (see Fig. 4). When players have decided how many bottles are missing, they can place the correct number of bottles in the refrigerator (by clicking on the correct bottles, or dragging and dropping the bottles in the correct place). To confirm their answer they have to close the door. After this, the players receive feedback on their answer and proceed to another attempt (when the answer was incorrect) or a new task (when the answer was correct).

In the blender subgame, the players encounter transformation problems. Here, the players need to complete a cocktail in accordance with a provided recipe. Again, the task is visualized on the board by offering the recipe to the players (see Fig. 5).

Fig. 5 The blender game. The player has to adapt one or two ingredients according to the recipe presented on the board. When they player thinks he/she is ready, he can confirm his answer by clicking on the blender button

The players are presented with a blender that already contains a mixture of yoghurt and strawberry juice, but the quantity of the ingredients does not fit the recipe. The players are asked to add yoghurt and/or strawberry juice to "fix" the mixture so that it is in accordance with the ratio that the recipe prescribes. The players can add the ingredients by dragging the bottles over the blender.

In the serving subgame, the players encounter comparison problems. Here, the players need to serve the drink that matches the order (e.g., serve the least sweet mix). Again, the task appears on the board at the upper right corner of the screen. To complete the order, players need to compare the mixtures that are presented in two pitchers and choose the mixture that fits the order. After selecting the correct pitcher players need to place it on a serving tray using a drag-and-drop motion (see Fig. 6).

In every subgame, four tasks (or items) are presented in which the learning content is integrated. Depending on the subgame, the players have either one or three attempts to solve the task. For the refrigerator and blender subgame, three attempts for each task are offered to the players. The incorporation of multiple attempts was done to lessen frustration (raise the chance for a correct answer), to stimulate the players to rethink their calculations (in-game reflection), and to discourage guessing (a wrong guess will not immediately lead to a new task). Due to the nature of the tasks in the serving subgame, only one attempt per task is possible. Either they serve the correct pitcher or they serve the wrong one. A second attempt would possibly bias the results because it would always be correct. If the players do not find the correct answer during the provided attempts, they automatically continue to the following task. The decision to continue the game even when a task was not solved was made to avoid players getting stuck in the game and becoming frustrated.

Fig. 6 The serving subgame. The task is presented on the board, i.e., put the sweetest cocktail on the serving tray. By placing a pitcher on the tray, the player immediately gets feedback about the correctness of his answer

The tasks in the subgames are implemented based on their difficulty level of the proportional reasoning types of problems (see above) and the difficulty increases as players progress through the levels. The first level is the easiest level and contains items of the first difficulty level of the missing value problems, transformational problems, and comparison problems. The second level is a bit more difficult and contains items of the second and third difficulty level of the missing value and transformation problems and the second difficulty level of the comparison problems. When players enter the third level, they get items of the highest difficulty level of all three types of problems. For the last level, we opted to combine items of the previous levels as a kind of rehearsal exercise but also to prevent feelings of failure and to provide all students with an experience of success at the end of the game. An overview of the types of problems and difficulty level of these problems per subgame are presented in Table 3.

Game Characteristics

In the following sections, specific game characteristics will be discussed based on literature and on the (pragmatic) choices we had to make when developing the game.

Goal. Because it is a relatively simple game, the goal was kept relatively simple and clear: make as much money as possible to travel as far as possible. Clear goals stimulate engagement and engage players' self-esteem (Malone, 1980). Therefore, the current game's goal is clearly presented to the player at the beginning of the

Table 3 Overview of the difficulty levels implemented in the game per level and type of problems (see Tables 1 and 2 for the specification of the difficulty levels)

Game level	Difficulty level
Missing value problems	
1	1abcd
2	2ab 3cd
3	4abcd
4	4d3c2b1a
Comparison problems	
1	1aa1bb
2	2aa2bb
3	3aaaa
4	3a2b2a1a
Transformation problems	
1	1abcc
2	2ab3ab
3	4abcc
4	4c3b2a1a

game (i.e., earn money for the journey; the more money the players earn, the further they can travel) and in every subgame (i.e., execute the tasks as good as possible to gain money). The importance of the goal is repeated throughout the game in both implicit (showing players the money they made) and explicit (showing players how well they perform in contrast to others) ways. As advised by Malone (1980), the goal is tailored so that students could identify with it (making money is something teenagers are interested in, as well as travelling), is given meaning by making it part of an intrinsic fantasy as sketched by the story line (the money was necessary to fund a holiday trip) and is different from, but related to, the educational content (the educational content plays a role in successfully achieving the goal).

Content integration. 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). Therefore, the story line and contexts that are addressed in the current game environment are designed to create natural settings that foster seamless integration of the learning content. The learning content is not an extra layer to the game or completely separated from it, but is an integral part of the game experience. Solving proportional reasoning problems is not an isolated activity, but is intrinsically integrated in the story line (e.g., filling the refrigerator in order to earn money). Also, the controls required to solve the problems are in line with all other game controls (point-and-click, drag-and-drop). In addition, the content is integrated in such a manner that the "fantasy-world" of the game actually shows the players indications of how their newly learnt skill (i.e., proportional reasoning) can be used to accomplish real world goals (e.g., adjusting recipes).

Tools. Within the game several tools to aid gameplay are implemented. They help players to understand the game mechanics to understand how to tackle the tasks and assist players during their problem-solving. Two kinds of tutorials are implemented.

Fig. 7 Tutorial in which player gets an overview of the game mechanics, tools, and tasks. This tutorial is interactive. Only after executing the operations that are described in the tutorial, the game continues. In this example, the player has to activate the extra aid (column), put the correct amount of milk in the blender, and confirm his answer by clicking on the blender button

A first tutorial focuses on game mechanics. When activating the subgames the first time, the tutorial starts automatically. Players get information about the tasks they have to perform, and what they have to do in the different subgames. Additionally, they get the chance to practice different functionalities like drag-and-drop (see Fig. 7). With this tutorial, we want to prevent uncertainties with students' gaming abilities, and give them the information they need to progress through the game. This tutorial is integrated in an interactive manner. By integrating an interactive tutorial, students might find the game easier to play, experience less frustration and understand the instructions better (Goodman, Bradley, Paras, Williamson, & Bizzochi, 2006). Next to these advantages, students who are confronted with a tutorial can perform better in the game-play (Goodman et al., 2006).

Secondly, a content-related tutorial is implemented. This tutorial is permanently accessible for the players during the game (see Fig. 8). This tutorial gives players information about the different types of proportional reasoning problems and the strategies they can use to solve these problems. This information is supportive to the learning of solving different proportional reasoning problems and provides a bridge between students' prior knowledge and the learning tasks (van Merriënboer, Clark, & de Croock, 2002). With this information, players should be able to handle the

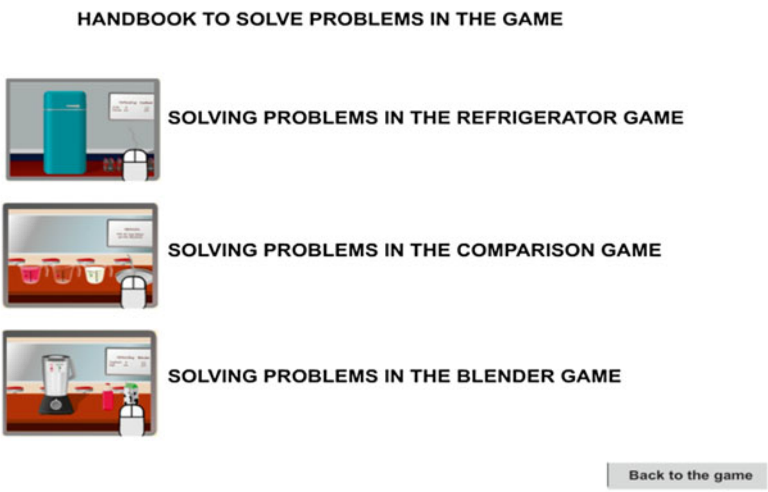

Fig. 8 Content-related tutorial. This tutorial can be activated by clicking on the book-icon which is visible during every subgame in the right upper corner of the screen. After clicking on it, players access the tutorial. They can choose for which subgame they want the additional information

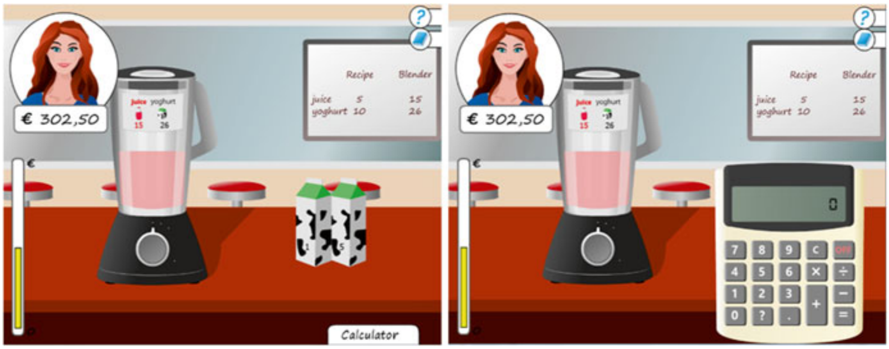

Fig. 9 The calculator can be used by players during the game by clicking on the "calculator" button. A calculator pops up and can be closed by clicking on the "off" button

problems presented in the subgames. This tutorial is not automatically activated but can be activated by the players whenever they need it. Although previous research indicated that using tools in accordance with the learning needs presupposes some self-regulation skills that not every student masters (Azevedo, 2005), this was preferred over an automatic (fixed) tutorial because a forced presentation of this tutorial might lead to loss of game-flow.

In addition to the tutorials, students can use several other tools that also facilitate their problem-solving. Students can add a column to the representation of the problems (see Fig. 9) to help them to simplify the first ratio. In this column, they can fill out their interim solution so they do not have to calculate too many steps in their head. Also, students can use their resources to "buy" help from a calculator (see Fig. 10).

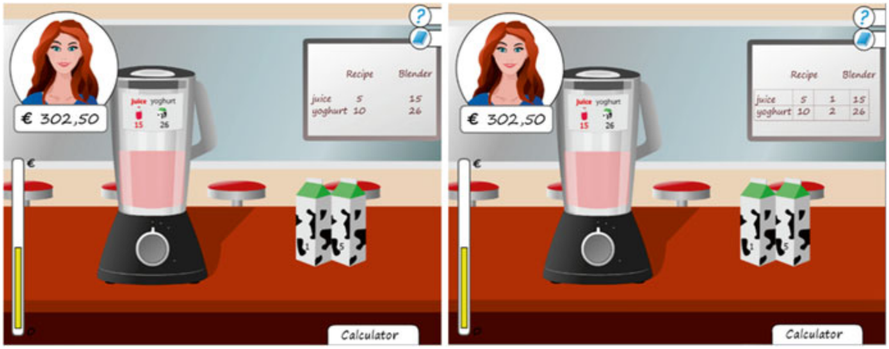

Fig. 10 An extra aid can be activated on the board by clicking on it. An extra column appears and can help solving the task

Feedback. During the game, players receive different kinds of feedback to their actions. This feedback is focused on the proportional reasoning skills of the players, as well as on their gaming skills. More concrete, the feedback is either related to their accuracy of solving proportional reasoning problems (after each item the player is told whether their solution is right or wrong), the efficiency of their gaming skills (whether they are not spoiling materials as dropping bottles, or whether they start off with a right move), or their performance of the overall game (after a sub-game players are told how their score, i.e., amount of money, relates to that of other players). The feedback is provided by one of the two NPGs, an increase or decrease in score, or a visual representation of ranking (Fig. 11).

Feedback on accuracy of solving the proportional reasoning problems is immediately provided after solving an item by an increase (correct answer) or decrease (incorrect answer) in score and by a visual component (point bar becomes green if the players answers correctly and red if the player's answer is wrong). This immediate corrective feedback about the accuracy of their answers coupled with the opportunity to answer-until-correct (with a limitation of three attempts) promotes greater retention and a greater correction of initially inaccurate strategies (Dihoff, Brosvic, & Epstein, 2003).

Additionally, feedback on accuracy of solving the proportional reasoning problems is also textually provided by an NPG. After the first attempt in a task, their feedback states whether the given solution is right or wrong (e.g., "Perfect!" or "Well done!"). 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 bottles of cola"). After a third attempt, the feedback states whether the answer is right or wrong and the game proceeds to the next task. During this feedback on accuracy, also textual feedback on efficiency is given (e.g., "Watch out! You are spoiling bottles of cola. They are not for free and go off your salary!").

Fig. 11 The map on which player can see which countries he/she can already visit (orange countries) and which countries the other virtual players can already visit (the red drawing-pins)

When a subgame is completed, players are automatically referred to the room from which they can access the map on which they get feedback about their performance of the overall game. On the map, they can see how many countries they can visit (the orange countries). Next to this, they see how their score relates to that of others. The players are informed that the other scores (visualized with red drawing-pins; see Fig. 11) represent scores from other players when these had played a similar time. However, these scores are a calculated adaptive representation that changes depending on the current score of the player. This was done because of technical limitations: Live updates of ranking were technically difficult to realize.

Scoring mechanism. Students earn money by solving the tasks in the subgames. They can increase the money by performing positive actions such as starting the task in a correct way (e.g., putting the first bottle in the refrigerator), but the money will decrease when performing undesired actions (e.g., using the calculator will cost money). On the map, players can see to which destinations they can travel with the money they have earned.

Conclusion

The development of "Zeldenrust" was time intensive and susceptible to opposite expectations between math educators and game developers. It implied many choices and decisions led by theoretical foundations, as well as by practical limitations and pragmatic considerations. The environment can now be used for several research purposes with our target group: research that focuses on the use of educational games in the classroom (e.g., effect on performance, motivation), research that focuses on learners' behavior in an educational game (based on the logfiles), and research that focuses on the design of educational games (e.g., which tools are stimulating, which kind of feedback is advisable). For the research purposes, customization options in the environment are available. For instance, the number of exercises or levels can be changed, the subgames can be deactivated (so only one or two types of problems are offered to the players). Additionally, more fundamental changes are also possible. A variety of versions of "Zeldenrust"—in which these changes are carried through, has already been employed in several studies (ter Vrugte et al., 2015; Vandercruysse et al., submitted) and proved its user- and research-friendliness. However, it is not possible for teachers and parents to carry through personal customizations since this has to be applied in the xml-files and they do not have access to it.

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