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Game mechanics in the design of a collaborative serious 3D game

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Background. This article investigates the potential of utilizing **game mechanics** in designing 3-D **serious games** for Computer-Supported Collaborative Learning (CSCL) and attempt to produce new information about designing **collaborative serious games**.

Aim. This article has two aims: first, to **clarify** how theoretical knowledge of collaborative learning was related to game design in previous studies; and, second, to **design** a collaborative serious game based on theoretical knowledge of collaborative learning and game design.

Results. The reviewed studies revealed the **potential** of using collaborative games in education. However, they showed that collaborative learning games were typically designed only from pedagogical perspective. Thus, **integrating** educational theory and game design perspectives was rare. Therefore, we argue that collaborative serious games do not necessarily take full advantage of their potential.

Conclusions. For future game design, this article highlights the importance of game mechanics in the design of serious games. The main contribution of this article is to present seven ways to **utilize** game mechanics in order to **create** favorable conditions for collaborative learning and to **structure** players' actions to boost social interaction and collaborative activities. This article concludes with an example of taking advantage of game mechanics in the design of a collaborative serious game. As designed, the game has three **multiplayer puzzles**. Designed to promote collaborative activities, these puzzles require effort and commitment from several players to complete the puzzles successfully. This article also uses event-charts to demonstrate the **practical implementation** of game mechanics in multiplayer puzzles.

KEYWORDS: collaborative learning; game design; game mechanics; interactive learning environments; serious game; review

It is generally agreed that games have the potential to empower learning. For example, games have been successfully applied to acquiring knowledge (Papastergiou, 2009), integrating knowledge and skills (Amory et al., 1999; Bagley & Shaffer, 2009; Rieber & Noah, 2008), developing new learning strategies (Sung & Hwang, 2013; Hummel et al., 2011), and promoting social and emotional learning (Hromek & Roffey, 2009). However, playing the game is not an obvious solution for achieving high-level learning (Hämäläinen, 2011). As Linderoth (2010) pointed out, sometimes players could play a game without learning anything. In the context of collaborative serious games, this "no-learning" situation parallels one in which players could solve tasks individually without needing to create shared knowledge or understanding the task to resolve it (Zagal, Rick & His, 2006).

According to Kiili (2010), one of the biggest problems of educational games was failing to integrate educational and game design perspectives. Especially collaborative games are difficult to design (Zagal et al. 2006). This leads to the question of how to make better use of the theories of collaborative learning and game design in developing collaborative serious games. This article attempts to address this gap by focusing on the ways to utilize game mechanics in the design of a collaborative serious game. Its first aim is to clarify how previous studies related theoretical knowledge of collaborative learning to game design. Its second aim is to design a collaborative serious game based on theoretical knowledge of collaborative learning and game design.

Review of collaborative learning games

In this section, we will take a detailed look at how previous studies have combined collaborative learning theory and game design. Multiple electronic databases (Academic Search Elite, EJS: Electronic Journals Service, SCOPUS, Web of Science, ERIC, and PsycINFO), supplemented by Web-based Google Scholar, were searched for relevant publications up to and including 2007 (the search was conducted in January 2013). The search terms we used were "collaborative learning," "game," "game design," and "serious game."

Because of the huge number of search results, three criteria were established to narrow the scope of works generated during the electronic search. The goal of such narrowing was to focus on how the theoretical knowledge of collaborative learning is related to game design. We eliminated from the review studies that concentrated completely on the technical development of virtual environments or platforms, and those that addressed the pedagogical use of commercial or existing games. We also eliminated studies that did not include empirical research related to learners' performance or learning itself. Using these parameters, we found 11 studies (see the Appendix) that included game design of collaborative serious games, implementation of the game environment, and empirical research on the use of games. We selected these studies for more detailed scrutiny.

This review focused on discovering: 1.) from which perspective the game was designed; 2.) what the purpose of the game was; 3.) what kind of tools for interaction the game offered the players; and 4.) what the main findings of studies were.

From the game-design perspective, our review indicates that in most cases (9 of 11), game design was educational theory oriented. Two studies (Hämäläinen, 2008a; Hummel et al., 2011), however, raised the idea of gameplay. More precisely, Hämäläinen (2008a) emphasized the meaning of close cooperation between game developers and educational specialists in designing pedagogically meaningful virtual environments. Hummel et al. (2011), in turn, pointed out that collaboration scripts seemed to be an interesting pattern of gameplay and should be further examined.

Both educational theory and gameplay perspectives were taken into account in game design in two reviewed studies (Susaeta et al., 2010; Echeverria et al., 2011). Susaeta et al. (2010) brought up the concept of Classroom Multiplayer Presential Role Playing Game (CMPRPG). CMPRPG is based on using massively multiplayer online role-playing games (MMORPG) in classrooms so students can immerse themselves in an educational activity and collaborate with one another. From this perspective, Susaeta et al. (2010) emphasized the meaning of the narrative and the players' predefined roles or the characters' abilities (for example, energy points and speed of movement) in designing collaborative serious games.

Echeverria et al. (2011) addressed the issue more extensively and presented a framework for the design and classroom integration of collaborative serious games. This framework incorporates both an educational and a ludic dimension. The educational dimension has two components: establishing the learning objectives of the game, and determining how the game is pedagogically integrated in the classroom practice. The ludic dimension of the framework is based on work by Schell (2008), who divided the elements of the game in four categories: mechanics, story, aesthetics, and technology.

The purpose of the reviewed games varied from teaching specific substantive issues, such as programming skills (Burton & Martin, 2010) and safety in the construction area (Hämäläinen et al., 2008), to more complex learning, such as problem solving in past disease epidemics (Kennedy-Clark & Thompson, 2011). The purpose of a game was related to the game's target audience. One game was designed for young children (Infante et al., 2010); three games for elementary schools (Susaeta et al., 2010, Echeverria et al., 2011; Sung & Hwang, 2013); two games for vocational education (Hämäläinen, 2008a; Hämäläinen et al., 2008); and four games for university students (Burton & Martin, 2010; Hummel et al., 2011; Bluemink et al., 2010; Kennedy-Clark & Thompson, 2011). One game (Collazos et al., 2007) was used for different levels of education.

Multiplayer games offer opportunities for social interaction that enhances the players' enjoyment of the experience (Adams, 2010, pp. 26-27). Although, offering tools only for interaction is not enough. When the goal is to achieve high-level collaborative activities, tools for interaction are still a natural and important part of collaborative serious games. Our review indicates that chat is the most common tool for interaction, and nearly half (5 of 11) the reviewed games included this function (Collazos et al., 2007; Hämäläinen, 2008a; Hämäläinen et al., 2008; Burton & Martin, 2010; Sung & Hwang, 2013). In addition to chat, three games offered a mailing system or VoIP speech system as a tool for interaction.

Four games did not offer any in-game communication tools for players, but the games were played in co-located settings, and players interacted face to face. Thus, our review indicates that synchronous tools for interaction, such as chat and VoIP, are the most natural way of communicating in game environments. Playing collaborative serious games in co-located settings, however, does not require technological tools for player interaction; face-to-face interaction is the spontaneous choice.

In general, all selected studies demonstrated a strong theoretical background in collaborative learning. These studies also showed that virtual game environments have the potential to encourage collaborative activities. However, the influence of this background on game design varied in the studies. At minimum, the game set a common goal for players, but the game itself did not guide players' actions in any way (Burton & Martin, 2010). Echeverria et al. (2011) closely integrated the theoretical background of collaborative learning and game design to achieve defined learning goals through creating an engaging and challenging experience.

Studies also showed that to achieve a high level of collaborative activities, it was necessary to guide and even force players to enter into collaborative-knowledge situations in which new knowledge could be created (Collazos et al., 2007; Hämäläinen et al., 2008; Bluemink et al., 2010). Studies explored different opportunities to guide players' actions and engage players in collaborative activities. For example, in collaborative scripts, pre-defined roles and different task structures were deemed useful for enhancing collaboration in games (Hämäläinen, 2008a; Hämäläinen et al., 2008; Hummel et al., 2011; Bluemink et al., 2010). To achieve effective learning, Collazos et al. (2007) also emphasized the importance of designing tools to support collaboration but also to consider such other aspects as a teacher's participation.

This review finds that games may offer a fruitful context for collaborative interaction and many ways to guide players. We conclude, however, that theoretical knowledge of collaborative learning and game design are rarely integrated in designing collaborative serious games. We also find that a game designed only from this perspective does not necessarily take full advantage of the engaging features of games. Therefore, an obvious need for studies combining the theoretical knowledge of collaborative learning and game design exist. Especially game mechanics appear to be a potential way to make use of game design in the design of serious games (Aleven, Myers, Easterday, & Ogan, 2010; Zagal et al., 2006; Mariais, Michau, & Pernin, 2011)

Defining collaborative learning for game design

In the game design context, the concepts of collaborative learning and cooperative learning are sometimes used interchangeably by mistake (Zagal et al., 2006). In a collaborative situation, participants share the task of solving problems; new knowledge must be built on others' ideas and thoughts (Arvaja, Salovaara, Häkkinen, & Järvelä, 2007). A cooperative task, however, is often split into subtasks, and each participant is responsible for a portion — or subtask — of problem solving (Dillenbourg, 1999). Collaborative learning is often defined as building shared knowledge through group activities, in which the participants are committed to or engaged in shared goals and problem solving (Dillenbourg, 1999; Roschelle & Teasley, 1995). Members of the group are engaged not only in individual activities, but also in such group interactions as negotiation and knowledge sharing (Roschelle & Teasley, 1995). Through sharing perspectives, experiences and understandings, learners are able to develop and debug new ideas, and to notice complexities of concepts and skills (Leemkuil, de Jong, de Hoog & Christoph, 2003).

According to Winne et al. (2010), each member of the group brings three essential resources to the collaboration. The first one is prior knowledge; others may benefit from it, especially those with less knowledge (see also studies in internal resources, Arvaja, 2012). This knowledge may encompass the task, the content, the life experiences or the collaboration. The second resource is information not known by others but can be transformed into shared knowledge through fruitful collaboration. In practice, this may lead to new knowledge that others in the group would not acquire alone (Stahl, 2004). The third is different learning strategies and tactics that can complement one another in a collaborative learning situation (for further descriptions, see Hämäläinen & Vähäsantanen, 2011).

Nussbaum et al. (2011) proposed conditions that collaborative learning should meet to boost the possibility of fruitful social interaction and collaborative activities. These conditions are: 1.) common goal, 2.) positive interdependence, 3.) coordination and communication, 4.) individual accountability, 5.) awareness, and 6.) joint rewards.

Common goal

Members of the group need to have a common goal that they strive to achieve (Dillenbourg, 1999). This goal aims to generate social interaction and collaboration between the members of the group, which may lead to more learning.

Positive interdependence

Positive interdependence is an essential element in effective collaboration (Collazos, Guerrero, Pino, & Ochoa, 2003; Wang, 2009). A common goal is one way to promote positive interdependence among group members (Wang, 2009). Interdependence links group members. No one alone can achieve this goal; all members must make the effort.

C*oordination and communication*

Coordination and communication involve group members' communicating with one another and managing their interdependent activities to achieve a goal (Nussbaum et al., 2011). By doing this, group members can reconcile their individual prior knowledge and information (Winne et al., 2010). At best, this activity leads to a situation in which joint understanding and knowledge are built on others' ideas and thoughts (Arvaja et al., 2007). In game environments, chat and VoIP are the tools most used for player-to-player interaction. However, game environments have been proposed to offer new forms of collaboration, such as non-verbal communication through the avatars (Manninen, 2004; Hämäläinen et al., 2008).

Individual accountability

Individual accountability is one of the principal elements. Each member of the group must have a meaningful role in solving problems. In an ideal collaborative situation, each member plays a critical role and makes a significant contribution to the group's work instead of one member working for all (Wang, 2009). In practice, this can mean designing game mechanics and puzzle structures that make "free riding" (Toups, Kerne, & Hamilton, 2009; Strijbos & De Laat, 2010) more difficult and encourage all members to do their best.

Awareness

By awareness, Nussbaum et al. (2011) mean that to collaborate successfully, group members must be aware of their peers' current state of mind and engage in mutual feedback that promotes decision-making.

Joint rewards

Finally, joint rewards create a feeling of winning or losing together, as a group. These encourage members to maximize their joint effort (Zagal et al., 2006).

Applying game design to promote collaborative learning

The aim of combining the theoretical knowledge of collaborative learning and game design is to find ways to take advantage of game design elements to promote collaboration (Echeverría et al., 2011). Designing collaborative games is extremely difficult (Zagal et al., 2006), and requires an expanded view of group dynamics, social roles, and interaction between players (Kim, 2000; Manninen & Korva, 2005; Zagal et al., 2006). Schell (2008, pp. 41-43) classifies game elements into four categories; story, aesthetics, technology, and mechanics. Game mechanics has been found to be directly affected by the learning objectives of the game (Aleven et al., 2010), and additionally game mechanics can be designed according to the desired activity or goal expected to be achieved (Mariais et al., 2011; Peppler, Danish & Phelps, 2013).

Story describes a series of events that make up the game's narrative. Aesthetics is about how the game looks and sounds, including graphics, design, sound, and music. Technology determines the materials and interactions which make the game possible. Mechanics are the factors that distinguish the game from other forms of media, because they determine their interactivity through the procedures and rules of the game. Schell (2008) further divided mechanics into subcategories: 1.) space, 2.) objects, attributes, and states, 3.) actions, 4.) rules, 5.) skill, and 6.) chance. We will take a more detailed look at mechanics from the perspective of using game design to promote collaboration.

Space defines the "magic circle" in which game takes the place. In line with that concept, Manninen and Korva (2005) found that placing players in different locations out of the line of sight and with no cognitive distractions (spatial isolation) encouraged them to start social interaction. Sharing the area where collaboration takes place (shared space) creates interdependence among the players (Johnson & Johnson, 1994) and increases the level of awareness (Nussbaum et al., 2011).

Objects, attributes, and states bring content to the game's space. Objects are things that can be seen or manipulated in the game. Attributes are categories of information related to the objects; each attribute has a current state. Objects can be used to generate collaboration and social interaction among players through shared objects with which multiple players need to interact to successfully complete the game or task (shared object). Limiting information that different players get from attributes and their states (encrypted information) may promote collaboration and emphasize individual accountability (Nussbaum et al., 2011).

Actions determine what players can do in the game. In general, two types of actions exist: operative actions (concrete actions) and resultant actions (strategic choices). Actions are related to the players' roles and how players coordinate and communicate with one another (Nussbaum et al., 2011). Although the use of roles is not a novel idea in instructional design (Dickey, 2005), games offer new possibilities in using roles, for example, pre-defined roles. In practice, players' actions or roles may be complementary; anyone alone cannot solve the problem, and each member of the group plays an important role in problem solving (complementary actions). Thus, positive interdependence exists among the players (Nussbaum et al., 2011). Complementary operative actions also help resultant actions emerge and encourage group members to stay aware of their peers' current state of mind. Actions can be also combined with limited access to information by providing someone with information that requires another player to act (indirect action).

Rules can be seen as the most fundamental type of mechanics. They bring another mechanics to life and give them meaning by, for example, defining consequences of the players' actions, constraints on the actions, and goals of the game. In the context of rules, establishing a common goal (cf. promoting collaboration; Nussbaum et al., 2011) is vital. Such goal requires effort and commitment from several players to successfully complete the game. It also must be challenging enough to engage players' attention and to give them a feeling of success in the form of joint rewards (Nussbaum et al., 2011). Rules should not guide and limit players' activities too much (Dillenbourg, 2002), but should permit the selection and development of working and problem-solving strategies (flexible strategies).

Skill refers to the skills (physical, mental, and social) that games require players to exercise or have. Game tasks need to be complex enough to require players to combine forces, and to contribute views and resources to achieve a common goal. Finding a balance of required skills and existing skills is crucial for engagement and motivation (Hromek & Roffey, 2009). Initially, it is vital to open up social interaction among the players. Later, however, it is important to increase the level of challenge (Howland, 2002; Zagal et al., 2006).

Finally, *chance* refers to unforeseen and uncertain events of the game, and it is very important in how a game can be fun.

Empirical example: game design process and game description

In this section, we will describe the game design process. We will also describe the game in general, and the game mechanics used in the design of the game. We further illustrate with an empirical example how these mechanics have been implemented in practice at different levels of the game (for a description of the game, see Oksanen & Hämäläinen, 2013). Our goal is to create favorable conditions for collaborative learning (Nussbaum et al., 2011) and to structure players' actions to boost and maintain social interaction and collaborative activities. Because the story of a game, aesthetics, and technology are not tied to specific levels, we address them first in the general description of the game. In the more detailed descriptions, we will focus on the game mechanics (Schell, 2008) used in each level (see Table 1).

The idea for the game came from the needs of the working life (Salpeter, 2003). The game design was based on eight (N=8) theme interviews (Gubrium & Holstein, 2002) with instructors who worked in different industries, for example, the customer service and metal industries. The interviews intended to develop a valuable game that addressed the requirements of a future working life. Based on these interviews, human sustainability was selected as a key substantive of the game. Human sustainability is essential to a working life, but teaching it can be very challenging. Therefore, the game had added value, offering the potential of illustrating, in a new way, the working life community, social relations, haste, flow of information, and leadership.

The game design process lasted about six months. Professionals from different fields (including teachers, researchers, game designers, and programmers) participated. Based on theme interviews, it was concluded that the goal (Adams, 2010, pp. 6-8) of the game was to emphasize: 1.) the importance of professionals from different fields sharing work; and 2.) the real-life relevance of creating high-level collaborative activities for players so they could expand their awareness of human sustainability.

GAMEBRIDGE is a 3-D-multiplayer game (Manninen, 2004; Manninen & Korva, 2005) that offers each player a first-person-view, shared game world (*shared space*). In a synchronous 3-D-game setting, each group member is visible to the others. This visibility may promote individual accountability, decrease "free riding," and increase the level of awareness (Toups et al., 2009; Nussbaum et al., 2011). The story of a game (Adams, 2010, pp. 155-199) is that players work as volunteers at a charity concert for human sustainability. Through three levels, they are supposed to make sure that customers are satisfied and that everything is ready for the band's gig. The aesthetics are designed to support the narrative of the game. The game lacks background music. Sound effects are used only when necessary so players can talk among themselves without audio interference.

In table 1 we summarize the game mechanics used in the design of GAMEBRIDGE to create favorable conditions for collaborative learning and to promote the emergence of social interaction and collaborative activities. The dimensions of game mechanics is based on the classification by Schell (2008). Sub-mechanics, in turn, are the ones we propose to be potential ways to take advantage of game mechanics in the design of a collaborative serious game. In the following subsections we will describe how these sub-mechanics have been implemented in practice at different levels of GAMEBRIDGE.

Table 1. Summarizing the game mechanics used in the design

Mechanic	Sub-mechanic	Target condition	Game levels	Argument
Space	Spatial isolation	Coordination and communication	I	Spatial isolation with no cognitive distractions encourages social interaction (Manninen & Korva, 2005)
	Shared space	Positive interdependence, awareness	I, II, III	Sharing synchronous 3D space for collaboration generates spatial interdependence (Johnson & Johnson, 1994) among the players, and further increases the level of awareness (Nussbaum et al., 2011)
Objects, attributes, and states	Shared object	Coordination and communication, individual accountability	I, III	Shared object with which multiple players need to interact for successful completion promotes social interaction and emphasizes individual accountability. (Nussbaum et al., 2011). This also makes "free riding" more difficult (Toups et al., 2009; Strijbos & De Laat, 2010).
	Encrypted information	Coordination and communication, individual accountability, awareness	I, II, III	Encrypted information promotes collaboration and highlights individual accountability so that players are aware of each other's state of mind (Nussbaum et al., 2011) and prior knowledge, (Winne et al., 2010; Arvaja 2012) which forms a basis for the new shared knowledge (Stahl, 2004).
Actions	Complementary action	Common goal, positive interdependence, individual accountability	II	Complementary actions emphasize the critical role of each player in problem solving, since anyone alone cannot solve the problem (Wang, 2009). Complementary actions may also lead to an emergence of resultant actions, which encourage group members to stay aware of their peers' current state of mind (Schell, 2008, pp. 140-142).
	Indirect action	Common goal, coordination and communication, joint reward	II	Indirect action refers to the situation where some of the players are given information that requires another player's action. Thus, these players have a common goal and they need to collaborate and coordinate their actions with each other for a joint reward (Nussbaum et al., 2011). Joint reward further encourages group members to do their best (Zagal et al., 2006).

Rules	Flexible strategies	Coordination and communication	I, II, III	Flexible strategies allow players to select and develop their working and problem-solving strategies through collaboration. Too strict guidelines may disturb natural interaction and problem-solving processes and increase the cognitive load (Dillenbourg, 2002)

Level I: Gate – aiming for co-ordination among players

At the beginning of the first level, players were locked up for a while in truck containers and had no cognitive distractions (*spatial isolation*). The only thing players could do was communicate with one another. After a time limit, they could leave the container and get the job of catering tent check-in. However, a locked gate prevented players' access to the area. The gate could be opened only by entering a password in its electronic lock. Each player had a part of the password (*encrypted information*), and these parts must be entered in correct order to open the lock (*shared object*). Each player had an equal right to use the keypad, regardless of the other players. However, only the player who was entering the password was aware of the state of the keypad (*encrypted information*). To reconcile their information and to organize their actions, players could discuss matters through VoIP and chat. Thus, each player had an active role, because solving the puzzle required effort from all of them (Nussbaum et al., 2011; Wang, 2009). They shared the required information, because they were jointly responsible for solving the problem. For example, one player could enter the entire password, but that player still needed to get the required information from other members of the group through discussion (*flexible strategies*). If any mistakes occurred while entering the code, players had to start over. In Figure 1, we illustrate on how players' actions affected the state keypad.

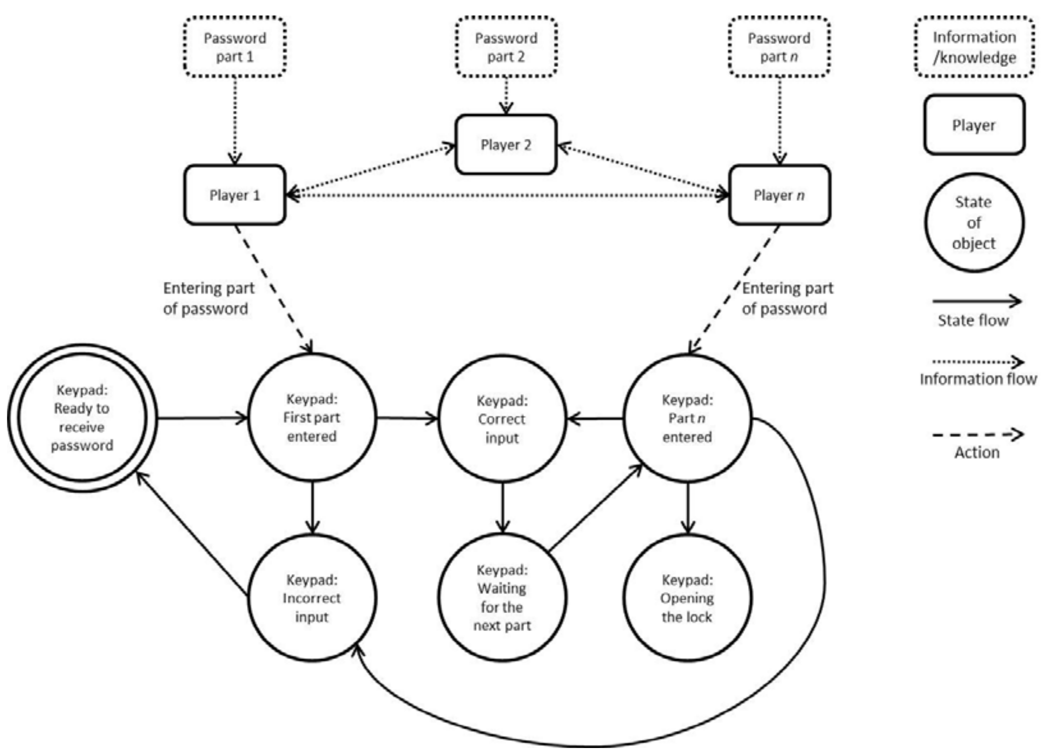

Figure 1. Event chart of the Gate level

Level 2: Restaurant – aiming for distributed expertise and mutual dependency of players

At the second level, players were supposed to keep customers and band members satisfied by serving them in the catering area. Players had supplementary inter-professional roles: cook, waitress, receptionist, and serviceman. These roles (De Wever, Schellens, Van Keer & Valcke, 2008; Hoadley, 2010) determined the challenges and actions the game established and offered to each player. Each role had its own responsibility area, and players were supposed to integrate and synchronize their individual tasks in a timely manner (*complementary actions*) to keep the customers satisfied. Despite the pre-defined roles, players still had a degree of freedom to choose their own working strategy (Dillenbourg, 2002). For example, they could agree that the serviceman mainly took care of cleanliness in the restaurant area or that the waiters could alternate in taking breaks (*flexible strategies*). At the end of the task, band members had lunch in the restaurant. One band member had a nut allergy, but he still wanted to have a portion of food that normally included nuts. Information about the allergy was available only to the receptionist (*encrypted information*). However, the receptionist could not directly interact with the customer; thus, this worker would inform the waiters and the cook about this specific requirement (*indirect action*) to solve the puzzle.

To maintain the balance between the players' skills and required skills (Zagal et al., 2006) the puzzle included additional tasks that hampered problem solving. Some the tasks needed to have been performed in a certain time limit; limited resources also impeded integration (Howland, 2002). Each player also had a certain amount of energy available. To increase their energy, players needed to take breaks and to synchronize the breaks between the tasks. This further increased the players' need to collaborate continuously. Running out of energy or failing to perform tasks caused players to take a forced break. In a forced break, players were moved to the break tent. There, they had time to reflect on what happened and tried to develop their working strategy.

In Figure 2, we illustrate on how players' actions were tied together and affected the state of the customer. As shown, the receptionist first invited the customer to the restaurant and informed the waitress about the incoming customer. After the customer settled in at the table, waitress was supposed to take the order from the customer and send it to the cook. Cook prepared the meal and gave it to the waiter, who then served the meal to the customer.

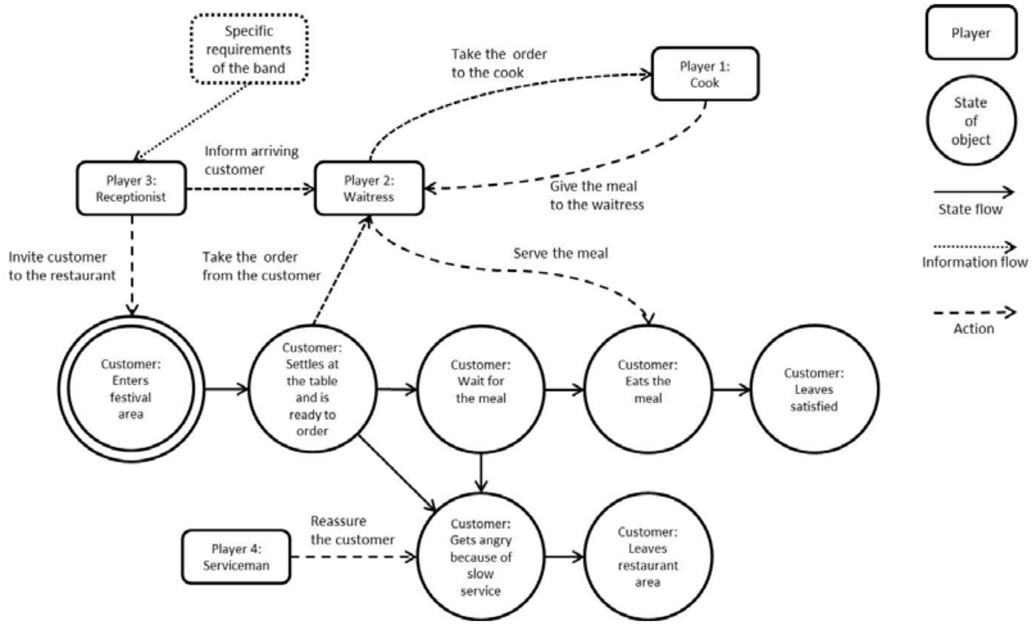

Figure 2. Event-chart of the Restaurant level

Level 3: Stage – aiming to solve cognitive conflict

At this level, players were supposed to identify each band member and organize the band's equipment in the right place on the stage. Identification was based on the tips provided by roadies and pictures on the boxes. Overall, five roadies were in the area, and each one gave unique tips to each player (*encrypted information*). This meant that no one had more information than the others, but all the information was needed to solve the puzzle. The large number of tips, however, posed challenges for reconciling individual information so as to create joint understanding. Piles of boxes were on the stage, and all players had an equal right to change the owner of each pile of boxes (*shared object*). The game gave them the freedom to decide their own working strategy (*flexible strategies*). For example, players may have decided that only one of them changes the boxes' owners, whereas others could explore pictures on the boxes. Eight piles of boxes existed, in which five belonged to the band members, and the rest belonged to the warm-up band. One by one, the players were supposed to identify the band members and recognize which piles of boxes belonged to the warm-up band. Game did not give continuous, immediate feedback from correct answers. Instead, every 10 minutes, the game gave players this feedback. This is because, otherwise, players could find the correct answer just by trying different options.

In Figure 3, we illustrate on how the task was structured. As the figure shows the structure of the task itself was simplified, but the challenge came from the players' collaboration and building shared understanding on the basis of individual information.

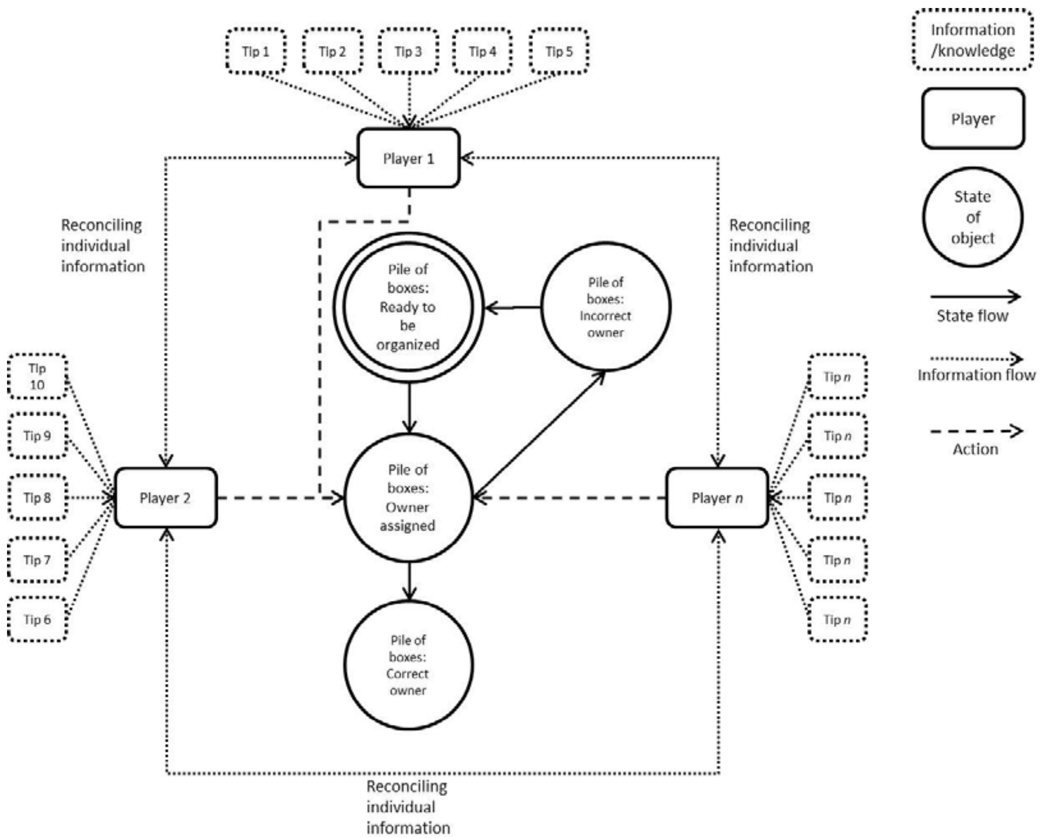

Figure 3. Event-chart of the Stage level

Discussion and future work

This article attempts to produce new knowledge about designing collaborative serious games. Our first aim is to clarify how previous studies related theoretical knowledge of collaborative learning to game design. The second aim is to design a collaborative serious game based on this theoretical knowledge and game design. Despite promising results related to collaborative learning in serious games (Sung & Hwang, 2013; Kennedy-Clark & Thompson, 2011), the game itself does not necessarily lead to social interaction and collaboration. An obvious need exists for studies combining theoretical knowledge of collaborative learning and game design (Peppler et al., 2013).

The limitations of this article should be noted. First, results of the review cannot be generally applied to all studies in this area, due to the limited number of reviewed studies. Second, this article offers one empirical example on how to design collaborative serious games. This approach should not be deemed the only solution. Instead, it should be viewed more as one way that game design can be used to help social interaction and collaborative activities emerge. Third, this article focuses on designing game mechanics. However, game mechanics are only one part of a game design that typically spans many dimensions, including story, technology, and aesthetics (Schell, 2008). Fourth, the design of GAMEBRIDGE was based on the theoretical grounding of CSCL; thus, other potential relevant learning theories were limited to the scope of the current study. Fifth, this article does not deal with debriefing, which is an essential element for game based learning (e.g. Crookall, 2010). This is due to the fact that this study does not include empirical section in which the game is used in practice (for the results of the empirical studies, see Oksanen & Hämäläinen, 2013; Hämäläinen & Oksanen, 2012; Oksanen, 2013). This article benefits from the fact that the reported game-design process involved professionals from the fields of collaborative learning and game design. Thus, both perspectives can be equally taken into account in the design of the game and finding ways to take advantage of game mechanics.

Because of this article, we are able to pore over the vantage points of the theoretical knowledge of collaborative learning and game design, and how they overlapped. It can be found that, in principle, research of collaborative learning and game design has similar objectives. The primary purpose of game design is to find solutions that engage players in the game and guide their actions so they can progress in and, finally, win the game. Accordingly, one aim of collaborative learning is to find ways to enlist learners in achieving shared goals and to guide their activities so these learners can achieve the goal, such as solving the problem. Interaction design is essential in both cases. In the context of collaborative learning, it has been found that to improve the possibility of high-level collaborative activities, learners' actions need to be guided. In addition, the learning of tasks must be complex enough to capture the learners' attention and to create a genuine need for collaboration (Hummel et al., 2011; Kobbe et al., 2007).

Our review indicates that the theoretical background's influence on collaborative learning varied among the studies. This is understandable, as collaboration is not a clear-cut pedagogical model or method. In this article, all reviewed studies fulfilled the notion that in addition to the individual's learning goals in successful collaborative learning, group members negotiate and adopt new, shared goals (Hämäläinen & Vähäsantanen, 2011). In game design, the studies had wide variation as well. This may be due to the problems in multidisciplinary design teams (Kiili, 2010). In general, our review shows that collaborative games may offer a fruitful context for productive interaction, and they offer many ways to guide players. However, we also pointed out a critical notion: It is rare to integrate the theoretical knowledge of collaborative learning and game design in designing a collaborative serious game. Therefore, we propose that the potential of collaborative serious games is not always fully exploited. It is particularly crucial to obtain new knowledge on how to best utilize game mechanics in empowering learning.

Our example of a theoretically grounded collaborative serious game illustrated the relationship of the theoretical knowledge of collaborative learning and game design on a practical level, focusing especially on taking advantage of game mechanics. Our aim was to create favorable conditions for collaborative learning, and to structure players' actions to boost and maintain social interaction and collaborative activities. The game consisted of three multiplayer puzzles that required effort and commitment from several players for successful completion. In terms of collaboration, the game's puzzles were designed to promote coordination (Barron, 2000), to encourage distributed expertise (Price et al., 2003), and to guide solving the cognitive conflict (Chan & Chan, 2001). To achieve these objectives, different sub-mechanics (including spatial isolation, shared space, shared object, encrypted information, complementary action, indirect action, and flexible strategies) were used to guide the activities of the players (Schell, 2008). We also demonstrated, with event-charts, how these sub-mechanics were implemented in practice.

Previous studies related to the use of GAMEBRIDGE in practice have shown that playing the game generated fairly positive game experiences (Oksanen, 2013), a strong sense of social presence (including psychological and behavioral involvement) (Oksanen & Hämäläinen, 2013), and shared knowledge construction among the learners (Hämäläinen & Oksanen, 2012). These results indicate that GAMEBRIDGE promoted collaborative learning by structuring the learners' knowledge construction (Hämäläinen & Oksanen, 2012) and supporting their socio-emotional processes, which can help them to evolve as a well-performing team (Kreijns, Kirschner & Vermeulen, 2013).

It is worth noting that although a positive and stable atmosphere during the game does not necessarily make players feel more comfortable (Oksanen & Hämäläinen, 2013), it still encourages members of the group to collaborate, and to have productive social interactions. This is because in such a supportive atmosphere, learners feel more confident in expressing their opinions (especially critical ones) and arguments, which can be seen as a prerequisite for productive collaboration (Rourke, 2000). Besides, the positively toned psychological involvement that the players felt during the gameplay (Oksanen & Hämäläinen, 2013) reflects how the collaboration was not obnoxious; rather, the learners found it to be a pleasant way to solve the puzzles. This is important because if the learners feel that they are forced to work together, they might hinder rather than promote collaboration (Hämäläinen, 2008b).

To conclude, as the main contribution of this article we have described seven ways to take advantage of game mechanics in the design of collaborative serious games. The proposed sub-mechanics are spatial isolation, shared space, shared object, encrypted information, complementary action, indirect action, and flexible strategies. This article is one step forward in developing a shared vocabulary and understanding for instructional and game designers. As Kiili (2010) pointed out, an obvious need exists for recognizing educational game design patterns to align educational and game design perspectives. Hence, our aim will be to recognize and describe collaborative game design patterns in more detail to improve their general application. Our future studies will focus on the effects of different game design patterns on the emergence of collaboration and social interaction.

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Author contributions

The first author was primarily responsible for the work reported in the article. Additionally Oksanen has played a significant role in the design of the GAMEBRIDGE. The second author (PI) Hämäläinen participated in the study design and implementation.

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APPENDIX: Collaborative learning games review

Author(s); Year	Design perspective	Purpose of the game	Tools for interaction	Main findings	N
Collazos et al. (2007)	Educational theory oriented	The game has four quadrants, and the goal of the game is to move a mouse from quadrant 1 to quadrant 4. Each quadrant has its own coordinator.	Chat	The design of well-specified environments could induce collaborative learning activities within a group. However, it is important not only to design the tool supporting the collaboration process but also to consider other aspects such as teacher's participation, in order to achieve effective learning.	44
Hämäläinen (2008)	Educational theory oriented	Game aims at epistemic task-solving and players are supposed to design four different customized hotel rooms.	Chat and VoIP	Epistemic scripts have the potential to make learning more efficacious in game environments. The major benefit of the virtual environment was in visualizing the design process in a way that would have been impossible in a traditional classroom setting.	20
Hämäläinen et al. (2008)	Educational theory oriented	Game aims at task solving in the area of work safety. Includes individual and collaborative tasks.	Chat	The game guided players towards shared problem solving and helped them to proceed in the different phases. At the games' best, carefully designed games may encourage and even force learners to enter into collaborative knowledge construction situations, in which new knowledge can be created.	64
Infante et al. (2009)	Educational theory oriented	Co-located players are supposed to count, recognize and order objects and move their avatar from place A to place B working collaboratively.	Face-to-face	Participants enjoyed playing the collaborative game and found the objectives to be an interesting challenge. The participants collaborated well in carrying out the tasks. A significant problem that affected their satisfaction, motivation, and expectations was the level of gaming and pedagogical difficulty.	36

APPENDIX: Collaborative learning games review (continued)

Author(s); Year	Design perspective	Purpose of the game	Tools for interaction	Main findings	N
Burton & Martin (2010)	Educational theory oriented	The game aims to improve the programming skills of the students and to give them experience in programming. Players are supposed to solve given problems collaboratively.	Chat	3-D environments have the potential to encourage learner-to-learner collaboration. In addition, this study suggested that a 3-D VLE, when designed collaboration in the forefront, has the potential to directly impact the knowledge creation of the students.	28
Hummel et al. (2011)	Educational theory oriented	The content of the game is related to the aquaculture. Players are supposed produce a report working collaboratively by combining different perspectives.	Email	Scripted collaboration improves the quality of learning output, and the collaboration script seems to be an interesting pattern of gameplay to be further examined in serious gaming research.	12
Bluemink et al. (2010)	Educational theory oriented	Social action adventure; to solve multiplayer puzzles collaboratively.	VoIP	Multiplayer games can provide a fruitful shared context for collaborative interaction when employed in a pedagogically meaningful manner.	24
Susaeta, Jimenez, Nussbaum, Gajardo, Andreu, & Villalta (2010)	Educational theory and gameplay oriented	Objectives of the game can be divided into two categories: 1) transversal objectives (such as promoting collaboration and responsibility), and 2) vertical objectives (such as describe and comprehend the processes of flow and exchange in hypothetical ecosystem).	Face-to-face	Proposed activities motivate the participation of the students and promote teamwork. According to discussion analysis, there are qualitative differences in the participation. The participants failed in achieving their goal in two of the three Quests.	10 (8)

APPENDIX: Collaborative learning games review (continued)

Author(s); Year	Design perspective	Purpose of the game	Tools for interaction	Main findings	N
Echeverría et al. (2011)	Educational theory and gameplay oriented	Game aims to teach the basic concepts of the electrostatics, specifically charge interaction and the law of forces between charges.	Face-to-face	Proposed framework can serve as a tool for designing educational video games and integrating them into the classroom. Playing the game increased the number of correct answer. Four of the six learning objectives improved significantly.	9
Kennedy-Clark & Thompson (2011)	Educational theory oriented	Game aims at collaborative inquiry-based problem solving related to historical disease epidemics	Face-to-face	Students attended to visual information with more specificity than text-based information when using a virtual environment. Fndings also showed that students who incorporated the implementation of their decision into their decision-making process were more successful in problem solving.	12
Sung & Hwang (2013)	Educational theory oriented	ame aims to guide students to organize knowledge collaboratively for differentiating a set of target plants for specific subject unit	Chat	Use of game with the repertory grid was helpful to the students in improving their learning achievements, learning attitudes towards science, learning motivation, and self-efficacy of using computers to learn, and their confidence in and expectations of learning collaboratively with their peers.	93