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Code Red: Triage Or COgnition-based DEsign Rules Enhancing Decisionmaking TRaining In A Game Environment

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Abstract

Serious games have a great potential for training and educating people in novel and engaging ways. However, little empirical research has been done on the effectiveness of serious games, and although early findings do point to a moderately positive direction, even less is known about why some games succeed in effectively educating while others do not. We therefore propose a serious game, *COgnition-based DEsign Rules Enhancing Decisionmaking TRaining In A Game Environment (Code Red: Triage)*, which is designed to empirically test a number of cognition-based design guidelines in the context of crisis management training that ameliorate mental model construction. Our purpose is to come to a set of design guidelines through empirical experiments that enhance the instructional design of serious games and can be used in the development of future games. Furthermore a method is discussed to extract the mental structure players have built during gameplay.

Introduction

Nowadays, games-based learning and its potential to revolutionise pedagogy by being able to facilitate teaching novel instructional goals, as well as more traditional educational material in a manner that is actually engaging to the learner, needs little introduction (cf. Gee, 2005; Shaffer, Squire, Halverson & Gee, 2005). For all the games that are being, or have been developed, surprisingly little empirical research has been done that substantiates the claims of the potential benefits. In a recent review of serious games literature, we found only 28 scientific publications with any empirical evidence pertaining to clearly stated learning goals (Wouters, Van der Spek & Van Oostendorp, 2008a). Similar concerns about the lack of (quantitive) empirical research were voiced by Vogel, Vogel, Cannon-Bowers, Muse and Wright (2006).

The empirical research that was published, some questionable methodologies aside, does give a relatively positive outlook on games-based learning as sound instructional media, with 56% of the total named learning goals met, 18% reporting mixed results and 26% ending with no significant difference or a decrease in learning (Wouters *et al*, 2008a). However, as Wilson *et al* also noted, very little is known on why some games are able to achieve their learning goals, while others fail to do so (Wilson *et al* 2009). As evidence is beginning to emerge that serious games can in fact educate the player in an engaging way—albeit with a lot of room for improvement, we contend that the real question is now how to make serious games more effective instructional media. In order to achieve this, we are currently developing a game called *COgnition-based DEsign Rules Enhancing Decisionmaking TRaining In A Game Environment (Code Red: Triage)*, which trains medical first responders in categorising the many victims of a mass casualty event (in this case a terrorist strike on the subway) according to urgency of needed medical attention (ie, to perform a triage). With this game, we will empirically test a number of design guidelines, based on the workings of the human cognitive system, to see if these improve learning while still letting the game retain its engagement. The result will be a set of guidelines that will help game developers enhance their instructional game design.

Crisis management

In our studies we focus on the training of responsible officers in crisis management. Performance during disasters always requires making decisions under time-pressure in dynamical and chaotic situations, which is contingent on an adequate level of situational awareness (Endsley, 1995). From a cognitive perspective an adequate level of situational awareness requires the construction of a dynamic mental model representing the major actors, events and the relevant information (Kintsch, 1998). This dynamic mental model will enable the officers to assess the situation and predict the direction in which it may develop. For two reasons games seem to be appropriate for training officers in acting adequately during crises (and consequently develop situational awareness).

First, games enable a high level of interactivity that enables a player (ie, the learner) to act in the game and be confronted with the consequences of his or her actions in real time. Moreover, other actors, such as victims, act and may change the game world in ways that will force the player to attend and comprehend the new situation. Second, contemporary games can be made highly realistic by means of sophisticated visual graphics, sounds and even tactile sensations. This leads to a sensual, and thereby cognitive, load more akin to the real situation, which is unattainable by training on paper.

Mitigating task complexity

Games as complex tasks

Playing a serious game in the domain of crisis management is a complex task. Three closely related components that determine this task complexity can be discerned. The first determinant concerns the inherent complexity of gaming. Typically, players have to visually attend different locations on the screen, each often with their own regime of change, and coordinate this with appropriate mouse or joystick movement. In addition, players have to learn and apply the rules and constraints that are part of the game.

The second determinant considers the specific characteristics of the domain at hand. In the domain of crisis management officers have to deal with an abundance of information that may appear as quickly as it vanishes again. Based on this information, players have to make decisions in often highly dynamic and chaotic situations.

The third determinant pertains to the limited cognitive capacity of humans. In combination with the perceptual and processing constraints of human cognitive architecture (cf. Anderson, 2000), the aforementioned game and domain complexity may pose problems to officers in training. Players may for instance become overloaded with information and hence fail to discern between relevant and irrelevant information. Additionally, the transitory nature of games implies that players will only develop a good understanding of a crisis situation (ie, a coherent mental model and situational awareness) when all parts of the game are adequately processed. Once players miss a crucial part of the game (eg, because the information is presented too fast) all subsequent information is likely to become incomprehensible.

The three components that contribute to the task complexity imply that special care has to be taken with the instructional design of the serious game, in order to guarantee that the game facilitates the necessary mental model construction within the player.

Helping the player

In trying to enhance the mental model construction of a player in a game world, we can discern factors that obstruct the construction of a mental model, and those that improve mental model construction. The first *grosso modo* pertains to problems with cognitive load, where the player is either cognitively overloaded, as in the examples alluded to above; or underloaded, where the player is not stimulated enough to fully focus on the subject matter. Therefore, we contend that mitigating unnecessary cognitive load when the game is difficult (extraneous cognitive load as it is called in Cognitive Load Theory, cf. Van Merriënboer & Sweller 2005) or increasing intrinsic cognitive load in the game when it is too simple, by, eg, guiding the attention of the player and information regulation respectively, could optimally load a player's cognitive capacity and lead to better knowledge construction.

One way to decrease extraneous cognitive load in serious games could for instance lie in dual coding theory (Clark & Paivio, 1991), which states that we process information from our visual and audible system via separate channels, and can do so relatively concurrently. If too much information is presented on-screen at the same time, for instance a text chat while trying to navigate a 3D world, one could provide the text audibly and thus offload information into the other channel, reducing the cognitive load on the visual channel. Mixed results of dual coding information in a multi-user virtual environment were found by Nelson and Erlandson (2007). Another way to regulate the information is by progressively increasing the difficulty/complexity level of the task or by imposing a strict time limit, the latter plausibly leading to a heightened feeling of urgency.

Sometimes the most relevant instructional material at a given time in the game is less salient than other parts of the game. For instance, if a small gas leak is creating a large fireball, an instructor might want the student to notice and attend to the gas leak, instead of the much more salient fire itself. One can use a number of different guidelines to focus the player's attention. For instance, a pedagogical agent can be used in the form of a nonplayable character fireman that tells the player where to look and correct his or her actions when necessary. Another way would be to cue the player's attention to a certain area of the screen, for instance by having important objects noticeably reflect light. One could also do this less subtle and simply instruct the player, eg, by a popup, to attend to a certain object. Last but not least, one can apply signaling (Mautone & Mayer, 2001), which entails stressing the parts of a text (in this case: a depiction of a certain to be learned mechanism) that are most important to understanding how different parts of a text relate to each other. For a more detailed look at some of these instructional design guidelines reducing cognitive overload in multimedia learning, see Moreno and Mayer (2007). For a more detailed analysis of how these guidelines could apply to games, see Van der Spek, Wouters and Van Oostendorp (2008) and Lawrence (2006).

To improve mental model construction, a designer can engineer what Kintsch (1980) calls the predictability and postdictability of the game 'text'. Essentially these describe how well a person can predict what is going to happen next (predictability), or explain what has happened previously (postdictability). Predictability can be engineered to reach an optimal moderate level by actively introducing gaps in the information presented to a user, which will prompt the player to think ahead to fill in the information gap. It can also be done by pretraining, activating relevant prior knowledge during the game by some salient event. Postdictability can be engineered to be at an optimal high level by introducing reflection prompts, events in the game that encourage the player to think about his or her previous actions, or by giving corrective or explanatory feedback. A schematic overview of the framework for design guidelines enhancing mental model construction can be seen below in Figure 1.

Code Red: Triage

Game setup

We contend that games should be goal-directed, a competitive activity and conducted within a framework of agreed rules, while constantly providing feedback to enable players to monitor their progress towards the goal (Wouters *et al*, 2008a). The goal of our game is to teach the player to perform triages, the performance of which is communicated by a score, which in turn adds a competitive factor; we therefore believe our training is fully a game, instead of a simulation.

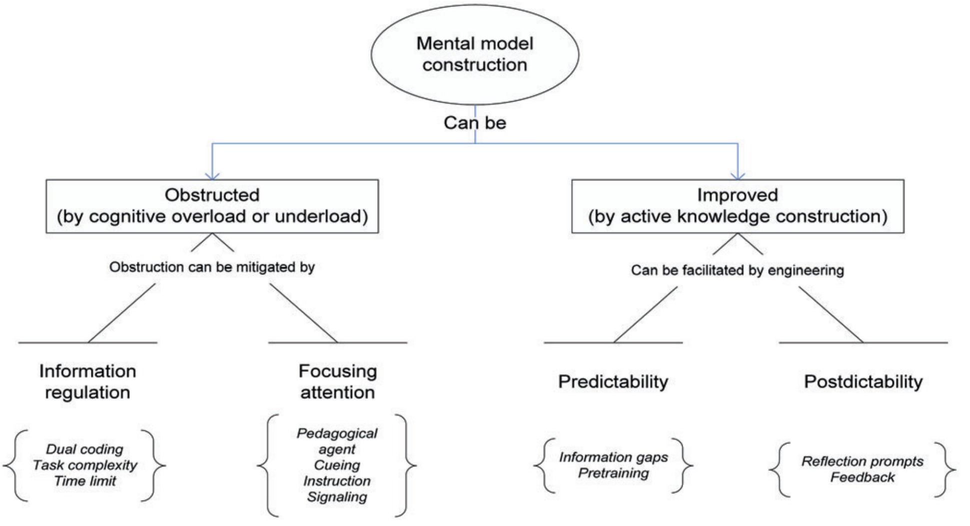

Figure 1: Framework for cognition-based design guidelines enhancing mental model construction

Figure 2: Trainstation in game

The game has been modeled with the Source Software Development Kit (SDK), a mod tool that comes free with VALVe Software's Half-Life 2 games (VALVe Software, Bellevue, WA). The player arrives in the central hall of the train station (see Figure 2), after which he or she will need to find the way to the subway line that was struck by the explosion. We deliberately made the tunnel to the subway station (see Figure 3) lengthy—a straight walk takes 2 minutes, the average about 4; as we hypothesise that this will give an objective measure of the player's proficiency with video games. We contend that

Figure 3: Corridors leading to the subway platform

experienced (first person shooter) gamers will breeze through the winding corridors, whereas novices may have considerably more difficulty with all the consecutive turning and maneuvering around objects. A measure for gamer experience may be necessary as some game design features, such as visual cues, could be more rapidly picked up by gamers, who have more experience with game specific guidance cues. This could be an important covariate for the effects of the cognitive games design guidelines.

Arriving at the subway platform, the player will encounter a total of 19 victim cases scattered about with varying degrees of injuries and should subsequently proceed with the triage task. A triage, categorising a victim according to the urgency of needed medical attention, is a relatively easy task that is set up in such a way that even laymen can quickly learn how to do it. In The Netherlands, and most other Western European countries, it roughly consists of the following consecutive steps. First, check the mobility (ie, can the victim walk); second, check whether the victim's airway is free; third, if the respiratory rate is within a certain range; and lastly, check the capillary refill time (CRT; ie, press on the nail bed and see when the nail regains colour, as an indication of blood circulation). After obtaining the results from these checks, the medic has to categorise the victims accordingly into either of four categories: T1 (red) for urgent, T2 (yellow) for delayed, T3 (green) for light or no injury and Dead (black) for death immanent or already deceased (cf. Hodgetts, 2002). A screenshot of the triage procedure interface menu in our game can be seen in Figure 4, with the different checks on either side of the screen and the triage categories at the bottom. There are eight check buttons in total, the four checks mentioned above, a 'general info' button and three buttons that vary and are primarily intended to distract the player and cost valuable time. After a classification is awarded, the victim is coloured accordingly (see Figure 5).

During the triage task the game keeps a score of how well the player is performing, and communicates this to the player. For every correct triage the player will get 100 points,

Figure 4: Triage procedure menu

Figure 5: Victim after being categorised as T3 (Green: slightly injured)

which is shown as a progress bar at the top, to a maximum of 1900 points for all the victims. A penalty is subtracted from the score when the player takes longer than 30 seconds. The feedback is given immediately after a victim is triaged, as it has been shown that this is most effective for learning in a similar procedural triage setting (Jarvis & De Freitas, 2009).

Cueing example

As an example of how a design guideline may work out in *Code Red: Triage*, we will here focus on cueing as a means of focusing the attention of a player (see Figure 1), which will also form the basis of one of our experiments. That guiding a player's attention to relevant information can be done by cues and that this improves the learning of instructional multimedia material (but not games), has already been shown by Jeung, Chandler and Sweller (1997). Additionally, the effects of implicit (eg, a far off mountain) and explicit (eg, a signpost) visual cues on navigation and path finding tasks have been researched by Steiner and Voruganti (2004). However, it may be difficult to say how well their findings can be to generalised games-based learning.

With our game we will test each of the four major components of the framework in Figure 1, but we will first try to find out the effect of cueing versus no cueing on mental model construction, decision-making skills and experienced engagement of the players, set out against their previous game experience. As an example of cueing in the path finding section, one can think of subtle puffs of smoke emanating from the right direction, or objects being knocked over in the opposite direction by the people trying to flee the scene of the explosion. A player's attention can also be guided with auditory cues. For instance in the triage task, one can help the player press the right button, for example for checking the airway, by cueing a breathing sound.

On the evaluation of a serious game

Problems with traditional evaluations

Until now the central tenet proposed why serious games often fail to reach their learning goals or improve on other instructional material revolved around problems concerning how and when to provide relevant information to a player without breaking the flow of the game. At least some of the seemingly disappointing results can also partially be explained by the methodology used. As was stated in a meta-analysis performed by Vogel *et al* (2006), many experiments did not include control groups or quantitative data. Of course for some researchers, knowing that their educational game was fun to do could be enough justification; in other cases, and more importantly, it may be because there is little consensus on how to evaluate the merits of a serious game. With traditional instructional material, one would normally ascertain learning gains by calculating the scores of the participants of an experiment by means of a paper test. However, verbal knowledge tests on paper may be ill-suited to assess the complete gamut of learning gains from playing a serious game. Contemporary games, especially 3D multiplayer games, not only provide verbal information, but demand that the player navigates through a virtual world, learns about its physics and social intricacies and improve on cognitive and motor skills. Furthermore, games can be used to teach the player how complex systems behave when small parts are changed (Gee, 2005), eg, in SimCity 2000 (MAXIS/EA, Emeryville, CA) where the player learns the effects of small changes in taxing on the investor climate of a city. Coping with complex systems may well be impossible to test on paper. Additionally, if the learning gains from a serious game are compared to that of a textbook, consisting of purely verbal knowledge, and the two are evaluated by verbal knowledge tests, it may be unsurprising that the textbook scores better as the type of information and test are more closely aligned.

On the other hand, the game itself can be considered an assessment of the skills and knowledge of a player, at least when the learning goals are aligned with the goals of the game. If an obstacle in the game is too difficult to overcome with the prior knowledge of a player then progressing past the obstacle, eg, by training the needed motor skills or solving the puzzle, is testament to the newfound knowledge or skills of the player. Finishing the game may be proof enough that the game is successful in teaching the educational material. In practice however, for many purposes it may prove impossible to adequately align the instructional content with the game rules or obstacles within the game, at least without losing the engaging flow of the game. Nonetheless, as games are digital media it is relatively easy to assign a direct numerical score to actions pertaining to learning goals or the correct carrying out of instructional material. If this score is then fed back to the player, as the main score of the game, via bonus points or Xbox-like Achievements, this will also increase the competitiveness of the game and thereby the engaging characteristics thereof. A high score would thereby imply that the game was successful in teaching the relevant material.

Some caveats to this paradigm should be noted though. First, chances of trial-and-error gameplay reaching to high scores should be minimised as much as possible. Second, overcoming obstacles in the game only implies newfound knowledge if the player did not have this knowledge in the first place, consequently the experimenter still has to test for prior knowledge of the participant. Last but not least, while game scores, and the progression thereof, can be used to compare the results between the subjects of an experiment, scoring is very game specific, and therefore difficult to use as a comparison with other games or instructional media.

Assessing mental model construction

Even when learning gains can be assessed relatively well verbally, this does not tell the whole story. Previously we have argued for design guidelines that may or may not improve mental model construction in a serious game. One of these design guidelines was cueing the correct procedure of the triage task in the *Code Red: Triage* game. It is likely, maybe even trivial, that this will help the player in choosing the right buttons in the given situation and thereby learning the procedure more accurately than people without help. However, the question is how well this generalises to other situations and for this we are interested in what Kahler (2001) refers to as 'strategic knowledge': the linking of procedural knowledge to conceptual knowledge, so that one not only knows which steps to take and how, but also why and when certain steps have to be taken. When a player has achieved this, one could say that the mental model has been constructed successfully. In order to assess the mental model relevant to the triage task, we used the method of comparing semantic relatedness between involved concepts (Day, Arthur & Gettman, 2001).

We elicited the strategic knowledge of the primary triage task from three experts, instructors of the triage protocol to ambulance personnel, with the aid of the Pathfinder software programme (Interlink, Gilbert, AZ; Schvaneveldt, 1990). We first derived 13 concepts and procedural steps pertaining to the primary triage task from an analysis of instructional material and interviews with subject matter experts, which can be found in Table 1. Pathfinder then randomly presents pairs of these concepts to

Table 1: Strategic knowledge concepts used for mental model representation

Mobility	*Length victim*
CRT—nail bed	Respiratory rate
CRT—forehead	Airway
Pulse	Stabilise victim
Cold weather	Blood circulation
Triage tape	Darkness
Classify victim	

CRT, capillary refill time.

the participant who has to rate the relatedness of these pairs on a scale of 1–9. From all the relatedness indices of these pairs, Pathfinder creates an undirected graph, or associative network, where closely related concepts are placed closer to each other, and less related concepts further away, or with more intermediate nodes. This graph is then a pictorial representation of the internal mental model of the expert. All three of the expert networks were subsequently averaged to come to a reference expert mental model, which can be seen in Figure 6 (translated from Dutch).

The main idea is then to derive a player's mental model by the above test before and after playing the game, and calculate their distance to the expert mental model to see if playing the game improved the way the information is stored in their head. Pathfinder does this by means of a similarity measure that, when corrected for chance, ranges between 0 and 1. However, upon eliciting the mental model of the experts, a number of problems immediately surfaced. First and foremost, the experts, having extensive field experience and not only in triages, reported difficulty in looking at the concepts purely from the perspective of a primary triage. As can be seen in Figure 6, the concepts airway and blood circulation are closely related, even though from a primary triage perspective they are not. Likewise, with the term 'stabilise victim' we meant the act of putting a person in a stable sideways position, something you do to relieve pressure on the airway. However one expert thought 'stabilise victim' implied the stabilisation of the airway, breathing and circulation; a well-known medical treatment, but not part of the primary triage. Furthermore it appeared that the experts would not always follow the correct procedure in the field, eg, all ambulance personnel would always check the pulse, even though according to the procedure checking the CRT would suffice. Similarly, according to the procedure, in darkness one cannot perform a CRT check, but one has to resort to checking the pulse. One expert remarked that 'for this purpose they always carry around a flashlight'.

This may in fact be similar to what, amongst others, Boshuizen and Schmidt (1992) discovered about the difference in clinical reasoning by novices, intermediates and experts. Whenever a doctor has to diagnose a patient, the amount of biomedical propositions (ie, textbook theory) used in the decision describes an inverted U-shape, where intermediates apply more theory but experts have encapsulated the biomedical theory

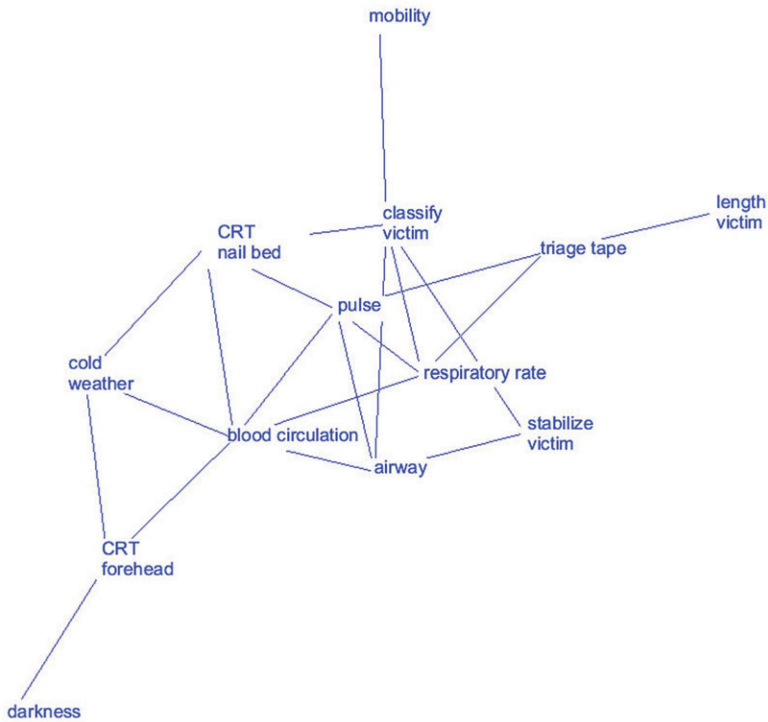

Figure 6: Averaged reference mental model of experts

and combine this with clinical knowledge from the field. As a consequence it may well be possible that participants with little prior experience in triages play our game and learn the procedure correctly, but in the end their mental model would still significantly differ from those of the experts. What we would therefore need when novices play our game is a reference mental model of intermediates, at the top of the aforementioned U-curve. Consequently, we created a theoretical version of the mental model based on the theory from textbooks, which can be seen in Figure 7.

Pilot study

In order to examine the usability of our game and the measurement scales particularly, we have done a small-scale pilot with an early version of the game, which did not yet include any of the guidelines or sounds and music. The triage procedure is easy enough to teach to laymen, but as professionals could give more useful insights, we chose real medical first responders as our test group. A total of 10 emergency physicians participated in our pilot experiment. They were all male subject matter experts (mean years on an ambulance 10.4, $SD = 9.0$) and ranged in age from 21 to 55 ($M = 41.5$, $SD = 9.13$). The pilot had a pretest-posttest design with a number of different instruments to measure knowledge acquisition in the videogame. First, the participant had to rate the

Figure 7: Reference mental model from theory

word pairs for mental model elicitation after which they received a conceptual knowledge questionnaire with multiple choice questions on triage concepts. The participants then played the game for approximately 18 minutes, right after which they filled in the engagement questionnaire of the Independent Television Committee-Sense of Presence Inventory (ITC-SOPI) (cf. Lessiter, Freeman, Keogh & Davidoff, 2001), followed by the same tests as before the game: the mental model elicitation and conceptual knowledge questionnaire respectively. In addition to this, we gave the participants two short questionnaires with procedural knowledge questions, one strictly verbal, the other with the aid of screenshots.

Ten physicians may be too little a number to come to any valid conclusions on learning gains, but some tentative trends can be discerned. Qualitatively, nearly all of the participants responded positively to the game (ITC-SOPI engagement questionnaire mean of 3.6/5), saying they liked how it looked, that it engaged them and that they found it particularly useful, as some admitted to not knowing the exact procedure anymore. Evidence for this can be found in the results of the pre- and post-conceptual knowledge tests, where the participants scored significantly better after playing the game than before ($N = 10$, pretest $M = 7.70$, $SD = 1.16$, posttest $M = 8.30$, $SD = 1.16$, $t(9) = -2.71$, $p < 0.05$).

The same, however, can not be said for the knowledge structures elicited by Pathfinder. While the participants reported no real problems in rating the concepts, most of them finishing the 78 pairings in under 10 minutes, the corrected similarity measures for the pre- and post-mental models do not differ significantly, and also do not correlate significantly to the scores obtained by the paper test. It is possible that the use of Pathfinder in this context is inadequate, but a number of alternative explanations for this unexpected result can also be given. First, while a significant increase in test scores was found, this increase was only very small; ambulance personnel already know how to perform a triage quite well, so it is unclear if a real change in mental model structure was to be expected, especially with so few participants. Second, the mental models of ambulance personnel may also have too much encapsulated knowledge, and are therefore more akin to those of the experts. Because of this it may be unlikely that playing the game will lead to a convergence with the theoretical mental model. However, comparing the mental models of the ambulance personnel to the expert reference model also did not yield significant results. Third, play time was relatively short at 18 minutes, perhaps too short for deeper learning to occur. A combination of any of these explanations is also possible, but as of yet the first explanation seems most likely; a short extra study conducted with only five laymen is bordering significance on a paired-samples *t*-test: $t(4) = -2.67$, $p = 0.056$.

Another interesting thing that came out of the pilot is that most of the participants did not have any experience in playing 3D shooter games, but still had little problems navigating the world with the mouse and keyboard, something we feared would be too difficult for non-gamers. The navigation task through the corridors of the subway station before the actual triage task that had been devised to assess the player's proficiency, actually turned out to be a good way for the participants to get to grips with the controls.

One person was not engaged by the game (SOPI score < 3), experienced problems with situational awareness as evidenced by the recategorisation of previous victims, and reported symptoms of cybersickness. This could be due to Half-Life 2's usage of a smaller field of view than normal, which is known to be nauseating for some (De Vries, Bos, Emmerik & Groen, 2007), but could also indicate a greater problem with (3D) serious games, that needs special attention in the future.

Conclusion

In this paper we argue that games are a promising instructional method for the training of emergency personnel. However, gaming is a complex task and the effectiveness for serious games is contingent on the ability of designers to facilitate players to deal with this complexity. Therefore, we propose a systematic approach of design guidelines for dealing with this complexity. For this purpose, we created a framework based on factors that obstruct or facilitate the construction of dynamical mental models and proposed a game, *Code Red: Triage*, as a means of testing these guidelines in a stressful triage training scenario. We have furthermore shown how to apply the cueing guideline to our game as an example. We have argued for the application of mental model representations as a valid means of assessing learning gains from a serious game and have tested this with a small-scale pilot. While the pilot may be too small to come to definite results, we found that the game was able to improve the verbal triage knowledge even of experts. However mental model composition did not significantly improve, therefore further testing will be needed to validate the use of mental model testing in short serious game experiences.

There are some additional caveats. To start with, we will focus on individual training in crisis management whereas team training and collaboration are paramount as well. The results should be interpreted with this in mind. Second, we would like to emphasise that the design guidelines should not interfere with the characteristics of games such as its narrative. For this we are developing a Game Discourse Analysis, which provides a structural description of the nature and flow of the information in a serious game enabling the implementation of design guidelines without compromising the game characteristics (Wouters, Van der Spek & Van Oostendorp, 2008b).

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