Balancing pedagogy, game and reality components within a unique serious game for training levee inspection

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Abstract. Most educational or training games, also referred to as *serious games*, have been developed without an underlying design theory. In order to make a contribution to the development of such a theory, we present the underlying design philosophy of *Levee Patroller*, a 3D first-person game used to train levee patrollers in the Netherlands. This approach stipulates that the design of a serious game is a multi-objective problem where trade-offs need to be made. Making these trade-offs takes place in a 'design space' defined by three general boundary criteria: 1. fun (game), 2. learning (pedagogy), and 3. validity (reality). The various tensions between these three criteria make it difficult to 'balance' or create harmony in a serious game. We illustrate this process with a discussion on the design of *Levee Patroller*. In addition, we translate the aforementioned general design criteria into a number of concrete design requirements for serious games.

Keywords: design methodology; emergency prevention training; game design; levee inspection; levee patroller; serious games

1 Introduction

Affordable computer systems, software, the ability to easily adapt or use existing content and the arrival of game editors have made it possible to use video games for purposes other than pure entertainment: so-called *serious games* [1].

The interest in this use of video games has resulted in a number of serious games, such as *Hazmat: Hotzone*, *Peacemaker*, and *Virtual U*.[1] Unfortunately, although created in a carefully controlled university environment, many of these attempts have not documented or published the underlying design philosophies. This makes it

[1] *Hazmat: Hotzone* and *Peacemaker* have been developed at Carnegie Mellon University, and *Virtual U* has been developed by a team consisting of independent game developers and Stanford University.

difficult for the emerging field of games studies[2] to establish principles, processes and procedures for such deployments of games.

The need for an underlying design and learning theories is extremely important, as [10] pointed out:

> "This interest in games is encouraging, but most educational games to date have been produced in the absence of any coherent theory of learning or underlying body of research. We need to ask and answer important questions about this relatively new medium. We need to understand how the conventions of good commercial games create compelling virtual worlds."

The need for such an underlying theory has been confirmed by the numerous educational games that have been used so far. They are not as compelling as their entertainment counterparts, have many design flaws, but most strikingly, the educational content is completely not integrated within the game [5]. For example, the player can only start playing when he or she has finished answering a number of questions. Or the gamer is continuously bothered with educational texts that are not really needed to play the game.

The purpose of this paper is to present the design philosophy underlying a serious game about levee inspection, rather than to present a rigid and validated theory of serious games. In this way, we can take a small step forward in order to actually develop an underlying theory of serious games, a theory which will guide developers in making *entertaining*, as well as *educating* serious games.

This game about levee inspection, called *Levee Patroller*, has been developed by an interdisciplinary team of Delft University of Technology, of GeoDelft, a research institute for geo-engineering in the Netherlands, and of the Dutch water boards. In the next section we explain why we decided to develop a serious game for this seemingly unique field. In Section 3, we delve into the big design philosophy behind *Levee Patroller*. The way this philosophy has been implemented in terms of gameplay and technology is described in Sections 4 and 5 respectively. The paper concludes with summing up the main points that can be extracted from this project and which might lead to a small impulse for establishing the much wanted serious game design principles.

2 The dangers of living below sea level

The Netherlands differs from many other countries in that more than half of the country lies below sea level. Natural and artificial barriers called levees protect the habitants and their goods from getting washed away. A failure of a levee would lead to large societal consequences as the Netherlands is a densely populated country, and an important economic center for Europe with its many distribution channels, ports and industries.

[2] Although the field of serious games might be young, it is strongly affiliated with the field of simulation and gaming, in which research has been done for more than fifty years.

Although failures are rare – estimates of failures are once in the 4000 or 1250 years – the National Institute for Public Health and Environment calculated that flood risks remain much higher than the risks of all other possible disasters added together [2]. It can be expected that flood risks will increase in the nearby future due to global warming and the ongoing urbanization. In addition, experts recently brought to the attention that more than 70% of the levees in the Netherlands do not totally fulfill the safety guidelines [11].

The large societal consequences, the high risk, the future developments and the lack of maintenance, all indicate that levees are critical to the Netherlands and that appropriate measures need to be taken to prevent major disasters from happening. Prevention of such disasters is a task of the Dutch water boards, which are the institutionalized organs in charge of the water infrastructures and the levees in the Netherlands. Every water board has a number of people that inspect the levees regularly or in case of emergencies. These people are referred to as *levee patrollers*. Ensuring that levee patrollers are trained to perform their jobs is one of the main preventive measures for safeguarding the Netherlands from flooding.

Fig. 1. A levee failure in Wilnis, the Netherlands. This levee breach was caused by the enormous drought in the summer of 2003.

A trained levee patroller should be able to timely recognize failure symptoms and to properly communicate relevant findings to a central field office, which upon reporting gives further directions or initiates procedures to take corrective measures. Recognizing failure symptoms requires an understanding of failures, and properly communicating requires to know which set of protocols need to be followed.

In short, it is necessary that levee patrollers get the right type of training to perform their duty, especially given the fact that failures are quite rare and difficult to notice: A layperson would only see that a failure is occurring in critical situations, actually when it is already too late. Without experience and without knowing what to look for, failures similar to that in Wilnis or even worse might occur again (see Figure 1).

Traditionally, levee patrollers have been trained with role-plays and lectures. Although they certainly acquired some necessary knowledge based on these methods, the water boards and GeoDelft were looking for alternative methods; methods that could give the levee patrollers more experience and insight of levee failures. Based on

an analysis of the possibilities it was concluded that gaming technology seemed the most promising option. A technology that would be able to create compelling worlds, i.e. make the training entertaining, and at the same time teach important concepts in a safe and easily configurable environment. In other words, a technology that educates. If designed correctly, of course.

3 The design philosophy behind *Levee Patroller*

The hardest struggle for developing serious games and at the same time the biggest difference between entertainment and serious games is the alignment between the learning of the content and the game itself. All games involve learning, whether eye-hand coordination skills, visual-spatial skills, or which buttons to push, and some games are better than others at teaching the player something [3,6]. On the contrary, not all games involve education.

This is the fundamental difference between serious and entertainment games: Serious games need to educate the player with a specific type of content, whereas entertainment games need to entertain the player with whatever; racing, puzzles, it does not really matter, as long as the player enjoys it. With serious games, content is superimposed on the player, while for entertainment games the content does not really matter. How can content be superimposed on the learner while still making it fun?

Entertainment game designers are not frequently concerned with this question. Their main objective is to make the game *fun*. Everything else, the content, controls, etc., should be “at the service” of making it entertaining. When this is done, harmony, an essential characteristic of good games according to game designer Brian Moriarty, is typically not very difficult to achieve.

For serious game designers this is different. They have multiple objectives: They want to create a compelling and fun, but educating and realistic game. To create this, they need to trade-off certain aspects of a game. In making these trade-offs they need to take into account that the system as a whole, the game itself, stays in balance. Otherwise the game looses its harmony.

We came to the conclusion that in designing a serious game three core objectives need to be achieved: 1. fun, 2. learning and 3. validity. A serious game, as the name suggests, is foremost a game, and a game which is not fun is simply not a game. Learning speaks for itself. The game needs to make use of pedagogical methods and theories to guarantee knowledge is obtained, instead of clicked away to continue playing, as in those early educational games.

The validity is related to the content. A game should not simply teach content, it should teach *relevant* content; content that can be applied outside the game world. A game designer has to ponder over how the relevant content fits into the pedagogical methods of the game and how the content fits into the game in general without loosing any validity.

Therefore, there are three components that need to be taken into account: pedagogy (learning), game (fun) and reality (validity). In the next sections, we elaborate these three core components of serious games.

3.1 Pedagogy

Many learning theories exist that can be applied to serious games, such as behaviorism, cognitivism, constructivism, situated learning, etc. [5]. From each of these theories we can extract some important properties:

Reflection. Games offer almost no opportunity for reflection as players are completely immersed into the game. Reflection is important to go from specific spontaneous concepts toward abstract scientific concepts [5]. Reflection can be stimulated by an instructor, but it could be a valuable addition if it was somehow included into the game.

Experience. Games are good at providing learning-by-doing. This means that the learning should happen alongside the doing. Many educational games make the mistake of providing pop-up windows with extensive amount of text that are supposed to have educational value and that have nothing to do with the game itself.

Low resource demanding. Too much information, time pressure or other factors inside a game environment could lead to cognitive overload or lead a person to filtering out critical information. These factors distract the attention away from learning the content.

Exploration. Another important property of a game is that it requires an active, participative attitude of the learner. The game world has to be explored by the learner and the game should only slightly direct the learner in doing this. Many poorly designed games force the player to do something, while they should just let the player figure it out.

Incremental. The learning process should occur incrementally because (i) it will otherwise be too demanding for a player, and (ii) that is the way the human brain functions. Humans acquire knowledge piece for piece and try to integrate this into existing structures. Scaffolding is a technique to establish this [8].

3.2 Game

Similarly to pedagogy, we can sum up the characteristics of the game component as follows:

Harmony. Games are systems [9]. This means that each element and component of a game is interdependent on each other. Everything has to fit. Otherwise the game cannot interpret information or give the right type of feedback. The game world needs to be a consistent and coherent world.

Uncertainty. Beforehand, the player should not know whether he is going to make it or not, and know what is going to happen. Randomness, uncertainty about the achievement of a goal, etc., make a game challenging and that makes it fun [7].

Interactivity. Computers are about interactivity and games should provide this too. A game should give the player a feeling of control [7]. The choices the player makes should be interesting: They should affect the outcomes in the game. Otherwise the player could just as well not decide anything at all.

Engaging. Entertainment games are fast and motivating. A player wants to really engage in something, be immediately rewarded for actions, and improve the high scores to show off against others. If none of that is included, the attention of a player is lost.

Flow. If a game is too difficult it becomes frustrating; if a game is too easy it is considered boring. Good games ensure the player gets into a "flow" [4]. Being in a flow means that certain tasks are frustrating, but that after practicing they become easier. A game needs to build up its difficulty. After a player masters some of the skills, it needs to become more complex.

3.3 Reality

The characteristics of the first two components, pedagogy and game, can almost be applied for any type of a game. For the third component, they have to be specifically derived from the subject the game is about:

Learning objectives. The learning objectives were largely derived from the existing levee inspection lecture. Recognizing the symptoms of a failure mechanism, the different phases and the severity of a failure mechanism, and being able to report and communicate the findings according to a set protocol are the main learning objectives to be achieved by playing the game.

Target group. Levee patrollers are clearly the target group, but other people from the water boards should be able to play the game as well. Ages of levee patrollers range from 20 to 65, with an average around 45. They are in general not very computer-oriented and therefore have little to no experience with video games.

Challenge. Levee failures are the focus and should for this reason definitely be the challenge of the game. The problem with levee failures is that there is not much known about them, except for some anecdotal evidence and controversial theories of experts. The failures are quite distinct from one to another; they differ in severity, time and the type and number of signals.

Clients. The clients of levee patroller are the Dutch water boards. After interviewing each of them, it turned out that expectancies about games were quite different, as well as at which type of content should be focused and how the game was going to be used. Each water board serves a different region and these regions have their own characteristics, which clarifies why each of them wanted a different emphasis.

Organization. The organization of levee prevention appeared to be significantly different among the water boards. Some used only volunteers, some used only employees, and others used a mix of volunteers and employees. Furthermore, the responsibilities differed. At some water boards the levee patroller was allowed to take measures, whereas at others it was clearly specified that 'a levee patroller is the eyes and ears' of the organization and nothing more.

4 The game design of *Levee Patroller*

The design of *Levee Patroller* proved to be a challenging task in itself. Balancing the three core components leads to many dilemmas that needed to be solved. Below, we describe how we solved these dilemmas in terms of gameplay, game world and game rules.

4.1 Gameplay

Without needing much deliberation we chose to create a 3D first-person game. Levee patrollers, as we were told by many water boards, are the eyes and ears of the organization, and what is a better way to emphasize this perspective than by developing a 3D first-person game?

Making the levee patroller the central figure and finding and recognizing levee failures as the central task was also not questioned. Another important decision was to make it a single-player game. Creating a multi-player game would lead to more complexity, as network technologies need to be taken into account, and a multi-player game would put the emphasis more onto the communication instead of the skills that they need to acquire for recognizing and reporting failures. The other design choices were not as easy to determine, as a seemingly unlimited amount of design space was available, while at the same time this design space was severely limited by safeguarding the core criteria of fun, learning and validity, and the technical applications that we used.

For the failures, we decided that they should occur at random places. This increases the enjoyment and also makes it possible to use the created maps more than once. The player or instructor can expressly choose the type and number of failures in the desired scenario, but it is also possible to let the computer decide and configure it.

The maps and failures are not the only options that can be configured; the weather and the number of responsibilities can also be configured. The weather is not an aesthetical addition: when it rains, the sight is limited as in reality. This makes playing the game a bit more difficult. We built in the option to configure the precise

responsibilities of the levee patroller, as they actually differ among the water boards, and as a way to differentiate in the difficulty of playing the game. Whenever a player has mastered a certain scenario, more responsibilities can be taken.

The latter design choice has been made in accordance with the "incremental" characteristic of pedagogy and the flow theory of games. However, the game at the moment needs more of these techniques to make it more playable. We created a training level for new players to get some grip on the game, but based on the many observations we made we have seen that it is really necessary to slowly build up the difficulty.

We built the training level also for another reason. Many levee patrollers did not grow up with computer technology and therefore have little to no experience with computers. We tried to make the user interface as simple as possible, but we nevertheless decided that the player needs to use the mouse and arrow keys at the same time, a parallel task (applied in many first-person games) with which inexperienced computer users have many problems. A levee patroller needs to walk and look around and we did not find a better alternative than using the arrow keys to walk and the mouse to look around.

We held strongly onto the experience, exploration and reflection properties of a game (see Section 3.1). The player has an inventory with all kinds of tools that can be used throughout the game and the player decides when to use these tools. Information about a failure can for example be looked up whenever the player wants to; the game does not force the information to be read. Every action in the game is initiated by the player and not by the game.

The gameplay can in short be summarized as follows: a player is assigned a region and has to find failures and report about them. The player knows exactly how many failures reside into the region – something that is not apparent in reality, but which we thought was necessary to create an engaging game –, but does not know where. Upon finding a failure the player has to fill in a report and depending on the state of the failure return to it to see if it gets worse. If not, the central field office should be told that the failure stabilized and otherwise that it is getting worse and that measures need to be taken. The game ends whenever the player found every failure and reported that they are either stabilized or that measures have to be taken. The game also ends when a player cannot find a critical failure. In the latter case this will lead to a levee breach that will flood the whole region.

4.2 Game world

The game world is important as it provides a context against which the player can learn, while at the same time it should give a feeling of being realistic. It was chosen to design a game world which would incorporate every important characteristic of the Dutch regions. In this way, every water board would feel affiliated with the game world. Other than that, a fictive world might also push the player to "step out of the box" instead of acting the game as in an extension of the daily routine. Stepping out

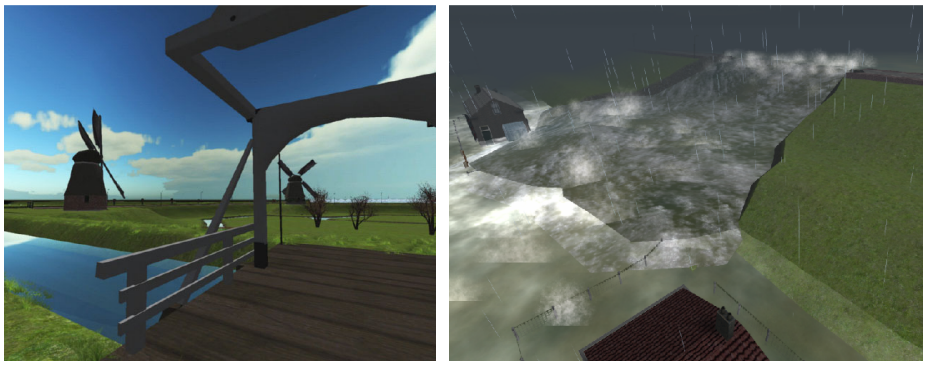

Fig. 2. Some impressions of the in-game graphics, showing an authentic Dutch landscape with clear weather (left) and a levee breach and its consequences (right).

of the box stimulates meta-cognitive thinking, a skill that is critical in acquiring new knowledge.

The world in itself resembles reality as closely as possible. The game world might thus be fictive; it still has many recognizable elements. The degree of realism was evaluated with a number of experts and levee patrollers and they were unanimous that the game world looked very similar to the real thing (see Figure 2).

A departure from reality is that we down-scaled the region to be inspected. It would be boring to walk around for five minutes without something happening. It is not a lesson in learning to walk, but in finding and recognizing failures. However, making the region too small would lead to being confronted with failures too easily and this takes away the surprise effect, which is part of the engagement. So we conceded enabling ability to "teleport" back to a failure whenever the player discovered one.

We tried to put the "eye-candy", things that are beautiful to look at, but that might interfere with learning, away from the levees. A player could thus decide to wander off and enjoy the virtual world, but when actually playing to prevent any levee failures he would not be bombarded with visual distracting artillery.

4.3 Game rules

When developing the game rules, the mechanisms that determine how player's input affects the outcomes in the game [9], we bumped into many problems. We decided to make a generic model of the development of a failure mechanism. A failure mechanism could develop itself into three phases: not serious, serious and very serious. Each phase would require distinct actions from the player. In this way, the computer recognizes whether the player has an understanding of the failure mechanism. In reality, the central field office asks the player to describe the severity of the situation. This pushes the player to reflect on the perceived symptoms.

However, the failures appeared to be so different that it was rather uneasy and artificial to fit all of them into this conceptual scheme. The world, as always, seems to be too disorganized to be mapped onto a rigid diagram. Solving this problem by

simply creating two phases instead of three was not that easy. Many mechanisms were fine-tuned to the conceptual scheme and because we decided to make a very flexible map, in which any failure could appear, we had to take into account many possibilities.

We somehow managed to fit everything together in the end, but it remains an important issue for future developments. When new failures are added to the game, they have to be deeply reviewed and processed to see how they fit into the scheme and with the rest of the game mechanisms. A game simply wants to be coherent, consistent and orderly, whereas reality is nothing like that.

An example of a game mechanism that forces a game to be coherent and consistent is the scoring system. Scores are very motivating. One of the levee patrollers yelled that he wants to take the game home and get that “100% score”. An excellent example of the motivating power of a score and an important reason to include scores in the design, besides that it is a strong way of giving feedback. The scoring system was adapted to the conceptual scheme and any failure that did not fit this scheme would lead to a not very transparent gameplay. If a tester asks “Why do I not get any points?” it is an indication that the game is not in harmony.

The main point about all of this is that it proved to be difficult to find a balance in between a slow, reflective, experiential learning process, a fast engaging, complete consistent and coherent fun interactive world, and an ill-defined, disorganized, very rich and diverse reality. Not using a generic conceptual scheme is unthinkable, but it does lead to many comprises and many steps away from reality.

5 Implementation of *Levee Patroller*

Levee Patroller was implemented using the commercial game engine Unreal Engine 2 Runtime, a simplified version of the “Unreal Engine 2” specially developed for non-entertainment games. In practice, it can be considered as a 'total conversion mod', as all digital assets in the game have been created form scratch for this purpose, and the same can be said of the essential gameplay elements.

Using this engine allowed us to concentrate on the specific aspects of our application, without spending precious developers' time in implementing basic functionality and classes (e.g. rendering, culling, particle emitters, skyboxes, texturing, movers and GUI’s). In addition, *Levee Patroller* largely capitalizes on the scripting facilities provided by the Unreal engine, which were thoroughly used for the specification of most control and behavior aspects. For example, the control for most levee failure mechanisms is handled through an AI scripted sequence of events, triggering the necessary animations, which can include movers and emitters.

Levee failure mechanisms are one of the most significant aspects of the game. They where developed in close cooperation with tutors of the levee inspection courses and other domain experts, since much of the training value relies on the realism and accuracy of these processes. Because failure mechanisms can be very complex, several animation techniques were used to implement each one of them.

Another important aspect for the realism was their placement. Ideally, it would be preferable to have all failures randomly placed across the game level; unfortunately,

this is not feasible in a truly generic way, as numerous variables would need to be adjusted depending on where each failure ends up. Also technical issues such as the correct lighting of the objects would be compromised by a complete freedom in failure placement. For this reason, levees were built using simple blocks (straight and curved) that can have a failure mechanism attached to them. Since the animations (that include the particle emitters and movers) of failures of the same type are very similar, they can be adapted and reused by level designers, in order to implement failures in the same or in different levels, making it much easier to build a complete new level. Additionally, this allows for more than twenty-eight mechanism variants per level all of which can have different severities. Typically, three to five failure mechanisms are chosen to be active in a level.

Similarly to the levee failure mechanisms, many other objects in the game were created for easy reuse, such as the particle emitters simulating mud, and the water animated textures that can be placed in any level.

Eventually, a good balance was found between the intended realism and the necessary game performance. In some cases, rendering performance had to be improved by using a variety of smart optimizations; for example, taking into account that *Levee Patroller* is inherently a single player, first-person game, the weather manager uses a rain emitter that is continuously set high above the player's location, spanning around that position a region large enough to achieve the desired effect. In addition, there is no point in performing collision detection of rain particles with for example roofs of buildings, since all gameplay in *Levee Patroller* takes place outdoors. Also, a meticulous selection and combination of static meshes, deco layers and grass meshes, with a proper culling distance set from the player's position, significantly improve the realism without compromising the performance. In order to improve performance, objects unreachable in the game but that can be seen from far away, are present, to improve realism, but with much less detail (for example, the cars in the highways are simple particle emitters and the forest is just a combination of textures). Finally, performance can be significantly improved, specially when using lower end graphics hardware, by adjusting at game startup the level of detail that the game engine will use for rendering most actors.

6 Conclusions

This paper discussed the application of a novel design philosophy for serious games. This philosophy was successfully applied during the design and development of *Levee Patroller*, a serious game conceived and developed in the Netherlands for the instruction of levee patrollers, a professional group with a crucial role in the national security. It has been observed that all too often serious games show a lack in harmony, which is an essential characteristic of good games. We put forward (i) that the design of a serious game poses a multi-objective problem: it needs to be educating, fun, and valid; and (ii) that it is fundamental to keep these three elements in balance. In addition to these conceptual challenges, serious games also pose many technical challenges, as the design space is often severely limited by the tools and budget available, usually much lower than for commercial entertainment games.

Levee Patroller shows that it is possible to design and develop a very engaging game that is at the same time very instructive and accurate. This could only be achieved by carefully balancing the three basic elements mentioned above, which in turn was facilitated by a close cooperation with domain experts and tutors of current levee inspection courses.

So far, *Levee Patroller* has been deployed by personnel of the participating water boards, who unanimously reported rather positive results, confirming the above conclusions. We are currently working on further development of *Levee Patroller*, both extending the domain dealt with and investigating how to satisfy a number of new desired features, conceptually as well as technically. Finally, future research will have to be made into the effectiveness of this application in the continuous learning process of levee patrollers.

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