Applying games in levee inspection training and education: A case study

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ABSTRACT: For flood risk management, and crisis management in general, training and education concerns an interesting challenge. While training and education is important for an efficient and effective dealing of crisis situations, it is difficult or even impossible to (re-)enact crisis situations in real-life. If practice-based training and education is difficult in reality, it may be a solution to get experience in a virtual environment. This paper focuses on the design, development, and usage of such a virtual environment. This concerns the game *Levee Patroller*, which is developed to teach and train levee inspection during extreme water levels. The case study shows how a game can be applied for flood risk management by portraying the concept and the implementation of the game. Based on the results and experiences with the game so far, it is furthermore concluded that the use of games may indeed be a valuable and potentially powerful addition to flood risk management tools.

1 INTRODUCTION

1.1 *Crisis training and education*

For over a century notable scholars have stressed the importance of *experience* next to theory (cf. Dewey 1916, 1934, Lewin 1951, Knowles 1990, Kolb 1984, Piaget 1974). Words and ideas are meaningless when they cannot be related to the real world. Additionally, if theory is not applied in practice, there is a high likelihood that it can be i) executed improperly and ii) inefficiently. More importantly, without practice there is no opportunity to falsify theory. If theory is incongruent with the real world, any action consistent with that theory is likely to be ineffective.

This poses an interesting challenge for flood risk management, and crisis management in general. The need for an efficient and effective dealing of crisis situations is obviously high due to the devastating consequences flooding and other disasters have (Alexander 1993, Blaikie et al. 1994, Hoyois 2007). However, crisis situations are difficult or even impossible to (re-)enact in real-life. It is simply too costly, too dangerous, and even unwanted. The difficulty of simulating crisis situations severely limits the training and testing of theories. Subsequently, it is problematic to improve the efficiency and effectiveness of crisis organizations.

Nonetheless, there are some possibilities for getting experience, and hence improving crisis organizations. One possible and feasible approach is to pretend as if a disaster occurs. In this way, certain parts of the crisis organization can be trained and tested, such as the communication between the parties involved. Unfortunately, the operational parts of the crisis organization, those units that need to observe the environment or implement measures, can barely be trained in this manner. For these more practical oriented parts an alternative approach, which is in fact extensible and complementary to the pretending approach, can be applied: A playful approach (Harteveld 2008).

1.2 *A playful approach*

A playful approach consists of the application of games for the training and education of professionals (Harteveld 2008). Games, whether digital or not, are rule-based systems with variable outcomes that players can exert influence on by manipulating the rules (Juul 2005, Salen & Zimmerman, 2004). They differ from other frequently used and seemingly similar tools in flood risk management, such as Decision Support Systems (DSSs) and simulations. Games are more focused on educating their users by involving them into a certain process, while DSSs and simulations are used to respectively prescribe and assess a particular situation.

The educational value of games consists of providing a compelling, experiential, authentic, and safe environment (Gee 2003, Harteveld & Bidarra 2007, Prensky 2001). These values have become enlarged with the arrival of computer game technology. This technology has made it possible to virtually (re-)create objects and situations, such as crises, quite realistically. In this way, professionals can be trained and taught easily and safely. They can make mistakes and learn from them without any consequences. Moreover, only a computer with the appropriate hardware is needed to start a session (and a computer network if it involves a game with multiple players). Last but not least, game sessions can be evaluated and as such, games can be considered a training and educational as well as a testing environment.

Besides an educational value, games have an organizational value (Harteveld 2008). The game can become a knowledge repository, in which organizational knowledge is stored. It further can allow for a strong shared and explicit mental model between organizational members, and stimulate elaborate discussions about its topic. By taking these organizational value characteristics together with the educational value characteristics of games, it may become clear that there is a potential for a playful approach to improve crisis organizations in dealing with disasters when they are for real.

1.3 *A case study*

The potential of using games has been recognized in many domains, also outside the area of crisis management (Bergeron 2006, Michael & Chen 2006). Games have for instance been developed to teach surgeons how to operate (e.g. *Pulse!!*) and for university personnel to acquire management skills and insights (e.g. *Virtual U*). Those games that are designed and used for non-entertainment purposes are referred to as "serious games" (Sawyer 2002). In this paper we discuss the design, development, and usage of such a serious game, namely the game *Levee Patroller*. This serious game has been developed to train and teach "levee patrollers". These are people, volunteers or professionals, who inspect levees (also called dikes or dykes) regularly or in case of emergencies.

In explaining the case study, we first give some background information in Section 2 about levee patrollers, the need to develop the game, and the project itself. In Section 3 we delve into the concept of the game. We explain the basic purpose of the game and its content. Subsequently, in Section 4 the technical and practical implementation is discussed. The final section concludes with insights about the case study and recommendations for further research.

2 BACKGROUND

2.1 *Levee inspection in the Netherlands*

The Netherlands is a unique country in that more than half of it lies below sea level. To protect the land it has thousands and thousands of kilometers of levees, 3.585 kilometers of primary (e.g. sea and river levees) and 14.000 kilometers of secondary levees to be precise. These levees fulfill a crucial infrastructural role. The failure of a levee could lead to large societal consequences as the Netherlands is a rather densely populated country and an important economic center for Europe with its many distribution channels, ports, and industries. For this reason, the prevention of levee failures is highly prioritized on the Dutch political agendas.

For prevention new techniques are being developed, such as laser, electrical, and satellite scans and sensitive geotextiles. Another prevention method concerns the redesign of existing infrastructures, like the fortification of levees or the expansion of riverbeds. Despite these developments, one of the oldest prevention methods will probably remain valid: The inspection of levees by human beings. These human beings are commonly referred to as "levee inspectors", "levee patrollers", or as the "levee army". The levee patrollers, as we continue to call them, are nowadays part of the crisis organization of the Dutch Water Boards. The latter are functional public institutes concerned with the safety, quality, and quantity of the Dutch water systems.

Within the crisis organization of the Water Boards patrollers are considered the "eyes and ears". Regularly, but in particular during high water situations, they search for subtle signals that may indicate the impending failure of a levee. Based on their observations, which are submitted to a central field office further action will be taken, like the implementation of emergency measures or the decision to evacuate certain areas. Although in general this picture of levee patrollers is similar in every Water Board, the exact roles, procedures, and other relevant aspects may differ per Water Board.

To guarantee a certain level of knowledge about levees and their failures courses have been organized. These courses are mainly theoretical. It is difficult to organize a practical course as failure signals are subtle and only occur during extreme weather situations. Simulation of these situations by using fake levees turned out to be insufficient and too expensive. Practicing during actual extreme situations is considered too dangerous and also inefficient. Failures are quite rare (i.e. levees are designed in the Netherlands to have a failure occurrence of once in the 1250 years for river levees and once in 10.000 years for sea levees). Most patrollers have in fact never seen one. This means patroller hardly have and get any experience at all.

In search for a solution, in which patrollers could learn to recognize different signals, what procedures need to be followed, and how their findings need to be communicated, the idea came up to design a game. By playing this game patrollers could learn the required knowledge and skills in a fun and safe but still realistic way.

2.2 *Levee inspection as a serious game*

The idea for designing a game to educate levee patrollers started when an interactive 3D-model of a levee reinforcement was made and displayed during a symposium by the Dutch national research institute for delta technology “Deltares” in the summer of 2005. Although merely made as a gimmick for this event, it quickly gathered the attention of the Water Boards. Knowing that a number of fire and police departments successfully applied an educational game environment, they were inspired by this model to inquire the research institute whether it was possible to create such an environment for levee patrollers with this technology as well.

As Deltares did not have any knowledge about designing games they looked for a partner who had. This partner turned out to be Delft University of Technology. In addition, five of the twenty-seven existing Water Boards were involved as stakeholders within the design process. From there, the innovative and explorative project took off in the beginning of 2006. First, the project contained only four people; a game designer, a programmer, a modeler, and a project leader. Later it was expanded to include ten people. The first full version was delivered in October 2006. Currently, the participating Water Boards are using the version 2.x. The third version is expected to be finished at the end of the summer of 2008.

3 CONCEPT

3.1 *The design and learning requirements*

The initial design requirements for the development of the levee inspection game, which was named *Levee Patroller*, were to design a flexible, modular, realistic, and challenging environment by using state-of-the-art game technology, in which users would learn by doing. This learning-by-doing ideology is consistent with the experiential learning scholars from the past (cf. Dewey 1916, 1934, Lewin 1951, Knowles 1990, Kolb 1984, Piaget 1974) and the ideas of e-learning gurus (cf. Aldrich 2004, Schank 1997). The flexibility requirement was important as early interviews revealed that the needs differed widely between the Water Boards. By making the game flexible, it can be used the way each Water Board wants to use it.

The modularity requirement was equally important. It would have been impossible to incorporate every thinkable scenario into the game from the beginning. By ensuring that new scenarios could be easily added to the game, the game allows for continuous development in which more content could be added over time.

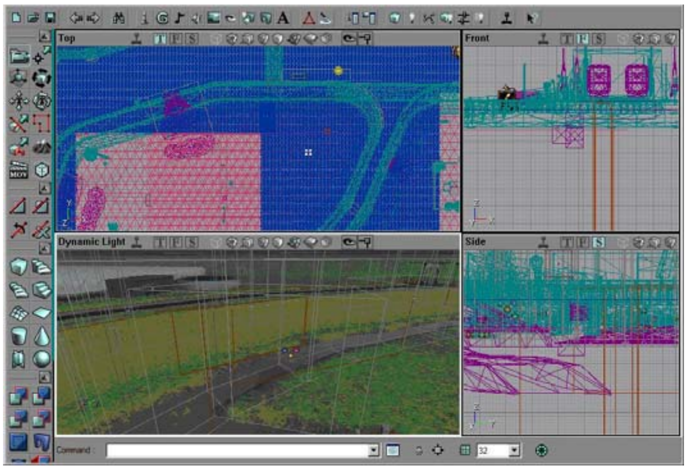

Figure 1. Screenshot of the UnrealEd, an in-game editor that comes with the Unreal Engine.

The requirements for creating a realistic and challenging game are self-explanatory. They are accommodated by the decision to use the commercial game engine “Unreal Engine 2 Runtime”. This technology has been used to create successful entertainment games, like Unreal Tournament, and was also used to create the interactive 3D-model for the symposium. Although the engine took a substantial part of the available budget, it enabled the team to quickly create a high-quality game and to focus on the design instead of technical aspects. For example, the engine took already care of some core functionalities, such as the interface between the game and the hardware (e.g. videocard, keyboard). Another clear advantage is that the engine is accompanied with powerful tools, such as an in-game editor (Fig. 1).

Besides the design requirements, the learning requirements were defined. After playing the game, users should be able to:

- Recognize different signals that may indicate the failure of a levee;
- Report signals correctly to enable easy interpretation by the central field office;
- Diagnose the situation based on the observed signals;
- Asses the severity of a situation;
- Advise about or take measures against failures.

With the previously mentioned design and learning requirements in mind and the decision to use the Unreal Engine 2 Runtime, the team started to creatively think about the actual game design concept. The wildest ideas came by, but finally one stood the test of time.

3.2 *The game design concept*

From the beginning the ambition was to create an actual game, not a *simulator*. With a simulator we refer to those products that use virtual worlds to simulate real world activities one-to-one to the virtual world. Microsoft's *Flight Simulator* is a good example of this. However, as the game needed to be realistic, it had to be somewhat simulator-like. In the end, the concept can be thought of as a simulator with strong game elements. The game elements are reminiscent of the classic game *Pacman*, but then with levee failures instead of yellow dots and in three dimensions (3D) instead of two dimensions (2D). This is reflected in the basic concept of the game.

The purpose of the game is to find every failure as a levee patroller and report it. Although the types of failures and their location are unknown, the amount of failures is known to the user from the beginning. Initially, the number was unknown as well. In playtesting it however turned out that users wanted to stop playing if they could not find anymore failures, while when the number was known, users kept playing until they found every failure. Therefore, by making the game slightly less realistic, it became much more challenging. One requirement had to be traded off against the other (Harteveld et al. 2007).

Upon finding a failure, users have to put down a red marker. After this, they are able to fill out a report for each failure-related signal. The reports consist of relevant characteristics for each signal. For instance, for cracks some characteristics are the type (i.e. longitudinal or perpendicular), the width, and the length. This means that for filling out reports users may need to make some measurements. This is done in the game by putting down yellow markers. The distance between two yellow markers is automatically calculated when users put these down. Next to the reports, users also have to indicate the failure location by marking the location on a map.

Ideally, if users finished these steps, they should call a computerized field office to communicate their findings. If users call the office without having any reports or without having marked the location, the office will tell them to take these steps first before calling again. If users fulfilled these necessary steps, the office asks them to give a situation assessment of the failure (i.e. is it not serious, serious, or very serious?). In response to the assessment, the office gives feedback about the situation based on the information that the user provided. Additionally, the office gives directions that users need to follow but can ignore, such as "carefully track this failure" or "take immediate measures".

As failures are dynamically implemented, users have to return to failures to see if they become worse or stable during a scenario. If a failure becomes worse, users may need to take an appropriate remedial measure. This can be done by selecting a measure from a list of possible options after approval of the field office to take a measure. After choosing a measure, a computerized levee expert appears who gives feedback about the user's choice. If users choose a wrong measure, they may try again until they choose the right one. If a failure stays or becomes stable, users need to report this to the field office.

A scenario ends when all failures are found, remediated and/or reported as stable. A scenario also ends when a player cannot find a critical failure. In this case a levee breach occurs that floods the whole region. At the end of a scenario a score is given from 0 to 100% (where a score of 55% is considered sufficient, but only if none of the levees are breached), which is based on the following criteria:

- Observed failures – the number of failures the user correctly found;
- Location accuracy – to what extent the user correctly reported the location of the failures;
- Observed signals – the number of signals the user correctly reported;
- Reporting accuracy – to what extent the user correctly filled out the reports;
- Situation assessment accuracy – to what extent the user correctly assessed the situation.
- Diagnose accuracy – to what extent the user correctly identified a failure mechanism;
- Measure effectiveness – to what extent the user immediately identified the right measure.

All in all, the development of the game design concept proved to be a difficult effort, since many requirements needed to be taken into account. In some cases, such as with deciding whether the number of failures is known upfront or not, requirements even contradicted each other and trade-offs needed to be made (Harteveld et al. 2007). The eventual concept can best be thought of as a complex and three dimensional *Pacman*-like game, in which users need to find, analyze, and possibly remediate failures.

3.3 *The content of the game*

Related to the content of the game an important design decision concerned the demarcation and focus of the game. In consultation with the participating Water Boards the decision was made to focus on eight well-known levee failures that occur in the rural sides of the country during extreme water levels. Hence, we omitted urban environments, failures related to drought, and problems related to the sea levees and dunes, among many other things.

For deciding on the actual content within this scope, the large variety between the worlds of the Water Boards had to be considered. The regions of the specific Water Boards differ; some have solely primary levees, some solely secondary levees, and others have a mix of both. Next to this, the soil composition of the levees, the responsibilities of patrollers, the inspection procedures, the organizational structure, and the terminology differ. We partly handled this diversity by creating a non-existing region that resembles the Dutch polders, but which also unites the unique characteristics of the several regions. Furthermore, the idea of a "scenario generator" was thought of, a tool for users to create their own scenario.

Figure 2. The failure development scheme. A failure can develop from "not serious" to "serious" or "very serious" or remain "not serious" or "serious".

The failures in the game (but also in reality) consist of one or more signals and are related to a specific failure mechanism. As no uniform terminology as well as categorization exists, we decided to make our own based on information from experts, reports, and interviews with the participating Water Boards. The failure mechanisms, the underlying causal patterns of failures, were categorized into piping, erosion outer and inner slope, macro (in)stability, and micro (in)stability (a.k.a. suffusion). The signals were divided into: Rip-rap/pitching stone damage, grass revetment damage, cracks, settlement, horizontal movement, uprise, liquefaction, water outflow, overtopping/overwash, floating waste, human activity, and biological activity (which includes burrowing animals).

Unlike pictures, games make it possible to dynamically portray objects from multiple angles. As most people have never seen an actual failure, it would be an important asset to dynamically visualize failures. For this reason, the decision was made to include dynamic failures. For each failure a development scheme was designed with the help of experts (Fig. 2). For instance, the failure that is caused by macro (in)stability first starts off with a number of longitudinal cracks on the top of the levee. At a later moment, the cracks become larger, perpendicular cracks start to emerge as well as a settlement and a horizontal movement. At an even later moment, the settlement is complete and another horizontal movement can be observed.

In the scheme, three possible phases are distinguished, a "not serious", "serious", and "very serious" phase. A not serious phase indicates that a failure is observed that does not cause any harm (yet). When a serious failure is observed, it should be tracked carefully. When it becomes very serious, immediate measures need to be taken. In the game, failures may become serious or very serious or stay not serious until the end of a scenario. The user does not know this upfront. Although the scheme is a bit artificial, especially time-wise compared to how failures develop in reality, it enables users to get an elaborate mental model of the development of a failure.

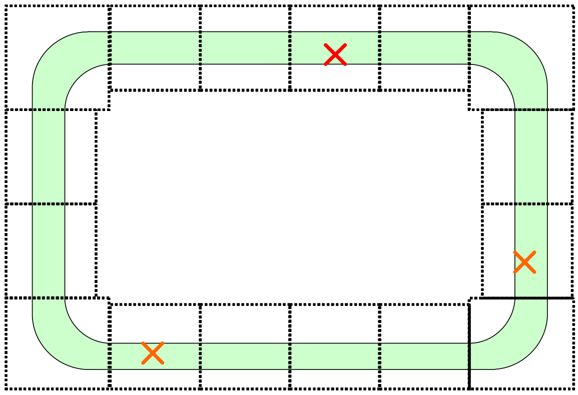

Figure 3. A levee ring built out of similar shaped building blocks. The crosses symbolize a failure.

To keep the game challenging (and modular), the levees were built out of similar shaped building blocks (Fig. 3). In this way, it becomes possible to place a failure in any possible building block. This makes a scenario much more challenging, because failures will not always appear at the same spot. If this would be the case, users could learn how to beat the game instead of understanding the underlying learning objectives. Of course, in some situations users may want to play the exact same scenario. This has been made possible by enabling users to replay a scenario.

The development decisions related to the inclusion of the content show that similar to the development of the game design concept trade-offs needed to be made (Harteveld et al. 2007). Failures may for example develop differently in reality, but for the purpose of the game it may be better to simplify them.

4 IMPLEMENTATION

4.1 *Technical implementation*

For the translation from the concept to the actual implementation, we made a couple of steps. For the region for instance, we first drew a large sketch, then created a more detailed drawing of a particular region, and then created a quick virtual prototype (Fig. 4). From there we kept on refining the environment until we were satisfied with it. This way of working is commonly referred to as “quick prototyping” or “rapid application development” (Martins 1990, Rollings & Adams 2003). By trying to build a working virtual model as fast as possible, it becomes possible to experiment with features and discuss with clients about how to improve the product. A major disadvantage of this way of working is the lock-in effect it has. When models have been implemented, it becomes difficult to redesign them, especially when the models are integrated into the overall concept.

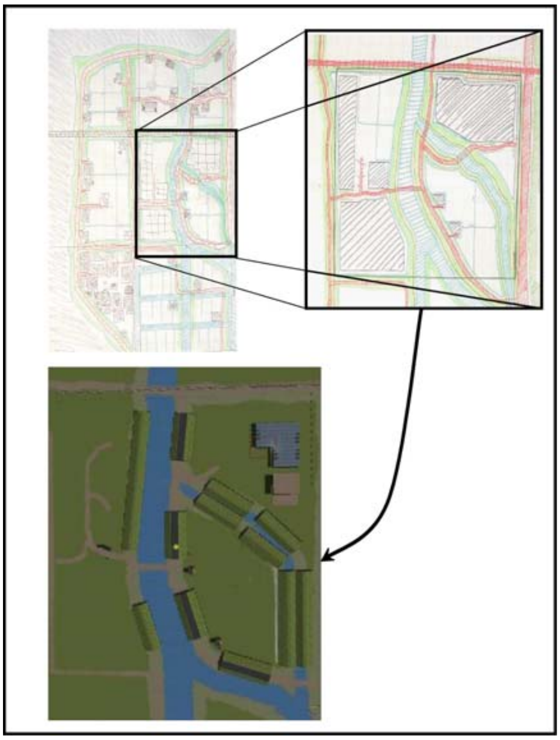

Figure 4. An initial large sketch is made into a detailed sketch, upon which virtual mock-ups are made.

The object and models in the game environment were developed by using 3D modeling software, like 3ds Max. These objects can vary from the trees and houses to the levees and failures. A general way of working is to first have reference material, photographs, pictures, etc., and then translate these to a virtual object. For the failures for example, reference material – if available – and advice from experts was used to create a virtual failure model (Fig. 2). An interesting element of the development of the failures is that it turned out that experts i) disagreed among each other and ii) revised their original held views continuously when their views were visualized. This shows that there is little consensus and knowledge about levee failures and that designing these proved to be a learning process in itself. This also means that users should be aware that although the designers tried to design the failures as realistically as possible, that in reality they may encounter failures that are not comparable to the virtual ones.

Behavior to objects, such as movements and interaction possibilities, was added by using a scripting language called the “UnrealScript”, a language specific to the Unreal Engine but with close similarities to well-know languages as Java. In small steps we created an increasing interactive virtual world. First, it was only possible to walk around. In the final stages, it was possible to prevent a levee breach by taking an appropriate measure.

Figure 5. Reference material from a real world failure is translated to a virtual failure.

Another important technical implementation concerned the scenario generator (Fig. 6). The idea of the generator was to increase the flexibility of the game, to let users decide for themselves how they want to make use of it. In the end, a system was implemented that enabled users to choose the region, the weather, the types of responsibilities, and the types and number of failures. For the failures, the generator also allowed the user to let the system randomly select the types and number of failures. When the selection is complete, the virtual world is generated and the player can start the inspection.

The actual placement of the failures into the building blocks turned out to be an enormous challenge. At first, we were unable to place multiple failure models into one block. Therefore, the decision was made to relate only one specific failure to one building block. This means failures occur much less randomly than we conceptually designed for. With a new method, which was labeled the "dynamic placement of failures", we were able to fix this at a later stage. With this method, the whole virtual world is designed when users start a scenario, while with the earlier versions the whole virtual world was already built. The difference between the scenarios consisted of which building blocks were triggered and which were not.

As for the game options, we implemented a training exercise, a complete exercise, and a single exercise. The training was developed to let users get familiar with the controls and with the game. The game has become quite complex and we decided to use the keyboard in combination with the mouse to interact with the virtual world. This combination is frequently applied in 3D games. However, the average age of levee patrollers is about 45 years old. On top of this, most of them have little computer experience. Therefore, it was not a surprise to notice that they have an initial trouble in using the game. We stuck to it as we noticed in early tests that despite the trouble users persisted in learning how to use it. Moreover, it is a logical control scheme for making inspection in 3D worlds possible. The arrow keys on the keyboard can be used as the legs of the virtual patroller and the mouse for its eyes.

Figure 6. Screenshot of the scenario generator. The region, weather, types of responsibilities and failures can be chosen.

The complete exercise is the realization of what we considered the "career-mode" once. It consists of a number of predefined scenarios that the user has to complete in succession. The single exercise enables users to get to the scenario generator and let them define their own scenario.

4.2 *Practical implementation*

Although *Levee Patroller* was set up as a stand-alone educational tool, it is usually used in combination with the original theoretical levee inspection course or with an adapted course which has been specifically designed around the game. We consider the presence of an experienced facilitator during the use of the game as extremely important as solely playing the game will not yield an effective transfer of the learning goals (Egenfeldt-Nielsen 2005). The facilitator debriefs players in between and after playing the game by relating the game experience to their real world experiences and by showing and explaining examples of failures that have occurred in the past.

The major advantage of combining the game with the theoretical course is that students can practice directly what they have learned. It is basically a combination of theory and experience. Next to this, it makes learning a lot more fun. Students do not have to wait and listen all the time. The disadvantage of using the game in this manner is that students are still restricted to specific course days. Currently, we are examining how students could effectively practice at home.

The game is at the moment licensed to six Water Boards (i.e. the five participating Water Boards and an additional one). These Water Boards have set up specific game rooms to play the game. Other Water Boards are still considering a license or organize in consultation with Deltares workshops in which the game plays an important part. The most basic problem the Water Boards encounter in implementing the game is the requirement of having a videocard installed on their computers. In the near future, when the old computers get replaced, this should not be a problem anymore.

The overall results of using the game are satisfactory. Patrollers indicated that they find it realistic, engaging, and educational. For many patrollers it is difficult to stop playing and some of them even asked if it was possible to take the game home. In general, since the integration of *Levee Patroller* with the levee inspection courses, the courses are appreciated more. Students are relieved to have theory and practice alternated. An unexpected effect was that because of the game, patrollers felt more appreciated by their organization.

Another interesting and unexpected effect is that the game has led to many other uses and spin-offs. For example, the participating Water Boards use it to attract new voluntary patrollers and a simplified version, which has been built for symposia and conferences, has been picked up by the NEMO science museum in Amsterdam to be included in their permanent exhibition. Moreover, the game has been modified for other but similar sorts of games, such as a game about construction inspection. For the game itself, work is done to improve it, by including more failures and refining the feedback users get, and to include a multiplayer option. In this version the central field office is actually going to be played by a human, not by the computer.

5 CONCLUSION

In this paper, we described the design, development, and usage of a game that aims to teach and train levee inspection. This project was initiated, since it is difficult to get experience in inspecting levees in reality. The game teaches and trains recognition, communication, and the assessment of levee failures in a state-of-the-art simulator-like virtual environment with strong game elements. Currently, six Water Boards are successfully using the game. In addition, the game makes an important part of a levee inspection course, which has been applied to an even greater number of Water Boards.

The case study shows that the development of a game is an inherent creative process, in which content, learning objectives, and game characteristics need to be balanced against each other. It also shows that the design is a learning process in itself. Failures had to be multidimensional and dynamically represented, while little knowledge and consensus was present about these failures. Finally, the game has inspired many new projects and had a number of previously not thought of uses and effects. All of this indicates that using a playful approach for flood risk management has a number of organizational next to educational values.

However, more research is needed to investigate the actual effects of the game. It is for example yet unclear to what extent users learn from playing and whether this learning leads to an improvement of the crisis organization. Furthermore, the game itself can be improved on several aspects, such as an increase in the number of possible failures and the feedback users get. Nevertheless, the results and experiences so far reveal that the use of games may be a valuable and potentially powerful addition to flood risk management tools.

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