SCORPIODROME: An exploration in Mixed Reality Social Gaming for Children

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ABSTRACT

This paper describes the design of SCORPIODROME a mixed reality game for groups of 3-4 children aged 11-14. SCORPIODROME is designed for social gaming; i.e., computer gaming that is intended to support and trigger social interaction between players to occur within and around playing the game. The paper discusses some of the lessons learnt from this design process and how SCORPIODROME paves the way towards the development of a whole class of mixed reality games. Finally, we reflect upon some of the methodological issues encountered.

Categories and Subject Descriptors

H.5.2. **[User Interfaces]** Graphical user interfaces (GUI), Interaction Styles, User-centered design. H.5.1 **[Multimedia Information Systems]** Artificial, augmented, and virtual realities

General Terms

Design, Human Factors

Keywords

Social Gaming, Mixed Reality, Interaction Design, Children.

1. INTRODUCTION

This paper describes the design of a mixed reality computer game for small groups of children aged 11-14. The SCORPIODROME game constitutes an exploration into *social gaming*: computer gaming that is designed to support and encourage social interactions within and around the game. Within this domain we are mostly interested in mixed reality games where physical and virtual game elements combine to create a rich and immersive gaming and interactive experience. With this design we set out to explore the opportunities and the interaction design challenges presented by mixed reality gaming applications for groups of children.

The broader class of interaction technology we discuss was first introduced for the office environment by researchers at Xerox PARC as part of the Digital Desk project [17]. Typical to the genre of systems that followed this early work is that physical objects are used as logical handles to control interactive virtual entities. The resulting interfaces are sometimes called tangible or graspable user interfaces. An overview of such work can be found in [15]. In the last few years, the interest in tangible interfaces and augmented reality has increased and has entered the domain of leisure and entertainment as a more pleasurable form of interaction.

There is as yet, relatively little work done in tangible interfaces in the domain of computer games. Recent research prototypes have experimented with using toys as logical pointers to computational artifacts related to a game, e.g., the READ-It prototype was a tangible augmented reality version of the popular "memory game" designed to help children 5-6 learn to read [16]. The POGO system [4] aimed to help children develop narrative skills and Ely the Explorer [1] was a game supporting a tangible user interface, designed with the aim of fostering social interactions between children through play. Recent compelling examples of augmented reality games, are 'The Hunting of the Snark' [10], that supported playful learning by groups of children visiting a room, and the 'Augmented Woods' that achieved a similar purpose but at a much wider geographic area, see [12]. Typical for all these works is that they have a clear educational purpose. In the cases above where the games were evaluated, participants enjoyed them. However, given that these were educational applications, the standard expectations and challenges for designing a computer game do not apply for those designs. These prototypes were not intended for pure entertainment purposes; they do not need to attract children to play more than once and especially outside the educational context of their use. We argue that the potential of tangible interfaces for supporting gaming is still unexplored.

The limited exploration of tangible interfaces for gaming might represent a missed opportunity from an entertainment perspective. As gaming moves out and away from the box (PC or TV) the opportunities offered by mixed reality and large-scale gaming areas are increasingly appreciated. KIDSROOM [2] was an early but forward-looking project at MIT that showed the potential of a room-sized game-area wherein children could move around and play. It represented a complex technology installation whose elements were tightly coupled to a specific game plot. The development of SCORPIODROME reported hereby paves the way towards a mixed reality infrastructure that can be shared between different games and in generalisable interaction design knowledge that can guide the development of games of the same ilk.

The initial idea for the SCORPIODROME arose during the design of pOwerball reported elsewhere [3]. The pOwerball game had a comparable mandate, namely to support handicapped and non-handicapped children to play. With the SCORPIODROME

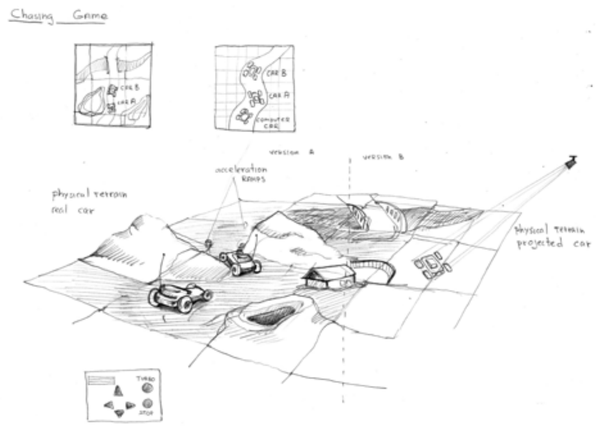

Figure 1. Illustration of one of the 6 game scenarios presented to experts. They were given also a text description and a list of relevant heuristics along which they could propose improvements.

we do not address the needs of handicapped children but, rather, we aimed at exploring the full range of capabilities offered by the interaction technology genre we are concerned with in terms of supporting a fun and engaging game.

Initially we set out to design a car-racing game for an interactive game table. We soon realized that racing with virtual cars on a table-surface adds little to traditional car racing in video games. Taking the best of virtual and physical worlds we set out to make a car driving game with remote controlled toy cars on a physical landscape, augmented with virtual game elements and various special effects. This concept is the foundation of the game we describe. The essence of the design activity, from that point on, has been to explore the strengths, weaknesses and opportunities offered by making different game elements virtual or physical. The exploration involved consulting literature, experts in the design of interactive products for children and of course, children participating in the study as informants [13] or testers. The design process involving tight loops of prototyping and testing was based on the RITE [9] method. As a result it is not easy to reflect the phasing of the design process in the structure of this paper. Rather, we first present the game concept and its evaluation. Then we describe the game in its final form and we present several lessons obtained by testing with children at various points intermediate points in the design process

2. GAME CONCEPT DESIGN

Fleshing out the game concept involves deciding upon the game mechanics (rules of the game) and the game elements involved. We were called to decide upon the right mix of fantasy, exploration, skill, etc., for the game that would make it fun for the children to play and to capitalize on the opportunities offered by the class of interaction technology we were investigating. For this purpose we consulted experts and organized a workshop with the participation of children.

2.1 Expert Consultation

A set of 6 game concepts was developed initially. They differed in the degree of competition, learning, and cooperation that they allowed. For example, in one concept the cars are used to explore a terrain and learn geographical facts. In another, users construct a landscape together. Scenarios were described with text and with sketches (see figure 1) and were presented in a leaflet that was given to a set of 5 experts in the design of interaction for children. Experts were prompted to suggest changes that would improve the game scenarios along several heuristics for designing fun in games. The heuristics were inspired from the work of Lepper and Malone [8] and Desurvire et al. [5] reflecting different aspects of fun in games: challenge, engagement, fantasy, curiosity, motivation and flow.

2.2 Concept Design Workshop

To explore the reaction of children to different game concepts, we organized a one-day workshop with children. The workshop was conducted in our LivingRoom lab; a typical usability laboratory setting furnished and decorated like a standard living room.

Three boys and one girl aged 10 to 12 participated. They were split to work in pairs. Children participants were given 3 games to play:

- **Racer.** A 2-player car racing game for standard personal computers was projected and played on the floor. The gamers were required to drive a virtual car over some beacons competing with each other to collect more points.
- **Landscaper.** This was a physical game with real obstacles and remotely controlled cars. Children cooperated to construct a landscape from elementary physical elements. They then had to drive the toy-cars over the landscape. The goal of the game was to drive over and around physical obstacles competing with opponents to win points.
- **Explorer.** This was yet another PC game projected on the floor, where players had to find 'diamonds', solve riddles and earn the diamonds if they answered correctly.

Racer, Explorer and Landscaper were designed and developed as early throwaway prototypes for the purposes of collecting feedback from the children during the workshop. The games were selected to provide a combination of competition, challenge, cooperation between players and construction supporting creativity and fantasy.

Workshop participants played each game for 35-45 minutes. An instructor facilitated the process and assisted children. Data was collected through observation behind one-way mirrors and the cameras installed in the laboratory.

The input from experts and children lead to the following conclusions that were later fed into the design of the SCOPRIODROME:

- Gaming in a group can be fun through allowing children to show creativity, especially in bypassing game-rules. This is particularly feasible and attractive because physical and virtual worlds are mixed. E.g., a player lagging behind can cheat and physically lift the vehicle over an obstacle. This affordance of the physical toy is very entertaining during group play.
- As hypothesized, the virtual part of the game can add value to the physical game (in this case remote control of physical cars) by inducing diversity and surprise. E.g., over and above driving a toy car, the game can offer numerous

Figure 2. (Left) The adapted Pistol controller with a GamePad input device wired at its base. (Right) Close up picture of the Scorpion cars showing the wires used for balancing, the cable for battery charging, the wire-antenna for remote control. On top of the vehicle is mounted a 'sonic disk' for tracking through the ISense 600 system.

difficulty levels, sound and graphical effects, variable elements of game-plot, etc.

- Technically the coordination of physical and virtual worlds must be 'seamless'. This can be supported in several ways: The physical landscape must be modeled computationally for supporting special effects and adapting the behavior of the virtual elements accordingly. Vehicles can interact with other virtual elements. The operation of the vehicles should go beyond driving, and include controls for shooting, having shields, etc., that are typical for video games.
- Children enjoy driving on a track that adds structure and challenge to the game. However, driving correctly a physical car on the track is too difficult. Typically, video games correct driver mistakes and provide a virtual 'groove' in which the car is driven. A compromise is to provide obstacles on a landscape and fixed target points that players can drive to, without having to stay on a physical track.
- To allow for both cooperation and competition, game play can be structured in two parts: a constructive part where children work together to construct the landscape for racing and a competitive high pace action component where they race their vehicles around this landscape.

3. THE SCORPIODROME GAME

The *SCORPIODROME* is an action game played by 3 players who each control one Scorpio. Each Scorpio battles its opponents in an unconventional off-road race. Scorpios are remote-controlled toy vehicles augmented with surround-sound, graphics, and animation effects. In our game they were built by modifying remote controlled toy-cars (see figure 2). The Scorpios fight each other and interact with the physical and virtual elements of the game. The main goals for players is to drive their Scorpio as fast as possible over virtual checkpoints that are scattered on the physical landscape, to collect virtual diamonds scattered on the terrain and to make the life of other Scorpios difficult. The game mechanics of the *SCORPIODROME* are described in detail in the following sections.

3.1 Controls

Players can drive their Scorpio by turning left or right and directing the car forwards or backwards. The steering control and the firing options are available on an off-the-shelf pistol-like controller. This controller was hard-wired at its base to a standard a GamePad control so that commands could be translated directly to input for the PC. (See figure 2). The controls have a 'Fire' button through which projectiles are fired. There is also an 'Exit' button that allows players to pause or stop the current game.

Figure 3: The physical part of the Active Landscape Grid is a hardboard grid on which cardboard tiles are fitted. Tiles can be flat or can have a relief upon them to provide a 3D morphology for the landscape.

3.2 Active Landscape Grid

The Active Landscape Grid (ALG) is a configuration of hardware and software components that support the SCORPIODROME game, but which also can serve for the deployment of a wide range of augmented reality games with physical remote controlled toy vehicles. The Active Landscape Grid, which is placed horizontally so that players can drive toy vehicles upon it. A computer that hosts the game software is responsible for coordinating the various parts of the ALG and the cars driven upon it.

The current prototype of ALG is a 3m x 2m board on which 48 tiles can be positioned on an 8x6 grid arrangement. These tiles can by just flat elements, or they can be adorned with landscape elements, like mountains, bridges, etc. (See figure 3). The topside of the tiles is sculptured with a 3D shape. Landscape elements are painted with a mat white paint, so that the computer graphics can be projected upon them.

3.3 Game Elements

The game elements of the SCORPIODROME are shown in figure 4. We describe them briefly below to give a flavor of the game.

3.3.1 Checkpoints

Checkpoints are small areas that Scorpios have to reach in order to gain points. A special type of checkpoint is the *base* that always stays visible. Scorpios are placed on the base before each game can be activated. The base is distinctive from the rest of the checkpoints and it serves also as a target for depositing diamonds.

3.3.2 Diamonds

Diamonds are virtual elements that appear at various points of the landscape. Depending on the scenario played, a diamond may be hidden until a Scorpio discovers it, or is visible throughout its existence. A Scorpio can pick up a diamond by moving close to it. This also applies to diamonds carried by other Scorpios.

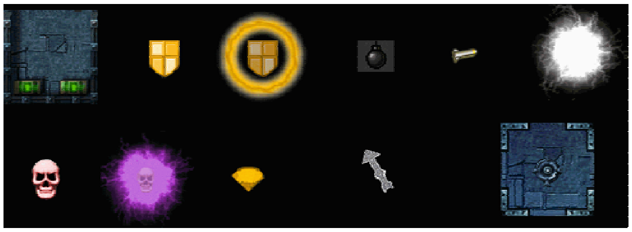

Figure 4. Graphical presentations of game elements. Above, in order from left to right: base, shield, activated shield, bomb, rocket, plasma-storm. Below: skull, activated skull, diamond, compass, and checkpoint

Scorpios have to carry the diamonds back to the starting-point in order for players to gain points. The number of points grows with the distance that the diamond had initially from the base.

3.3.3 Bombs and Missiles
Scorpios can pick up and use (virtual) bombs and missiles scattered on the landscape in order to dismantle other Scorpios. By default, all projectiles have a limited life span, after which they are either removed from the inventory, or activated automatically.

Bombs and missiles can be fired at the direction of Scorpions driven by other players (tracking their position). They may explode by hitting the other (physical) Scorpion, and physical or virtual obstacles. When hit by a bomb or a missile a Scorpion will malfunction temporarily.

3.3.4 Shields.
Shields are virtual elements scattered on the landscape. They are automatically activated when picked up. They protect the holder from the impact of the bombs, missiles, sculls and plasma-storms.

3.3.5 Plasma Storms
Scorpios may be attacked by a plasma-storm, or collide with a scull. A plasma-storm is an autonomous agent that appears and disappears at random intervals on the action space. The plasma-storm moves over the action space following a smooth curve and it changes its direction when it hits a mountain or the borders of the platform. When it nears a Scorpio, the plasma-storm takes control of the Scorpio and starts spinning. The effect of a plasma-storm stops after some seconds, or if the car hits another obstacle, e.g. a mountain.

3.3.6 Sculls
Periodically one ore more sculls appear on the action space. If a Scorpion moves by accident over a scull, the scull takes over control and starts driving the car on a zigzag curve for a short time.

3.4 Scenarios
Players are able to adjust the difficulty level of the game by altering the position and the number of physical obstacles on the platform terrain. Apart from this implicit mechanism for game leveling, the players can choose to play one of the scenario alternatives described below. In all these scenarios the overall goal is to gather as many points as possible. All scenarios last 3 minutes. After this time the score summary for every player is displayed and the game can recommence with another scenario or with reconfiguring the landscape.

3.4.1 Race through checkpoints
Given the landscape, the system creates inline a track of checkpoints through which the Scorpios have to race. The next checkpoint of the track that each Scorpio has to reach is highlighted until the Scorpio moves over the checkpoint. Whenever a Scorpio advances to the next checkpoint target, the Scorpio earns points. Each time a Scorpio gets points the system places some projectiles randomly on the action space.

3.4.2 Be the first to the checkpoints
In this scenario only one checkpoint is visible at a time. The first Scorpio that reaches the visible checkpoint brings in points, and then another checkpoint becomes visible. Every time a Scorpio gets points the system places some projectiles randomly on the action space.

3.4.3 Bringing diamonds to the base
In this scenario the Scorpios have to bring as many diamonds as possible back to the base. Initially one diamond is placed on a random block of the action space. The Scorpios have to go to the diamond, pick it up, and bring it back to the starting-point. When a Scorpio places the diamond on the starting-point, he gets some points, and another diamond is placed on the action space. The number of points that the Scorpio gets is proportional to the distance that the diamond had initially from the base. Once again, each time a Scorpio brings the diamond to the base the system places some projectiles randomly on the action space.

3.4.4 Stay alive
In this scenario the Scorpios get points by shooting each other. Whenever a player fires successfully a missile or a bomb over the Scorpio of her opponents she gets a number of points that reflects the damage (accuracy) of the hit. Accordingly, a player gets points when she defends her Scorpio with the shield. Finally when she suffers an accident her opponents get extra points. In this scenario, the system makes sure that there are a variety of projectiles over the action space at any give time.

4. IMPLEMENTATION
The implementation of SCORPIODROME factors out game specific elements, e.g., the vehicles, the game elements, the audiovisual effects, etc., from the generic mixed reality components. The latter constitute the Fun Augmented Reality Landscape (FARLAnd). FARLand, consists in the Vehicle Control and Acquisition Unit (VCAU) and the Active Landscape Grid described above.

The VCAU controls the movement of the toy-cars and tracks their position on the ALG. This unit can be seen as a pipeline from the user to the vehicle. In this pipeline the user provides input through USB game controllers (currently the customized pistol controllers shown in figure 2). Input is redirected to the application and modified as necessary, e.g., when special effects have to be applied. Then, the required commands are sent to the vehicles via a parallel port controller that is connected to the game-host computer. Currently, 3 radio transmitters operating at 35, 27, and 42 MHz are placed on this controller. A motion-tracking device tracks the position of the vehicles. For the current implementation this is the InterSense IS600 Mark-2 system. This consists in a cross bar of 4 receivers that is placed on top of the ALG which track up to eight small ultrasound transmitter discs which are mounted on the toy-cars. The IS600 system returns 3D

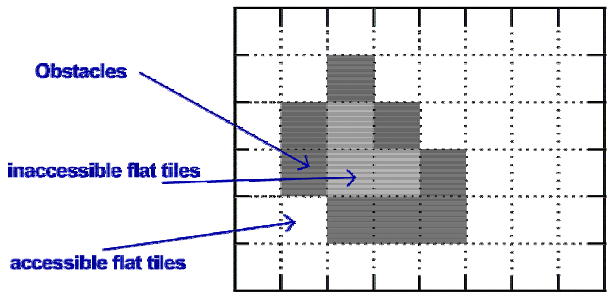

Figure 5: Example configuration with 8 obstacles.

coordinates of the cars; this input is redirected to the game application. Other motion capture alternatives can be implemented to support this SDK.

A Component Modeling (COM) Software Development Kit (SDK) abstracts the ALG on the game host computer, so that different game applications can build upon its functionality. The tiles making up the surface are represented in the computer as a Drawing Exchange File (DXF) format so that their exact shape is available to a game application in cases where it is necessary. For example, the model of the 3D shape helps to detect collisions, to avoid projecting text on uneven surfaces, etc. Typical game elements that compose a game (such as dialog interfaces, sprites, special effects, lighting, motion paths, sound buffers) are abstracted also in the SDK, to make the development of games an easier process.

A data projector pointing downwards placed at ceiling height on top of the ALG is used to project the visual virtual elements; a Hi-Fi audio system was used to amplify sound effects. The game was played with low ambient lighting to increase the impact of the graphics projected on the sculptured surface.

5. DETAILED DESIGN

Here we report some key design decisions for shaping the SCORPIODROME.

5.1 Optimizing the complexity of a landscape

The area where the cars are able to move fluently is constrained by the landscape. As one can observe in figure 5, The car

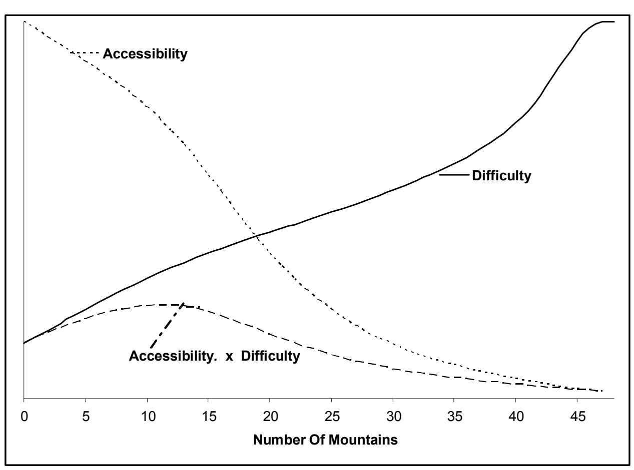

Figure 6. Combination of Accessibility and Difficulty.

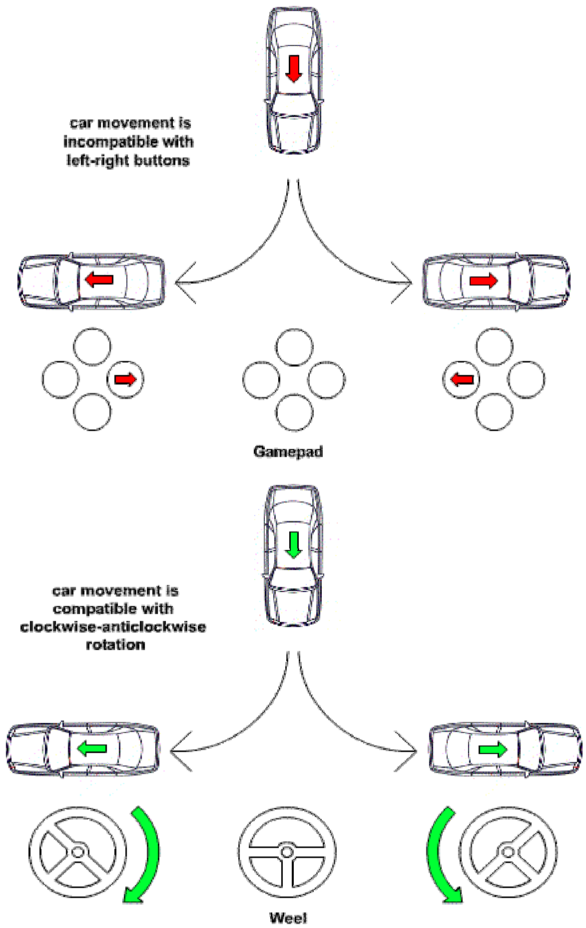

Figure 7. Controlling the car with a GamePad (top) featuring buttons for 4-directional movement and the steering wheel (below). The figure illustrates how game pad buttons can have the opposite than intended effect when the car drives towards the player.

accessible area is not proportional to the number of obstacles: the configuration of figure 5 has 37 out of 48 tiles accessible although only 8 obstacles are used.

The average accessible area for different numbers of obstacles was calculated with a Monte Carlo simulation making the approximation that obstacles are homogenously distributed. A good indication for the difficulty level of a certain landscape configuration is the average number of obstacles (including the platform boundaries) that are neighbors of accessible tiles. For example, the difficulty level for the configuration of figure 5 is 1.16. Once again the average difficulty level for different numbers of obstacles was calculated with Monte Carlo simulation. Taking in account that a good combination of difficulty and accessibility is required we decided that about 11 obstacles is a reasonable number of obstacles to provide to the players.

5.2 Choosing between input devices

Following the RITE method [9], a series of mini-evaluation sessions were held in the KidsLab where a functional prototype of the game was set up. The KidsLab is a special purpose usability laboratory for testing applications with children. 12 children aged

8-12 from the Regional International School in Eindhoven participated in these sessions. In each session, a group of 4 children took part.

The children were instructed to carry out several tasks with two different controllers: a pistol-like controller (which was the one eventually adapted as in figure 2) and standard game-pad control for PC games. Tasks included repeatedly driving from one point on the landscape to another and navigating through the on-screen dialogs that were projected on the landscape. The game scenarios were played to identify problems in the game mechanics and the game interface.

Even though the general game-pad was more familiar to the children, after experiencing the pistol-controller all participants preferred the latter. Figure 7 shows the situation where the car driving on a horizontal surface (around which the children players are positioned). When the car moves towards the player its direction is incompatible with the buttons of the game-pad. During this test, the maneuverability of cars was shown to be problematic: cars made sharp turns at high speed, sometimes rolling over. Players found it hard to tell the front from the back of a car during the game. Also, checkpoints were not always noticed. Players requested the display of feedback on their score so that they could compare with opponents throughout the game.

Based on the participant's suggestions and aforementioned study it was decided to continue with the pistol-controller, which was customized in the manner shown in figure 2. Henceforth, a short explanation of the controller would be given at the beginning of the game in the form of an instructional poster showing how to hold it and the function of the buttons. Finally the unused buttons of the pistol-controller were removed.

The speed of the cars was diminished by software terms to increase the maneuverability of the car. "Legs" made out of colored wires were added to both sides of the cars to make them more stable. (See Figure 2).

The toy cars were equipped with a tail and a 'head' to distinguish front from rear. The colors of the Scorpios were made compatible to the corresponding base and checkpoint colors.

Figure 8: Children building the landscape they wish to drive their cars on.

5.3 Dialogue Management

Having made several modifications on the basis of the first test session, a second group of 4 children participated in testing the improved game. Players were asked to perform a similar set of tasks, this time only with the pistol controller and to spend more time playing the game. Modifications concerned mostly the sprites used and the feedback offered to users

Players experimented with a dialogue management system for supporting players. This had 3 settings:

- Random selection. By sampling all controllers every 100 ms, this setting gives equal power to all players for controlling the game.
- Common Agreement. The dialogue management system samples controllers every 100 ms, looking for unanimous agreement in the choices made. The common input is then used to control the dialogue.
- Master Controller. One of the input devices and by consequence one player is treated as the Master that controls the dialogue.

The Master controller option was selected as it reflected best the players' expectations and did not appear to give rise to disputes among players.

5.4 Delineating game boundaries

After effecting the change recommendations from the 2nd evaluation session, the final group of 4 children tested the revised version of the game. From this final evaluation it was clear that children could not differentiate different scenarios.

The final changes were to differentiate screen design for different scenarios, give them memorable names, and implement a graceful ending for the game with titles, music and final score.

Apart from rather trivial problems identified in this stage, we discovered that children wished to change the configuration of the tiles while playing the game. This is a desirable option that is though not supported by our current implementation.

6. EVALUATION

Having effected improvements through the iterative cycles described above, we carried out a more extensive evaluation in order to evaluate some critical aspects of our game, trying to elicit requirements for this class of games and interaction technology.

6.1 Set-Up of the Evaluation

12 pupils (9 boys and 3 girls) aged 8 to 12 from the Regional International School in Eindhoven participated in this evaluation. They came to the KidsLab in 4 groups of 3, escorted by their teacher. Children were shown around the usability laboratory where they were shown the cameras, the microphones and the observation room behind the one-way mirrors.

Children were asked to play the SCORPIODROME for a period of approximately 40 minutes. Researchers would observe the children from behind one-way mirrors controlling also the 3 cameras placed in the room for taping the session for subsequent analysis. One researcher stayed in the room acting as a facilitator.

Game play was evaluated according to the three dimensions of fun described by Read et al [11]: Expectations, Engagement and Enducaribility.

Figure 9: Children driving the Scorpios.

The dimension of *Expectations*, compares the fun children report that they expect prior to playing the game, to what they report after they have played it. Children rated expected and experienced fun using the Smileyometer [11]. This is a 5 point Likert scale where different points in the scale are associated with a face icon (ranging from sad to smiley) coupled with words; the words used in the scale were: Awful-not very good-good-really good-brilliant.

Before playing the game, testers were given a small description of the game on a sheet that was also read aloud by the experimenter. After making sure that everybody understood the description, all participants were given a Smileyometer and asked to tick one face that corresponded with their expectation of the game; how much fun the game they thought would be? After playing the game, participants had to tick how much fun the game really was on another scale.

Engagement was assessed through observation and through a review of the video records of the session. We were looking for signs of animation, expressions of joy, excitable bouncing, concentration, etc.

There are two facets to *Endurability*. The first is *Remembrance*; our likelihood to remember things that we have enjoyed. The other is *Returnance*; the desire to do again an activity that has been fun [11]. After playing the game (1st measurement) participants were given a sheet of paper with the prompt "What did you like the most about the game?". One month later (2nd measurement) the same participants were given a sheet of paper with the same prompt? The difference between these two lists was used as a measure for remembrance.

At the end of the game all participants were asked if they wanted to play the game again.

6.2 Results

The evaluation sessions were very much a success. Children were vocal, expressive, excited, at ease with the laboratory environment and the researchers. They were very thankful for their participation in the evaluation. Indicative is that when asked later on, what they wished as an appreciation present, they requested the instructions poster for the SCORPIODROME. Children learned to play the game with ease just by being shown the instructions poster; they enjoyed themselves, cooperated in shaping the landscape and enjoyed the competition afterwards.

Creating the landscape was an enjoyable component of the game play and all teams experimented with different layouts. In the building phase of the game, children were in constant interaction with each other. The routine consisted in negotiating how they were going to alter the landscape in terms of a scenario they wanted to play out, discussing how the ultimate shape of the landscape should be and, finally, building that landscape.

In a few groups one child took the leading role in coordinating the construction of the landscape. However, for most groups, players participated equally having equal say. In all 12 cases, all the children participated in the whole process; only in one case a player abstained temporarily when he saw the others were having a different plan than him.

One team concentrated all 11 mountains they had at their disposal at one part of the platform, making it unreachable. After the game proved too difficult they placed mountains in a square enclosing unreachable flat tiles. Another team formed the letter 'F' with mountains (this team baptized our platform as FARLand). At some intermediate stage of the session every team tried out (unprompted) a completely flat configuration with no mountains before deciding that was too boring; then they gradually added back difficulty, e.g., 3-4 mountains and then some more till the right level of challenge for them was reached.

One test participant was a true 'gamer'; he proved to be much more skilled than his peers in driving the car. One of his playmates gave up trying to beat him by the rules and started to move the car physically from base to base. The children enjoyed the session, though the 'gamer' child still won the game.

In general we saw the children having a good time, cheering in joy when they would win a game, making exclamations, e.g., "I got you", "In your face", "Cool Music", etc. When they got a missile they tried to threaten or to impress their opponents ("Yes! I got a bomb! …Bye, Bye!").

They often showed signs of engagement leaning towards the platform when the competition was tight. In one occasion a child was so absorbed in the game that he leaned forwards increasingly till he fell over the platform. Mistakes were commented, such as when the cars got stuck on a mountain, or when the driver had problems to reach the checkpoints because he didn't drive the car well. In a situation where the two Scorpions got tangled up (due to their tails), the children enjoyed trying to fix the unexpected problem through maneuvers rather than physically.

The results regarding expectations were quite encouraging. All of the participants, given the description of the game during the instructions, predicted that it would be very fun to play. After experiencing the game, their high expectations were met in all cases. Additionally, three of them reported that the game exceeded even their (anyhow high) expectations.

All participants remembered almost as many aspects of the game just after the game as one month later of the game; this indicates a very high Remembrance.

Returnance was maximum, with all children expressing unprompted their wish to play the game again after the session.

Indeed, the only way to stop them was to stop the computer and switch on the room lights.

Although it was clear from the evaluation that all the children really liked the game, there were individual differences in how they reacted to the game. Not all children expressed their enthusiasm in the same way. Some were very quiet but very focused displaying a high degree of immersion in the game. Others were very expressive, constantly sharing their experiences with their fellow players and often displaying vocal signs of engagement.

There was also a difference in appreciation of the game between boy and girl players. Some of the girls stated that they preferred to watch rather than to play the game; this probably relates to the battle-like form of the contest, which is clearly more appealing to boys.

7. NOTES ON METHODOLOGY

From a methodological viewpoint we have experienced some successes and some difficulties. The main success was the involvement of children. The tight iteration advocated by the RITE method [9] together with the involvement of children as informants [13], showed to be a very effective and efficient way of converging towards a design that would not suffer from usability problems and would be fun for the children to play. Children were especially valuable informants during the workshops where they tested early prototypes. Because of their slightly long duration (2-3 hrs), children got to learn what kind of input the team expected to get from them. When they had moved beyond the initial excitement of visiting our laboratories and playing with the technology they were able to provide very concrete advice to the team regarding their wishes and preferences.

On the contrary the testing sessions conducted at the end of the project for evaluative purposes were not as informative as anticipated originally. On the one hand, we managed to verify the success of our design effort when we witnessed the level of enjoyment for the child-testers. On the other hand, children seemed to be excited and enthusiastic about their experience from the moment they entered the laboratory. Their enthusiasm could have made them overlook deficiencies of the design and make concrete suggestions for its improvement. Our own conclusion is that the difference of the two sessions had to do with the setup of the final evaluation that was more structured rather than open and informal and more geared towards evaluative instead of formative purposes. Another important factor was the duration of the involvement of children. We believe that at least for entertainment applications for children a longer-term participation in the evaluation is more productive in terms of inventorising and prioritizing changes for the next version of a game. This contrasts methodological advice offered by Hanna et al [7], who suggested to keep testing sessions quite short.

8. DISCUSSION

With the design of SCORPIODROME reported here, we have created a mixed reality game that was shown through an extensive empirical evaluation to be very enjoyable to play.

In our evaluations, children played as a group, talking to each other, cooperating to customize their game and enjoying mixed reality as a medium for the delivery of the game. There are several factors to this success. We believe that an important component is achieving the right balance between cooperation and competition that made the social interactions around the game very pleasurable. Another important component was the nature of the interactive mixed reality platform. Children could stand and move around the game, handle physically game elements at the same time enjoying the special effects, the pace and the plot that are made possible through the system.

The game we developed provides a large-scale (sub-room size) physical platform around and over which children can move during the play. It bridges virtual and physical worlds in several ways:

- Physical objects are tracked by the computer and provide input (as is traditionally the case with augmented reality).
- Virtual game elements, like missiles, bombs, etc., interact with physical elements, e.g., mountains or cars. For example, missiles will track a car, explode at contact with a car or a mountain, etc.
- Physical game elements react to the presence and neighborhood of virtual game elements, e.g., the remote controlled car will skid over the virtual plasma storm.

Linking physical and virtual game elements in this way, plus the large scale and immersive nature of the display create a grasping interactive experience. Nevertheless, we think, that the start we have made is still modest and we plan to scale up the scale of the game and the display even further.

The FARLand platform is reusable so it can provide the basis of a whole host of games following the idiom demonstrated with the SCORPIODROME and capitalizing on the functionality offered by the ALG and the VCAU. This gaming idiom can be outlined as follows:

- Alteration between cooperative construction and puzzle solving followed by or interleaved with competitive high pace action gaming.
- A shared horizontal display around which children can move helps bring players together and breaks down the isolation typical for playing with traditional input/output devices [14].
- During the construction, players create a landscape / context for the action component of the game. The level of challenge is set indirectly by the structure of the constructed landscape.
- A rich interaction experience is enabled by interactions of virtual and physical elements of the game.
- The game alternates between cooperation and competition.

The gaming idiom outlined, goes beyond tangible augmented reality that has been explored in the context of educational applications, like Ely [1] and Snark [10]. We believe that the idiom outlined has a large potential to be explored in the context of gaming applications specifically those aiming to support social interactions between players. The support for social interactions can be enhanced further as in [3] by favoring cooperation tactics between the players during the action component of the game.

9. ACKNOWLEDGEMENTS

We thank the children of the Regional International School in Eindhoven for participating in our study; the following are thanked for their support: Wolmet Barendregt, Mathilde Bekker, Don Bouwhuis, Martin Bosman, Sasja Geerlings, Wen Xu, Bas Brederode.

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