pOwerball: The design of a novel mixed-reality game for children with mixed abilities

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ABSTRACT

This paper presents the design of pOwerball, a novel augmented reality computer game for children aged 8-14. The pOwerball was designed to bring together children with and without a physical or learning disability and to encourage social interactions surrounding the play. The contribution of this design case is two fold. From a design perspective, pOwerball exemplifies an emerging class of computer games where the interaction style and game mechanics support social interactions amongst the players. From a methodological perspective, we describe the various ways children became involved in our design process; we highlight the related difficulties and successes in the context of relevant research literature.

Keywords

Social Gaming, GameDesign, Augmented Reality.

INTRODUCTION

This paper describes the design of a mixed reality computer game that aims to bring together children aged 8-14, with and without a handicap, to play together and to have social contact with each other.

This design effort had two main starting points: one was motivated by research into augmented reality and tangible user interfaces as interaction technologies for children. The second was collaboration with the foundation "Stichting Bio-Kinderrevalidatie" (Foundation for the rehabilitation of children) that will be mentioned as Bio in the remainder of this paper. Bio cooperated with us in order to obtain interactive installations suitable for children with a disability boarding in their premises and mixed groups of children, with and without a handicap, that spend some holidays in the Bio campus.

The structure of this paper follows the phasing of the design. We describe the context of the project, research in user needs, the game concept as it developed iteratively, the implementation and evaluation of a functional prototype. In the final section we reflect upon the methodological issues encountered during this project and discuss how pOwerball is representative of an emerging class of games offering the potential to encourage and support social interaction amongst players.

CONTEXT OF THE PROJECT

This project is part of a research program into interaction design for children. The objective in this case was to explore games that bridge the physical and the virtual worlds. Compared to the range of offerings on the market, there are only a handful of toys that fill this niche. Notable examples are Lego MINDSTORMS (see (http://www.legomindstorms.com) and CyberK'NEX (see http://cyber.knex.com). Such games are justifiably the focus of researchers who have produced a range of experimental game concepts. Two compelling examples of such research prototypes, are 'The Hunting of the Snark', that supported playful learning by groups of children in a room, and the 'Augmented Woods' that achieved a similar purpose but at a much wider geographic area (a forest instead of a room), see [6]. Other examples are the POGO [3] that aimed to help children develop narrative skills and Ely the Explorer [1] that was also designed with the aim of fostering social interactions between children through play.

Starting from our prior experience with tangible table-top augmented reality (applications that involve a tangible user interface for manipulating interactive elements displayed/projected on a table surface), we wanted to explore what opportunities may arise from this interaction technology, with respect to computer games for children. Our emphasis on technology and on creating educational value was less prominent than in the projects mentioned above. The foremost concern throughout the design process was to create a game for the children boarding at Bio, to which they would return time and again to play, be entertained and become engaged.

Bio is an organization that offers education, care, residence, schooling and revalidation for young people aged 0 to 27. Bio develops therapies and treatments for handicapped people. At the premises of Bio, a multi-media cafe is being constructed, where Bio wants to install recreational multi-media applications. Their plan is to share this facility with the neighboring Mytylschool Mariendael. Mytylschool is a special school for children up to 14 years of age. Bio operates a small holiday centre for the families of children with a physical disability. They wanted to create activities, e.g., for a bad weather day, through which children with and without a handicap, who do not know each other before the holiday, can obtain more social contact. Finally, two more schools participated in the study:

- The Mytylschool Eindhoven: a special primary and secondary school for physically disabled children.
- Basisschool "De Boog": a mainstream primary school situated in Eindhoven.

Preliminary inquiry

Interviews were conducted with employees of Bio, teachers at the Mytylschool Mariendael and members of the cultural centre of the Mytylschool. It became clear that children in the vacation school at the Bio premises and at the Mytylschool needed an application to encourage group play. For children with a handicap it is difficult to spontaneously join in play with children that do not have a handicap. In numerous earlier projects with Bio the following causes have been repeatedly encountered: First, other children do not accept them in their play because of their handicap. Second, their handicap does not enable them to participate in common activities.

While they often enjoy playing games with each other over the computer network, they do not obtain social contact. This effect has been noted before with more homogeneous groups of children, and it has been attributed to the nature of input devices that support individual use [9]. A tabletop tangible augmented reality could potentially encourage social contact between these children. After this preliminary inquiry, it was decided that the design aims should be to:

- Enable joint play by children with and without a handicap.
- Extend the attractions of the multi-media cafe for Bio and Mytylschool.

During these discussions the targeted user group was refined. It became clear that children at Bio are competent personal computer users by the age of 8. As they leave the school at the age of 14, we decided to design the game primarily addressing 8-14 year old children with physical handicap and learning difficulties. This group compares in developmental terms with children aged 8-12.

GETTING TO UNDERSTAND THE TARGETTED GROUP OF CHILDREN

The first author spent several days at the Bio premises conducting contextual interviews and observations. For example, this meant sitting in classes, observing play in the playground, the multi-media room or inside the school.

It quickly became clear that it would be unwise to construct a stereotyped profile of the 'handicapped' child. There are as many variations of handicaps within the school as there are different characters of the children. The physical limitations go hand in hand with some cognitive limitations, often limiting social development, but are not an unequivocal description of the child's needs. For example, Max (group 8) is quadriplegic and sits on a wheelchair. He lags very little behind in development when compared to children at the mainstream schools. Because of his handicap his spatial perception is comparable to that of a 4 to 5 year old with normal development. This means that Max faces problems with arithmetic, drawing, building blocks, etc., everything that relates to spatial relations. On the contrary, Maartje has the same age and handicap but manages well with these topics at school. While Max is social and plays with his friends at the playground (e.g., other children help him climb on a trampoline), Maartje is more withdrawn, stays home with her mother and prefers to read books.

The inquiry into the children's needs involved:

- Contextual interviews with children.
- Naturalistic Observations of group play.

Interviews

In total, 31 children were interviewed in 3 different schools. 16 more children provided written answers to a questionnaire. In all cases, questions were open to allow children to answer what was important to them. The interviews were conducted in a part of a hallway, or a small room next to the classroom, or even outdoors. The interviewer tried to help children relax, e.g., by leaving them room to exchange stories about favorite games or programs. For the questionnaires, the researcher provided help and explanations and was assisted by the teachers in doing so.

A wealth of information was obtained from this survey. Equally important, it became possible for the designer to acquire some empathy with the group and gain an appreciation of what appeals to them. Jokingly, we called this the "cool factor" in later stages of the project to indicate conformance to current tastes and pleasure needs of children (see [7]).

The most fundamental and compelling outcome of this study was that the likes and dislikes of our targeted group are not dissimilar to other children. For them to like the product it has to be attractive for other children too but possible for them to play.

The interviews showed that the children enjoy playing in a group. The children indicated the following order of preference: Computer games, Board Games and Creative Activities (drawing, handcrafts, etc.).

Children with a handicap seem to play more than other children with computer games. This is very likely because they divert their time and effort from other activities in which they are limited by their handicap, e.g., in physical games or sports. Another attraction could be that computer games provide them a fantasy world in which their handicaps vanish, e.g., a child with muscular dystrophy mentioned that he enjoys the "FIFA World Cup" computer game, because he can so play football, something he cannot do in actuality.

Their choice of computer games seems to match that of other children, but they also play games intended for younger children because they are easier to play. Their favorite games are Rollercoaster Tycoon, and GTA Vice City. Rollercoaster Tycoon (see www.atari.com/rollercoastertycoon) requires relatively limited motor skills, but provides varying levels of challenge; this seems to be a good approach for designing a game appropriate for a target user group with mixed abilities. GTA Vice City (see http://www.rockstargames.com/vicecity), on the contrary, is quite demanding: it requires simultaneous use of keyboard and mouse in a 3D environment, something that is generally difficult for children with a physical limitation. The children at Mytylschool are relatively good keyboard users, as the keyboard requires less motor skills than, say, a mouse or a trackball.

Observations

The interviews focused on what aspects of computer gaming each child likes; we sought insight into how these children play in groups and what makes group-play with a computer game enjoyable. Observations were made of group play of children with a handicap to find out more about their conduct, their choice of activity within a group and whether their abilities and choices confirm those that they reported during the interviews.

The observation involved children from 4 classes from the Mytylschool Eindhoven. These were:

- Children aged 8-9 with learning difficulties.
- Children aged 8-9 without learning difficulties.
- Children aged 13-14 with learning difficulties.
- Children aged 13-14 without learning difficulties.

Each of these classes played 5 different games:

- Dynamite: a relatively easy computer game.
- Rayman Multiplayer: a difficult computer game.
- Ludo: an easy board game.
- Monopoly: a difficult board game.
- Drawing together – a specific assignment was given.

By varying the constitution of the group, the complexity and type of the activity we aimed to gain some understanding of the difficulties confronting children at a physical and cognitive level. Also, we aimed to gain some insight into how the difficulties they encountered would influence the social interaction between the children.

In total 20 observation sessions were held, each lasting 40 minutes. A session started with a preparation session, followed by the actual play and ending with an interview. The experimenter kept notes throughout and wrote a small summary after each session. The observer was not completely passive; in a few instances he probed with questions, helped the children out of difficulties with the games and even played with the children a few games.

To play board games children would sit around a table or around the folding table of a wheelchair, in the cases that one of the players would be using one. The camera was positioned to capture the upper body of the players. Where the children played with a computer game we recorded the hand activities as well as the on-screen activity by mixing video signals.

During the ending interview children were asked about the difficulty of the games and to rank different game aspects in order of preference. The game aspects presented to the children were: competition, cooperation, talking about the game, had been identified during the interview study.

Observation sessions were taped and analyzed qualitatively. The analysis of these sessions aimed to answer the following questions:

- What makes a game fun?
- What stimulates playing together?
- What should a designer take into account when designing for children with a physical limitation?

Children found computer games more fun than board games and creative activities. They can concentrate longer on them and get very engaged. They choose easier, slower pace games to relax and to be able to talk about them during play. For example, one child said: "…shall we play without the "fire-monsters"? That's more relaxed." Also, Ludo that was considered an easy game was nevertheless considered fun; next to providing competition and exciting moments its low difficulty and lower pace allows for socializing to take place around the game. Analysis of the video showed that there seemed to be more cooperation and interaction amongst the children when they played against each other rather than against the computer opponent.

Children with a physical limitation will sometimes prefer to be 'lazy' with the physical challenge of a game. For example, during these sessions a girl asked to play with the keyboard rather than the mouse saying she could not use both hands. Later on she used both hands very effectively for another game. Children sought or offered help to each other to get around the limitations posed by a physical disability.

From this investigation we concluded that the following design goals are essential

A. Equalizing Effect and Competition. The game should be designed to have an equalizing effect, i.e., allowing children with some disability to compete on equal ground with other children as happens now with computer network games operated through keyboards. As competition is an important motivating factor in the game, but also one that encourages social interactions, it is ideal that players should feel empowered to compete.

B. Participation and Dialogue. The game should be crafted to draw in all players in the game, requiring team effort, rather than let individuals withdraw and stand by. Shared goals are a good way to encourage social interaction amongst players.

C. Fun. This can be achieved by having a simple clear goal, excitement, and alteration between constructive and competitive elements of the game. Variation, trying out new things and discovery can make the game more fun.

D. The 'cool' factor. Graphics, sounds and the game elements should be in line with current trends in gaming and tastes of the children. Also, children must get the feeling that the interaction with the game is tuned to their capacities and understanding. The children should be able to play without the guidance of a supervisor.

THE POWERBALL GAME CONCEPT

Out of several preliminary design concepts the pOwerball concept was selected for further development.

pOwerball is a tabletop tangible augmented reality flipper game for 2-4 players sitting around a table. The graphics of the game are projected on the table surface (see figure 1). Graphics and animations are associated with virtual artifacts but also with each physical element involved in the game.

The main goal of the game is for all players together to cooperatively liberate imprisoned creatures. Some creatures are situated in hard-to-reach areas of the playing field. This brings a puzzle element into the game; e.g., a creature is imprisoned at the top of a mountain. For each puzzle there is a difficult solution, involving the playing field elements (trampoline, accelerators, reflectors), e.g., playing the ball over the trampoline to make it bounce. There is also an easy one using the creatures sometimes offered to the player, e.g., liberating a 'bounce' creature that swallows the ball and makes it a bouncing ball for a limited amount of time. The combination of a skill-based and a chance-based version of the same function is part of the equalizing effect (addressing design goal A) that was set as a goal for the game design.

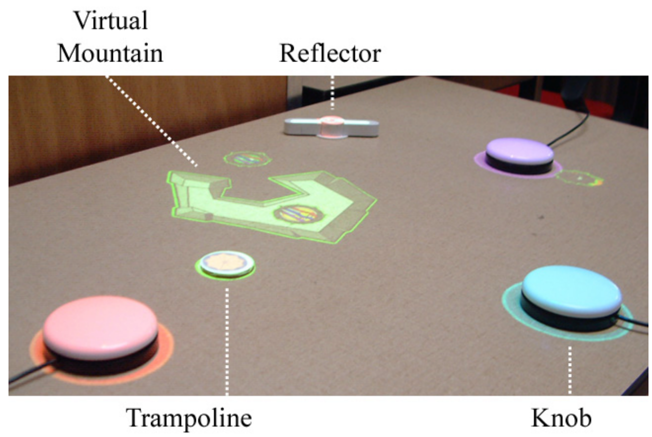

Figure 1. Close-up view of the pOwerball game table. The appearance of its elements results from their physical form and the graphics projected upon them. The tangible Reflector is at the top of the image. A virtual mountain with an enclosed pOwercreature is shown in the middle. The small circular tangible component is the Trampoline. The 3 large buttons are augmented with graphics and animations projected upon them.

The players can interactively modify playing field elements that alter the trajectory of the ball, even while the game is played. They do this by moving tangible objects that act as 'handles' for virtual obstacles and assistive elements. For example, a tangible trampoline element bounces the (virtual) ball so it can reach the creature on the top of the (virtual) mountain projected in the middle of the table.

There can be several balls at play depending on the stage of the game. The players have to collect colors on the ball using the knobs in order to break the colored prison bars in the cage. When all bars are gone, the cage breaks and the creatures are free. Collecting the right colors requires cooperative action (design goal B), e.g., passing the ball to the player who has the right color for freeing the creature.

The secondary, competitive (design goal A) objective is to collect the most creatures on special spots around the pushbuttons or on tangible tokens. The player with the most creatures at the end of the game gets an award. Children are able to steal creatures from each other. Apart from liberating the creatures, players can earn 'style applauds'. The style applauds were a later addition to the game, meant to award (design goal A) more skilled players and encourage children to build challenging and varied tracks (design goal C) with the play-field elements.

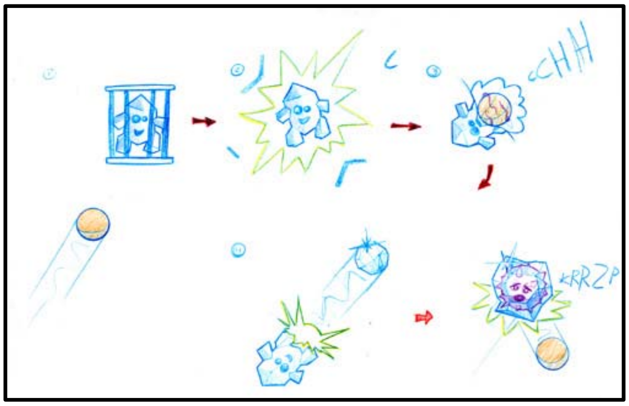

Figure 2. Storyboard of the game used during the concept evaluation phase. The top part shows the ball hitting the cage and liberating a creature. The bottom part shows the creature turn the ball into ice before temporarily encapsulating the computer opponent inside an ice-shell.

Players shoot the ball by hitting large circular physical buttons, positioned on the gaming surface in front of them (see figure 1). These buttons are augmented with projected graphical and animation effects, projected upon and around them: When the player hits a knob its graphics expand outwards in all directions shooting the ball. Balls in the vicinity of a button gravitate to it, and revolve around it, allowing the player to shoot at all directions using only one finger. Altogether, the button makes pOwerball accessible to a large group of children with very different physical disabilities (design goal A).

GAME CONCEPT EVALUATION

An informal evaluation of the game concept was conducted to check whether children understand the game and to get feedback regarding its individual elements. 6 children participated in the concept evaluation that had also participated in the earlier observation studies. They were taken out of the both lower classes (with and without learning difficulties) and the most cognitively advanced children from the last class in our range.

Children were given a storyboard describing parts of the game (see figure 2). They were asked to comment upon the game elements presented to them by answering some set questions. They were then asked to solve some problems following the game rules and using some paper mock-ups of game elements. For example, they were asked to find how to reach a creature with the ball at the top of a mountain with minimal effort.

Children were able to comment both on game mechanics and on game plot. For example, a couple of their remarks were that:

- Players should be able to shoot the ball with varying force (harder or softer).

Figure 3. The set-up in the development environment, with the mount for the projector and the tabletop user interface. The graphics displayed in the programmer's monitor to the right are projected on the table to the left for the players.

- There should not be too many playing field elements on the table – at most 2 of each kind (accelerators, trampolines and reflectors) at a time.
- There should be an element of competition in the game.

The problem solving was only possible for the eldest and cognitively most advanced of our users; as a result it was decided to make the game mechanics simpler. Clearly we could not be confident that the result of problem solving on paper would correspond to the actual difficulties of planning their actions during the game; checking whether the game provides the right level of challenge is something that needed to be further tested on a working prototype.

Following up on the children's remark on competition, it was decided to add a computer opponent to the game, to make it more challenging. The players win the game if all pOwercreatures are liberated and they lose the game if the opponent has caught all the balls. In this way, competition

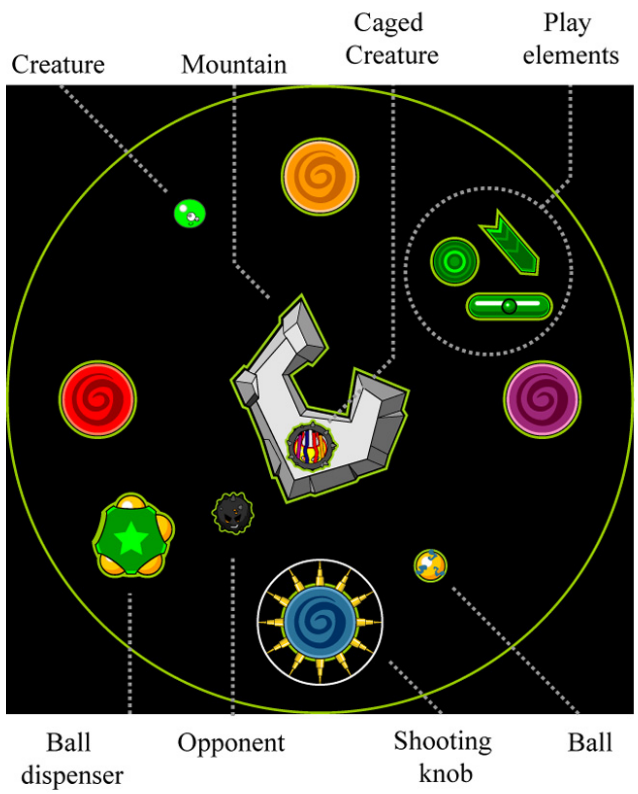

Figure 4. Graphical design of the pOwerball interactive elements. The background is always black. When projected, the users see the table surface as the actual background; the other graphics are projected upon white objects, (buttons and cardboard cut-outs).

does not interfere with the design goal to let the children make a team effort and to stimulate group interactions.

DETAILED DESIGN AND IMPLEMENTATION

The game concept was adapted to the feedback from the children. Initially, a minimal working prototype of pOwerball was created that supported only those elements that were necessary to let children experience the essence of the game. Since then, this prototype has been extended by Bio to support a more extensive version of the game.

The prototype consisted in the following physical artifacts: A table, a data projector, a set of 3 large physical buttons, 2 tangible user interface components cut out of cardboard and a PC and the virtual elements of the game (mountain, opponents, etc.). The data projector was mounted on a purpose-made mount that eases the logistics of installing the projector at different locations (see figure 3). Clearly, this is but a functional prototype, whose form and aesthetics need to be redesigned for an eventual deployment. The data projector is directed downwards and is used to display computer output on a table, which becomes the gaming surface. The particular projector used had a modest resolution of 1024x768. The three large physical buttons have a diameter of 4 cm and are activated with a light-pressure (100-200gr). Most children of the Mytylschool are able to use such buttons. The buttons are connected through a switch to the serial port of a PC. The tangible interface components are shown in figure 1. They are the "trampoline" and the "Reflector", shown in figure 1.

The game was programmed in Macromedia Flash MX running on a PC. The following game elements were implemented:

- A pOwerball: it bounces, gets hit and takes the color of players who hit it.
- Tow play elements which are the virtual counterparts for the tangible components. The trampoline makes the ball jump and the Reflector reflects it and increases it's speed.
- Two pOwerbeasts were implemented: the Bouncing Beast and the Fire beast.
- A virtual mountain element.

A clear graphics style was chosen for the elements of the game with high contrasts. This is in accordance to the trends in the computer games the children play but is also suitable for a projected display. The background of the game is black to maximize contrast (see figure 4); in reality the users see it as the color of the surface that the computer display is projected upon (see figures 1 and 5).

EVALUATION

The prototype was installed in the Mytylschool Eindhoven. The evaluation had a summative goal, i.e. to ascertain the extent to which the design goals set out at the outset of the project had been met. It also had a formative role, aiming to prioritize improvements and fixes to the game design and implementation.

9 boys and 9 girls were recruited with the help of teachers of the Mytylschool Eindhoven. Children were split into

Figure 5. Snapshot of children playing the pOwerball during an evaluation session.

groups of 3; 5 groups were mixed and one consisted of girls only. 4 out of the 6 groups were from children in the age group (10-12) and 2 were from the youngest children at Mytylschool (8-10). Each group played one session lasting approximately 40 minutes.

Sessions started with a preparation phase followed by free-play part (15 minutes) and structured play where they were given 3 tasks. The evaluation tasks were game goals (e.g., 'shoot at the cage via the trampoline and the 'Reflector'), so that the role of the child as an evaluator would not compete with playing [2]. Finally, a semi-structured interview was conducted to obtain feedback for the game.

The experimenter acted as an observer looking for signs connected to the design goals for the game: equalizing effect and competition, participation and dialogue, fun, and the 'cool' factor. An indication that the game was designed to have the right level of challenge and competition would be the degree to which children would request his help during the game-play. After each session a short group interview was conducted.

From this evaluation, we concluded that:

- All children were able to play the game from both a cognitive and physical perspective. Only two of the children (who had a serious muscular illness) and a girl with quadriplegia did not take part in moving the tangible components, although this was within their abilities (design goal A).
- The game stimulated social interactions and cooperation, during the constructive phase of a game and especially through tactics requiring joint action (design goal B).
- The design of the interactive elements succeeded in putting the participating players at an equal footing (design goal A).
- Children wished for more competition to be injected in the game (design goal C).
- Children liked to experiment with different tactics and different game configurations; they saw an extra challenge in this (design goal C).
- Though the technology was new for the children, they had no difficulty in understanding it (design goal D). Some aspects of the technology contributed to the fun unexpectedly, for instance projected pOwercreatures appeared to be "walking over" a child's hand thanks to the projection used.

NOTES ON METHODOLOGY

From a methodological perspective, we have found the involvement of children a critical factor to the success of the project. Throughout the project the children of the collaborating schools became very much at ease with the first author and vice versa. It was clear by the end of the project that he had become much more attuned what would appeal to the children than the other co-authors.

There is a considerable gap between children and designers and this is even larger considering children with a handicap boarding in an institute. To bridge this gap a large involvement of children in design was desirable, but may not always be feasible. A participatory design process where children would be seen as design partners, an approach advocated by Druin [4], was not possible in the short time span of the project (initially we aimed for 9 months, though it took 13 eventually) and because it would have been very demanding from the children in terms of time, discipline and effort. So while children were not treated as full partners in the design process, we found that their involvement in the project for longer periods of time is critical for gaining good understanding of their likes, preferences and need.

Informant-based [8] design was used as it enables good information to be drawn from the analysis, empathy to be created with the children while at the same time it does not put the children under stress. The mixed group of children, with the support of their teachers, turned out to be very valuable native informants, who could provide feedback regarding abstract concepts, game-rules and game-plot as well as concrete aspects of the game. There can be of course reservations as to the veracity of such advice. Our evaluations only looked at a first exposure with the game. More confidence to our conclusions would be obtained by assessing whether the game maintains its attraction after prolonged usage.

It was mentioned how a flexible protocol was used during the observations. Relaxing the observation in this way, proved to be very effective in making the situation less stressful for the children, while still making it possible to moderate, encourage and assist the children, eventually yielding timely and useful information from them.

The children were very comfortable in front of the camera, contrasting earlier findings of Druin who noted that children tended to perform or "freeze" in front of a camera. Nevertheless, they were by no means oblivious to the camera. In one instance when they realized that they had misbehaved in front of it they stopped their play to ask reassurance that the experimenter would not tell the teacher; then they continued their play.

Another methodological issue concerns concept evaluation. While the potential benefits of involving children during the concept evaluation were pretty clear to us, it is not yet a settled issue whether such an evaluation can give useful feedback. Recent research by Hanna et al [5] suggests that children 8-9 can give feedback on a game concept described using a low fidelity prototype. Our experience reinforces the conclusions of Hanna et al. who relied on a scenario and a few screenshots. In our experience with the design of pOwerball, we found children quite capable of relating to sketch storyboards when adequate explanation was provided and in a relaxing context. Hanna et al. recommend against asking children for suggestions for improvement, as they are likely to mention elements of products they are familiar with. In the present case, they were able to give very accurate feedback on critical design decisions, avoiding the pitfall noted above.

An important part of the design process was dedicated to collecting and analyzing videos during the observation session. This helped us understand what aspects of different games helped social interactions, provided fun and challenge. In retrospect, the thoroughness of that analysis was perhaps excessive and at the expense of prototyping and testing time.

TOWARDS A BROADER CLASS OF GAMES

pOwerball can be seen as an example of a novel class of gaming, that can be fun but also can support social interactions around and within the game. The essential components of this type of games are the following:

- A shared horizontal display helps bring players together.
- 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 mixes cooperation and competition.

The game type outlined, shares some similarities to earlier experimental games for supporting social interactions around play by means of tangible augmented reality. Such works like Ely [1] and the Snark [6] have focused on learning rather than gaming that was the focus during this project. Within this latter context, we believe that the type of games outlined has a large potential to be explored.

Cooperation can be built into the game and requires careful attention to the low-level interaction. In this game, children share the same objective to liberate creatures and beat the 'bad creatures'. The competition against a shared enemy makes the children cooperate, advise and explain tactics, which makes it a truly social game. A large component of the fun was observed to stem not from the gaming itself, but from the dialogue between children. Nevertheless, a longer-term evaluation that brings in the viewpoints of parents and staff of the school would be needed to establish the extent to which individual aspects of the design contribute to this phenomenon. As an interaction technology, tangible tabletop augmented reality, has met our original expectations for supporting social interactions around game play. Follow up work is developing this technical component further and is exploring re-usable interaction design patterns for the domain of social gaming.

CONCLUSIONS

From a research perspective, the design of pOwerball has provided a two-fold contribution. It is a fist example of a class of gaming applications whose purpose is to encourage social interactions around the game. Follow up work is under way to explore this design space further. From a methodology perspective, the project has enabled us to put to the test some of the methodological advice presented in recent literature. The experience of designing pOwerball has been most instructive as an attempt to gain contact and empathize with a very diverse user group, for which traditional design techniques are seriously challenged. We are content that we have succeeded to a large extent in understanding this group of users and mapping their needs into the design of the game mechanics, plot and interaction of pOwerball. Longer term involvement with these children in the design of other games and applications to meet their specific needs, could lead to a more complete and refined understanding of this user group.

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