Bridging the Gap between Children and Tabletop Designers

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ABSTRACT
This paper presents a case study of the design lifecycle of games involving tangible interaction toys handled on an active surface tabletop. The games are oriented to 3-6 year old children, so special care has been taken in the methods used to involve them in a child-centered design lifecycle. The iterative nature of this design paradigm was supported by frequent test sessions where data relating to usability and fun was captured and analyzed in order to guide successive design iterations until a finished product was achieved. The aim is to guide designers intending to involve children in similar tabletop game creation projects. Details are given of how data collected from test sessions with children revealed usability problems and helped to create, evolve and improve the games.

Categories and Subject Descriptors
H.5.2 [Information Interfaces and presentation]: User Interfaces --- Interaction styles, User-centered design, Prototyping

General Terms
Design, Human Factors.

Keywords
Children, Tabletop, Tangible, User Center Design, Usability, Evaluation Methods.

INTRODUCTION
Communication allows people to share their mental models of the world. Using a metaphor, non user-centered design is a one-way communication between designers and users, in which the former "impose" their models on the latter. On the other hand, a user-centered approach establishes two-way communication channels so that users can share their mental models of the products they want to use [26]. Designers have many methods to establish communication with users, but obviously, as language is the most powerful tool for communication, many of these methods are based on verbalization [33]. For this reason, very young children have not been directly involved the design of products created specifically for them [4]. However, in the design of interactive technologies, more important than what users say is what users do [39]. Usability evaluation methods aimed at retrieving user mental models directly from user actions could provide the perfect opportunity to involve children in the creation of interactive and innovative technologies designed for them. Among the most promising technological innovations are active surfaces devices, such as interactive tabletops, which are currently attracting much attention in Human Computer Interaction (HCI) research and commercial applications. Moreover, children receive special attention as users of tabletop technologies because this kind of interaction can offer them many benefits in their ludic and learning activities [1]. Educational projects such as Mesosfera [38], Classification Table [25], or SIDES [30], among others, use tabletop devices with pedagogical applications. However, while many HCI researchers have written about how these technologies encourage learning [28] [31] [35], fun [11] and social skills [6]; many others claim that not everything that glitters is gold [22] [3]. Tangibles may not have the putative benefits we could expect. Tabletop applications based on multitouch interaction might be difficult to use with young children [19] [12]. Obviously, in this aspect, tangible and tabletop technologies are no different from others: if they are well designed and adapted to user necessities, they will offer an enjoyable interactive experience [27].

This paper describes the experience of the authors during the design of games for the "NIKVision" Tabletop prototype. A child-centered design approach was used throughout the lifecycle of the games. Details of this tabletop device are given in the following sections.

OVERVIEW OF "NIKVISION" TABLETOP
This tabletop is designed for use in nurseries and schools for children of 3-6 years old [20]. It is based on the physical manipulation of traditional toys over the table surface (fig.1_1). There is active image output on the table surface, and a conventional computer monitor (fig.1_6) adjacent to the table is also used to bring tabletop games closer to the conventional multimedia graphics approach that looks attractive and fun to little children. Technically, NIKVision uses visual recognition software (fig.1_3) to track the position and orientation of toys placed on the surface, provided by a printed marker attached to their base

(see fig.2) [17]. An infrared light USB camera (fig.1_2) captures video from underneath the table and streams it to the computer station which executes the visual recognition and game software. Active image projection on the table is provided by retroprojection (fig.1_4) through a mirror inside the table (fig.1_5).

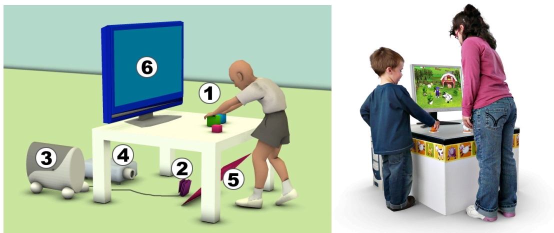

Figure 1. NIKVision Tabletop.

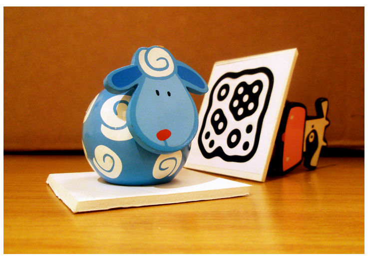

Figure 2. Toys with printed marker attached to base.

NIKVISION GAMES USABILITY LIFECYCLE

The engineering lifecycle adopted for NIKVision games starts out from the Mayhem Usability Lifecycle [23], with some adaptations incorporated to reflect the dual character of tangible interactive applications (see fig.3): virtual and physical design when working on ideation and during the prototyping of both physical and logical aspects of the games. The Mayhew Usability Lifecycle takes users into account and reflects the iterative nature of the design of interactive technologies. In user-centered software engineering, developers iterate through a process of ideation, implementation, and final installation. Much of this iterative development is focused on the early detection of usability and design problems using structured evaluation methods in planned and frequent test sessions, followed by successive "go-backs" in the development process to resolve them.

During *concept creation*, designers need to ideate concepts according to the *user profile*. When users are young children, the key at this stage is to possess knowledge of their mental and psychomotor development, as well as to know their needs, desires, and expectations in relation to the kind of product designers are working on. Once the concept is ideated, designers start working with developers. In tangible interfaces, *implementation* is not only software coding, but also physical building. Thus, *prototyping* will require a *physical* prototype and a software *graphic interface* prototype. Developed by successive iterations, the prototype will evolve into a product with all its functionalities implemented.

During the *functional system* stage, the product will be iteratively refined and fixed in order to achieve an error-free finished product ready to be commercialized or installed in its intended environment. Lifecycle iterations are guided by *test sessions* with the involvement of children. Depending on the evaluation method used, the children's role in the sessions can be described as "informants", "testers" or "users", from greater to lesser involvement in the design decisions [8].

Participation of children in technology design of products oriented to them is always desirable, but it carries many challenges [32]. Bringing children to work in the lab with designers very often disturbs studies and family routines, so it is usually difficult to find families that are willing to let their children take part in this kind of project with a high degree of involvement. Also, special care must to be taken in working with children. From toddlers to adolescents, their needs and social skills vary drastically. Guidelines provided by J. Read [34], P. Markopoulos [21] and A. Druin [7] might help designers to handle children's involvement in their projects. Ethical questions must also be considered [9].

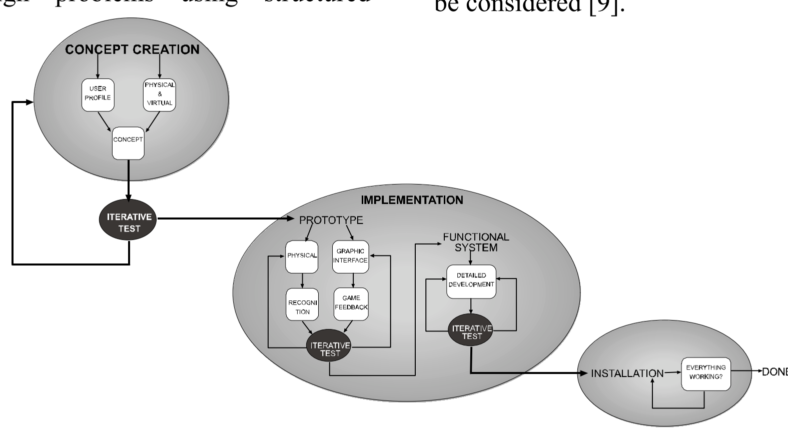

Figure 3. Usability Engineering Lifecycle Used in NIKVision adapted from MAYHEW.

From concept creation to prototype and functional system, the design of games for the NIKVision tabletop has evolved with the involvement of children at each stage. As NIKVision is currently only oriented to research, no installation stage has yet been carried out. The following sections describe the stages that have been made and discuss the specific situations and methods used to capture and analyze information from the test sessions during the design of NIKVision games.

CONCEPT CREATION

When intending to create a new product for users with very particular characteristics, such as 3-6 year old children, it is important to have a detailed user profile in relation to the benefits that the new product can offer them. As described by Piaget [29], children between 3 and 6 years are in the preoperational stage in which they begin to develop the symbolic function (language, symbolic games, mental image, imitations), and they use manipulation and handling to build their mental image of the world. Use of physical manipulation in children's education has been seen as beneficial by Montessori [24] and Alibali [2] who came to the conclusion that children can solve problems better by handling materials than by using pictures only. Chao et al. [5] called this concept the "tool of mental sight". The physical nature of Tangible Technologies fits this user profile.

Inspiration to create new concepts in tabletop games can be derived from observing children playing with non technological and technological toys. First of all, many non-computerised children's toys are played on horizontal surfaces such as a table or floor (see fig 4). In fact, these are "non computer enriched" tabletop games.

Figure 4. From left to right, MB "Guess Who?", Melissa & Doug Wooden Clock, Tiger Supermarket and Playmobil.

On the other hand, computer technologies are nowadays present in children's lives from very early on. Nursery schools have computer stations among their facilities and children use them to play multimedia games from the age of 3. The observation of children playing computer games in their nurseries shows that they usually play in little groups around the computer station. However, as there is only a mouse and keyboard for one child to use, the others keep looking at the back or touching the screen to encourage their friend to make some action. In this situation is where tabletop technologies overcome the limitations of keyboard and mouse, offering children collaborative playing and social experiences.

Tabletop concept ideation should be based on an appropriate combination of the "*physical vs. virtual*" nature of tangible interfaces:

a. Designers can start from a virtual concept (pre-existing multimedia game based on keyboard or mouse) and enrich it with physical embodiment. The inspiration in the case of the NIKVision tabletop emerged from a traffic safety education videogame where children use the mouse to help a cartoon character cross a street (see fig.5 Left). Thinking of tabletop interaction, the game was adapted to the physical world using Playmobil toys and plastic cars (see fig.5 Right). This way, up to 3 children can play the game at the same time and learn how traffic lights work.

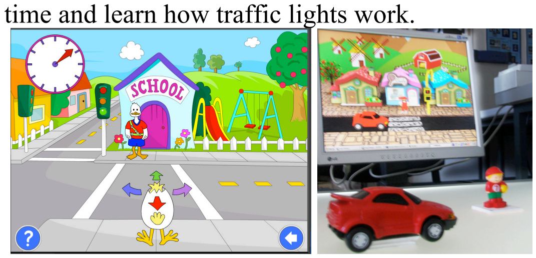

Figure 5. Left: mouse based cross the street game. http://www.ottoclub.org/ Right: Tabletop adaptation using toys.

b. Designers can start from a purely physical game concept, and think about how computer augmentation could enrich it with active images on the table surface. When creating NIKVision, the designers observed in nurseries how children love to play with wooden farm toys (see fig.6 Left). A tabletop game concept was thus created based on a virtual farm, where the animals were physical toys interacting with each other and with virtual elements in a 3D farm scene (see fig.6 Right).

Figure 6. Left: "Le Toy Van" wooden farm toy. Right: Tabletop concept for farm game.

During this stage, children act as informants for designers. Adults can ask their opinions about the toys and games they like most, and assess their potential expectations [36]. Even if their verbal skills are not sufficiently developed, designers can retrieve lot of useful information by observing them playing. Although this is not a develop stage, sometimes implementing a very simple initial prototype might help to obtain more information from the children about the ideas designers are working on. In the previous tabletop farm concept, a very simple conceptual farm game prototype was implemented. Children could play by placing rubber animal toys on the tabletop surface, and virtual animals appeared on a 3D farm on the monitor. No more interaction was implemented. A pair of children participated in some tests relating to this ideation. Their reactions were observed while they played. Parents turned out to be very useful in this scenario. While child and parent were playing together, their conversations provided valuable subjective reporting of the child's impressions of the concept, and this was the base for developing a prototype of a more interactive farm game.

PROTOTYPE

At the end of the *concept creation*, designers need to draw up the specification of the concept game so that developers can start coding. At this point, it is important to mitigate the risk of spending too much time and effort on developing design decisions that might prove to be unviable in later user evaluations. This is why test sessions must be planned with very early prototype designs. However, prototyping with physical interaction (such as tabletop interaction) is not only prototyping the *graphical interface* and providing *feedback* to the user; *physical interactions* and *gesture recognition* must also be prototyped. Algorithms to robustly detect user gestures and manipulations on the tabletop are hard to code, and at this stage designers do not yet know if their decisions about gestures and manipulations will be wasted after being tested by users. In prototyping it is common to ask the user to "figure" or "imagine" that some system functionalities are working; but this is not a good idea with children [37]. It is important to remember that children are not really "testing" our prototypes; they are really playing, and they will only do so for fun. In this situation, a Wizard of Oz [14] method would enable a prototype with simulated functionalities to be developed while children remain unaware of this.

In the tabletop farm concept, the "Wizard of Oz" approach was adopted to capture how children would naturally manipulate the toys to interact with the virtual elements of the game. Another important design question in the farm game was the autonomous agent responsible for guiding and helping children during the game. Children were involved in these issues using a "Peer-tutoring" [13] approach. The experience obtained from both techniques is described in the following subsections.

Wizard of Oz

The farm game prototype consisted of a virtual 3D farm to be shown on the monitor, and a 2D yard to be shown on the table surface. A set of virtual objects was placed in the 3D virtual farm scene and in the 2D table surface yard: plants, animal feeders, a nest, a barn, a bucket... (see fig.7).

By using a keyboard placed beside the NIKVision table, adult evaluators were able to change the state and appearance of these objects: to pick a strawberry, lay eggs in the nest, give milk, eat, etc.

Figure 7. Farm game in NIKVision tabletop

A test session was planned in a school with 4-5 year old children who were brought in to play in pairs with the farm prototype. They were asked to use the toy hen to lay eggs, to feed the animals or to give milk, but it was not known how the children would physically perform each action. Their gestures with the toys were observed by an adult designer who played the role of "Wizard of Oz", triggering the game events using a keyboard beside the tabletop (see fig.8). In this way the children were really receiving feedback from the game that motivated and encouraged them to continue playing. By observing how the children manipulated the toys to perform the game tasks, the designers retrieved information about how they performed actions while having fun with the game.

Figure 8. Adult "Wizard of Oz" observes children playing and triggers game events with a keyboard.

Using this approach, many unexpected gestures were discovered which most of the children made for each task. For example, one of the tasks was picking virtual strawberries from some bushes (see fig.9left). The children performed the action in a very physical manner, shaking the animal toys very vigorously in the bushes as if they wanted to shake the plants in order for the strawberry to drop. Another task was laying eggs using the toy hen. There was a 3D nest on the virtual scene (see fig.9right). Most children placed the hen on the nest and thumped the toy on the table. After the session, we coded these gestures to be recognized by the NIKVision software, and they proved to be very viable actions in later test sessions. However, not all the actions proposed by the children were finally used. For example, in the “feed the animals” task, most of the children just tilted the toy in order to lower its head to the virtual feeder. The system cannot technically detect this gesture and consequently the feed gesture was discarded from the game.

Figure 9. Left: Virtual pig looking for strawberries. Right: Virtual hen laying eggs.

Thanks to this Wizard of Oz approach, the children were again playing the role of informants in the design process of the tabletop game.

Peer Tutoring

A 3D farmer character was modeled, animated and embedded on the farm scene. This character was designed to guide children during the game. Many design questions about the farmer behavior emerged. What are the best verbal expressions it should use? At which situations in the game should the farmer help? How and where will it guide (monitor or tabletop surface)?

Again, children were involved in these decisions as informants, adopting a “peer tutoring” approach. In a test session in a school, designers worked with a class of 4-5 year old children, taking them in groups of three but letting one of them learn how to play before the other two. It was explained to the first child that later he/she would help other children to play the game. The child was given a farmer’s hat to encourage him/her in the role of a farmer (see fig.10).

The sessions were video recorded and later analyzed in order to design the verbal expressions to be used by the virtual farmer and to see at which points help is required.

Figure 10. Farmer child is guiding his friends in the farm game.

FUNCTIONAL SYSTEM

During the iterations of the prototype stage, the farm game was improved and new activities were added. With the data retrieved during the prototype stage, a final farm game was implemented, which was composed of three minigames:

1. “Making a cake” minigame. The farmer asks the animals to help make a cake. Strawberries, eggs and milk are needed to bake the cake. The children use the animal toys to pick strawberries and provide milk and eggs (see fig.11a).
2. “Hide and seek” minigame. The farmer’s son tells the animals to hide in the farm while he counts to ten. The farm scene has some places to hide (a barn, a plant, a hat... see fig.11b). The children hide the animals before the farmer’s son reaches ten. Then, the farmer’s son starts looking for the animals and trying to find where they are hidden.
3. “Babies go to sleep” minigame. The pig and sheep have three babies each. They are wandering around the yard (table surface), but now it is time to go to bed. The children have to use the pig and sheep toys to “push” the virtual babies to the area where they sleep (see fig.11c).

All this comprises a functional game that children can use autonomously. As the games approach completion, the children’s role changes to testers, and near the end of the product design lifecycle they become users. As testers, children mainly participate in “multivariable testing”, making comparative studies of different versions of the same game. For example, in the “babies go to sleep” minigame, different ways of “pushing” the babies were tested, looking for the best balance between usability (time to finish the game), and fun (hard to measure). As users, sessions with children need to focus on the evaluation of the product and its achievement of the 5 main usability goals: learnability, efficiency of use, ease of retention, error handling and user satisfaction [26].

Figure 11. Farm Minigames. a: “making a cake”; b: “Hide and Seek”; c: “babies go to sleep”.

The number of children needed to carry out the evaluations increases in relation to previous stages, as evaluations become primarily summative, and analyses of collected data are based on statistical methods whose results need to be reliable. In this new scenario, adult intervention during sessions must be minimised. The capture and post analysis of data must be a well structured process in order to minimize the "evaluator effect" [16].

Capture of video data

It is desirable to capture everything that happens during test sessions; not only in relation to game events. Children's emotions and sense of fun are important data to record. In the NIKVision tabletop, it is easy to place a video camera just below the monitor and capture a very close and frontal view of children's faces while playing. This view gives information about the emotions that children are experiencing during the game, both positive (fun, motivated, interested) and negative (puzzled, bored, frustrated). Because NIKVision has two different image outputs, it is important to observe what children are looking at during their play: tabletop surface, monitor, partner, adult assistant, or elsewhere. Software detection of gaze is not necessary as this can be visually noticed during manual analysis of the videos (see fig.12). If the video camera has a microphone incorporated, children's verbalizations can easily be captured.

Figure 12. Different focus of attention, left: tabletop surface; right: monitor.

A video camera in a corner of the test room gives a general view of the tabletop and surroundings. Placing the camera high up on a tripod gives a view of the tabletop surface and children's manipulations on it. This video will provide information about usability during the game (problems in carrying out a task, difficulties in performing the physical gestures, etc). If more than one child is playing at the same time, collaboration details can also be retrieved (to see if they play independently or help each other, or if some child stops playing to watch his/her partner).

All the video cameras are synchronised to be reproduced at the same time in order to provide information about usability and the degree of fun during the analysis stage.

Automatic log recording is another important source of usability data [15]. This is especially useful in tabletop devices, as information is provided about "what the system is detecting of handlings and gestures". NIKVision software records log files automatically for each minigame played. Each movement of the toys is registered, and it is seen if the system is recognizing some specific gestures (such as a toy being thumped or shaken). Furthermore, a log file stores all the feedback the game sends to the children and what the autonomous agent is doing at every moment. All events are stored with a time stamp.

These log files need to be read using software tools that show graphically what occurred in a test session with a set of specific toys, at a specific instant of any minigame. The log tool developed for NIKVision is able to export this information to video stream files in order to reproduce in real time what happened during the session and to synchronize these log video streams with video recordings of the children (see fig.13), giving a complete overview of the test.

Usability evaluation

The final step in the analysis of video streams is to find temporal relations from the synchronized streams. Some observed usability problems could be neutralized by other events if they happen at the same time; e.g., a child performing the wrong action while expressing emotions demonstrating interest might not be considered as a usability problem, but as a desirable challenging game situation [10].

Figure 13. 3 video streams synchronized. Left will be used for emotion analysis. Central will be used for usability analysis. Right will be used for system recognition, game events and feedback.

The usability of NIKVision farm minigames was evaluated in a test session with 4-5 year old children in a local school. The children played all the minigames in pairs, and all tests were video recorded and logged. Later, live recordings and log video streams of each session were synchronized.

Many problems were discovered from the detailed analysis of these videos related to system performance, misunderstandings, feedback and levels of challenge. Such problems often feature in usability breakdowns in interactive applications:

System performance

Breakdown:

Normally, when the system is not detecting user gestures on the tabletop, this is easily detected in the evaluation. However, there may also be more elusive usability problems, for example the system detecting a gesture that a child was not doing on purpose. During video analysis, this problem can be discovered when the child looks puzzled or when he/she verbalizes that he/she did not understand what has just happened. However, children's emotions are not always very predictable.

Findings:

The "Making a cake" farm minigame had a "wrong gesture detection" problem with the cow and the giving milk action. Many times the children triggered this action but not deliberately. In one particular test, one child tried to lay eggs with the cow on the nest, and the system interpreted this as giving milk, sending feedback with a "moo" sound. The child interpreted this as the cow laying eggs. This did not puzzle him but, rather the opposite, it seemed to him to be very funny! (see fig.14)

Recommendation:

Algorithms of gesture detection must be tuned. Two usability issues must be balanced: 1-Gestures should be done at the right place, at the right moment, and begin and end in a precise time interval. 2-Children are not precision machines. If (1) is predominant, the system will not detect most of the gestures children intend to do. But if (2) predominates, the system will detect too many unintentional gestures.

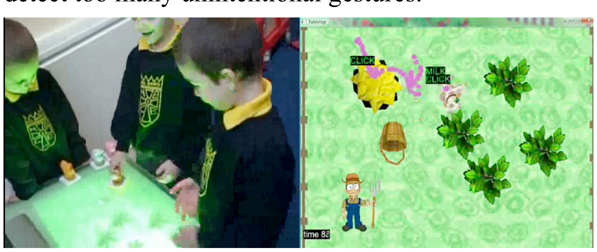

Figure 14. Child is "unintentionally" giving milk with the cow, and child is interpreting this as the cow laying eggs.

Wrong actions due to misunderstanding

Breakdown:

An action that is not appropriate for achieving the game goal but that the child understands to be correct is a wrong action. The important thing is to find the reason for this misunderstanding. This frequently lies in discrepancies between what designers and children understand as a correct action. A test session is where such discrepancies can be discovered, but subsequently designers should be prepared to accept that the children had a different vision of how to play the games. A tricky situation can occur when discrepancies are found among different children.

Findings:

This situation is still unsolved in the "Hide and seek" farm minigame. The designers defined that one animal is "correctly hidden" when it is "inside" any virtual object in the yard (i.e. inside the bush, inside the barn, inside the barrel...). However, log video streams showed that the children had different opinions about how to hide an animal. Most of them understood that the animals were hidden if the animals were "behind" an object in the yard. But "behind" was not the same for all the children. Some placed animals "behind" an object from the viewpoint of an autonomous agent on the screen (see fig.15), others placed animals at a position which was behind an object in relation to the children themselves, and some children even hid the animals behind the monitor! Such differences in what the children understood by "hidden" has necessitated the concept of this minigame to be redesigned, even though it is the game that attracted the best "positive fun" emotions.

Recommendation:

Designers should understand that "children are always right", and must be prepared to carry out important changes in their game concepts. Trying to balance children's expectations and mental models with usability and fun may often be tricky and challenging.

Figure 15. Cow and pig are hidden behind a bush in relation to autonomous agent.

Lack of feedback

Breakdown:

Many puzzling situations occur when the game is not giving enough information about the player's progress and status. Children need to receive clear feedback on completed and pending tasks.

Findings:

The "Making a cake" farm minigame revealed many feedback problems. As children were allowed to get the cake ingredients in any order, they were not conscious of what ingredients they had already achieved and what were pending. The game did not give information about this. Giving fun feedback when a game is complete is also important. "Making a cake" and "Babies go to sleep" did not have fun endings, merely a "thanks" or a little more verbalization from the farmer. Children sometimes did not understand and asked, "why does the game quit?" On the other hand, in the "Hide and seek" minigame, the virtual character announces when it has found all the animals and encourages children to try harder next time. For this reason it was the game that the children liked to replay most.

Recommendation:

A game must keep children informed of their progress at any time. But it is important to keep in mind the fun element, especially when the game goal is reached. Fun animations at the end of the game will encourage children to repeat playing.

Challenge

Breakdown:

Mallone [18] pointed out challenge as one of the essential elements needed in computer game applications: "The user should be uncertain about achieving the goal (not too easy – not too hard)". The optimal level of challenge is not the same for all users. For this reason most videogames allow the user to choose the level of difficulty. But tangible interaction adds challenge in the manipulation: are physical actions too easy or too hard to do in a specific game? Between 3-6 years, children are developing their motor skills. Substantial differences can be found between children with a one or more year age gap.

Findings:

The first version of the "Babies go to sleep" minigame required very precise toy movements to drag the virtual babies to their beds. 3 year old children were not able to finish the task, but 4 and 5 year old children liked to find funny ways of "pushing" the babies; thus, there was enough challenge for them not to get bored or frustrated. An easier way of pushing the babies was tested: when a toy got very near to a baby, it became attached to the toy position. In this case, younger children were able to finish the task and they had fun; on the other hand, older children could do the task very quickly and did not find it sufficiently challenging to be fun.

Recommendation:

Generalization is impossible. It is desirable to be able to regulate the level of challenge to accommodate it to the skill of each child. The ideal should be that the game accommodates the difficulty by itself detecting when the child is faced with either too much or too little challenge.

CONCLUSIONS

This paper has described the design lifecycle of a set of games based on tabletop interaction using physical manipulation of conventional toys. Throughout the process, a child-centered approach has been taken by means of frequent test sessions where children played with the games. As the games evolved from very early concept prototypes to finished products, the children's roles in the tests evolved from informants to testers to users. Different evaluation methods were used in the test sessions, both adapted to children's skills and focusing on what children did or intended to do while manipulating toys on the tabletop surface. The designers collected and analyzed data relating to usability and fun in order to iteratively evolve and improve the games, according to the children's mental models. In early stages of the project, the children informed designers about their preferences in games and suggested new ways of interaction with tabletop devices. As the development of the games approached the final product, evaluation methods focused on discovering usability problems. Detailed analysis of video recordings and system logs gave complete details of all the events during a test, and helped to find relations between game feedback, and usability and fun events occurring at the same time.

Participatory design of children on development of new technologies is a field of high interest on the HCI research community. Although works and researches that included children as design partners are well considered, simply "coo-working" of children and designers cannot guarantee useful and valid results. In order to optimize time and profit of this relationship, well structured and adapted methods are required. The experience gained in NIKVision project may help out using suitable methods focused on "*letting the children simply use, play, and have fun*" with technology, and retrieving data from "*what users do*". Working with children in constructivist projects is always desirable, but the usual budget and time restrictions in commercial projects are often a hindrance. A better knowledge of suitable methods of involving children in the creation of new concepts of innovative interactions will hopefully help to normalize the presence of children in all design decisions affecting technologies aimed specifically for their use.

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