Tangible interaction and tabletops: new horizons for children's games

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Abstract: This paper presents the design process of a set of games involving tangible interaction using toys handled on an active surface tabletop. The games are oriented to young children, so special care has been taken to involve them in a child-centred design life cycle. The iterative nature of this design paradigm was supported by frequent test sessions, where data relating to usability and fun was captured and analysed in order to guide successive design iterations until a finished product was achieved. Details are given of how data collected from test sessions with children helped to create, evolve and improve the games and toys. The final aim of our work is to bring recent proposals in natural interaction closer to young children, adapting them to children's development and preferences.

Keywords: children; tabletop; tangible; user centre design; usability; evaluation methods; arts; technology; games; toys.

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1 Introduction

Children nowadays are becoming technology consumers from a very early age. However, conventional computer stations and interactive applications based on mouse and keyboard are not appropriate to their cognitive and psychomotor skills (Healy, 1998) and do not offer them as many benefits in fundamental aspects of their development as group activities, physical playing and manipulative learning (Piaget, 1952).

Among the most promising technological innovations are active surface devices, such as multitouch tabletops, which are currently attracting much attention in human computer interaction (HCI) research and commercial applications. 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 (Africano et al., 2004). Educational projects, such as Mesosfera (Utani, 2010), classification table (Morris et al., 2005) or SIDES (Piper et al., 2006), among others, use multitouch tabletop devices with pedagogical applications. Nevertheless, some studies are showing that tabletop applications based on multitouch interaction might be difficult to use with young children (Harris et al., 2009; Mansor et al., 2008), as their fine motor skills are not yet well developed until they reach the age of seven.

On the other hand, technologies based on the physical manipulation of 'smart' objects (Ishii and Ullmer, 1997) are proving to be better adapted to young children's interaction. Many HCI researchers have written about how these technologies encourage learning (O'Malley and Fraser, 2004; Price and Rogers, 2004; Rick and Rogers, 2008), fun (Rick and Rogers, 2008) and social skills (Cheok et al., 2006).

The use of conventional objects to control computer applications has been detailed by Ullmer and Ishii (Ullmer and Ishii, 2000), who classified them, depending on the function of the application, as '*Name*' (a physical object is represented uniquely by a virtual object in the application) and '*Verb*' (a physical object represents an action that modifies some elements in the application when manipulated).

This paper proposes the use of conventional toys as controllers of tabletop games oriented to young children, combining the tangible interaction paradigm with a tabletop interactive surface. A child-centred design approach was used throughout the life cycle of the games. Details of this tabletop device and games are given in the following sections.

2 Overview of 'NIKVision' tabletop

The NIKVision tabletop (Marco et al., 2009) uses well-known techniques for multitouch active surfaces (Schöning et al., 2009), but its design is mainly focussed on tangible interaction in the handling of physical objects on the table surface. It is oriented to kindergarten children; therefore, it has to be robust and safe. Moreover, it has to be easily mountable and dismountable in nurseries and school classrooms in order to be able to carry out tests with children (see Figure 1).





Children use NIKVision by manipulating conventional toys on the surface (Figure 2(1)). A USB video camera is placed inside the table, capturing the surface from below (Figure 2(2)). Visual recognition software runs in a computer station (Figure 2(3)) that also handles the game software and the tabletop active image provided by a video projector under the table (Figure 2(4)) through a mirror inside the table (Figure 2(5)). The image output is also shown on a conventional computer monitor (Figure 2(6)) adjacent to the table. Visual recognition and tracking of objects manipulated on the table is provided by reacTIVision framework (Kaltenbrunner and Bencina, 2007) and a printed marker attached to the base gives each toy a digital '*Name*' (Ullmer and Ishii, 2000) (see Figure 3).

The tangible interaction is achieved by manipulating the toys on the table surface. During play, children move the toys over the translucent surface of the table, putting the base of the toys in contact with the table to enable the camera to see the markers located under the base. The manipulations that visual recognition software is able to track are:

- *Movements over the surface (see Figure 4)*: Children can grab the toys and drag them over the surface. The software tracks the position and velocity of the toy over the table.
- *Rotate toy (see Figure 5)*: The toys can be rotated on the surface and so long as the base with the marker remains on the table, the software can track their orientation. Thus, toys that have a distinguishable front and back can be oriented by the child, during the game, e.g. a toy car is moved and oriented on the tabletop and a virtual 3D car on the monitor will move and orient the same way as in the game.



Figure 2 NIKVision sketched components (see online version for colours)

Figure 3 Toys with printed marker attached to base (see online version for colours)



Figure 4 Drag toy over the desktop (see online version for colours)







Several games have been developed for the NIKVision tabletop. In the next section, the development methodology is presented.

3 NIKVision games usability life cycle

The engineering life cycle adopted for developing NIKVision games starts out from the Mayhew's (1999) usability life cycle. This cycle takes users into account and reflects the iterative nature of the design of interactive technologies. In user-centred software engineering, developers iterate through a process of ideation, prototyping and final functional development. 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. We have adopted the Mayhew engineering life cycle, adapted to reflect the dual character of tangible interactive application (see Figure 6), combining virtual and physical design when working on ideation and during the prototyping of both physical and logical aspects of the games.

During *concept creation*, designers need to create 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 commercialised or installed in its intended environment. Life-cycle 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 (Druin, 2002).

Figure 6 Usability engineering life cycle used in NIKVision adapted from Mayhew (1999) (see online version for colours)



The participation of children in the technology design of products oriented to them is always desirable, but it involves many challenges (Raisamo et al, 2006). 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 be taken to while working with children. From toddlers to adolescents, their needs and social skills vary drastically. Guidelines provided by Read et al. (2002), Markopoulos et al. (2008) and Druin (1999) might help designers to handle children's involvement in their projects. Ethical questions must also be considered (Farrel, 2005).

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. The following sections describe the various stages and discuss the specific situations and methods used to capture and analyse information from the test sessions during the design of NIKVision games.

3.1 Concept creation

At the beginning of the NIKVision project, the question to be answered was how technologies based on tabletop and tangible interaction could be used in pre-school children education. In order to start researching this question, we first needed to know our users, children. Then, we had to originate new concepts of tangible applications suitable for the NIKVision tabletop, adapting usual nursery and school activities to the new interaction paradigm.

3.1.1 User profile

When intending to create a new product for users with very particular characteristics like three–six-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 (1952), children between three and six years are in the preoperational stage in which they begin to develop the symbolic function (language, symbolic games, mental image, imitations), while using 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 (1949) and Alibali and diRusso (1999) who came to the conclusion that children can solve problems better by handling materials than by using pictures only. Chao et al. (1999) 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 like a table or floor (see Figure 7). In fact, these are 'non-computer enriched' tabletop games.

On the other hand, nurseries and schools have computer stations among their facilities, and children use them to play multimedia games from the age of three. 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 one mouse and keyboard for one child to use, the others spend their time looking at the back or touching the screen to encourage their friend to act. This is where tabletop technologies overcome the limitations of keyboard and mouse, offering children collaborative playing and social experiences.

Figure 7 From left to right, MB 'Guess Who?', Melissa and Doug Wooden Clock, Tiger Supermarket and Playmobil (see online version for colours)



3.1.2 Physical vs. virtual

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

- 1 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 Figure 8 (left)). Thinking of tabletop interaction, the game was adapted to the physical world using, Playmobil toys and plastic cars (see Figure 8 (right)). This way, up to three children can play the game at the same time and learn the traffic rules.
- 2 Designers can start from a purely physical game concept, and think about how computer augmentation could enrich it with virtual environments. When creating NIKVision, the designers observed in nurseries how children love to play with wooden farm toys (see Figure 9 (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 Figure 9 (right)). The complete development of this farm game has been at the centre of the NIKVision research activities, and its life cycle will be detailed in the following sections.
- Figure 8 A: mouse-based cross the street game, http://www.ottoclub.org/ B: tabletop adaptation using toys (see online version for colours)



Figure 9 A: 'Le Toy Van' wooden farm toy. B: tabletop concept for farm game (see online version for colours)



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 (Scaife and Rogers, 1999). Even if their verbal skills are not sufficiently developed, designers can retrieve a lot of useful information by observing them playing. Although this is not a development 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 above-mentioned 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 further 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.

3.2 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 (like 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 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 (Sluis-Thiescheffer et al., 2007). It is important to remember that children are not really 'testing' our prototypes; they are in fact playing, and they will only do so for fun. In this situation, a Wizard of Oz (Höysniemi et al., 2004) method would enable a prototype with simulated functionalities to be developed while children remain unaware of the fact.

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.

3.2.1 Gestures prototyping

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... and a virtual farmer character that collected the objects gathered by the animals (see Figure 10).



Figure 10 Farm game in NIKVision tabletop (see online version for colours)

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, give wool, etc.

A test session was planned in a school with four-five-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 or wool, 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 Figure 11). 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, valuable information was retrieved about how they performed actions while having fun with the game.

Using this approach, many unexpected gestures were discovered that most of the children made for each task. For example, one of the tasks was picking virtual strawberries from some bushes (see Figure 12 (left)). 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 Figure 12 (right)). Most children placed the hen on the nest and jumped the toy up and down on the table.

After the session, we coded these gestures to be recognised 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 11 Adult 'Wizard of Oz' observes children playing and triggers game events with a keyboard (see online version for colours)



Figure 12 A: virtual pig looking for strawberries; B: virtual hen laying eggs (see online version for colours)



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

3.2.2 Graphics and animations: the shear problem

Using the gestures defined previously, the hen, cow and sheep were involved in specific activities (laying eggs, giving milk and giving wool, respectively). The sheep's activity had a slightly different design from the others. We got the idea of playing with colours: the sheep would give wool on barrels with different colour tints (see Figure 13). The children could shake the sheep toys on any barrel of their choice, and the wool would turn out to be the colour of the barrel on which the sheep was placed.

In the test sessions held in a school, the shearing activity was tested, as well as the strawberries, eggs and milk activities. No problems arose with the latter three activities during the trials, but the shearing activity was very confusing for the children. They had no problems in triggering the activity using the shake gesture, but when we asked them to explain what was happening, none of them were able to explain it. Despite being

physically appropriate for children, the activity was not well designed graphically. There is no sense in placing the sheep on a coloured barrel, and the children did not see any connection between the shaking and the tinted wool that appeared on the barrel. In consequence, this was not considered a fun activity.

Back in the lab, we brainstormed how to redesign this activity in a way that was better adapted to young children's understanding. We got the idea of making a metaphor between the shearing and going to the barber to have a haircut. So we modelled a barber's chair (see Figure 14 (left)), and animated the virtual farmer with scissors as if he were cutting the sheep's 'hair'. The activity was triggered when children placed the sheep on the chair (see Figure 14 (right)).

In the following test session at a school, an adult assistant showed the sheep activity to the children. They understood it perfectly and found it great fun.



Figure 13 First concept for an activity for the sheep (see online version for colours)

Figure 14 A: barber chair for shearing the sheep; B: the farmer is 'cutting the sheep's hair' (see online version for colours)



3.2.3 Guiding agent

The developers implemented algorithms to automatically recognise the shake and jump gestures. After this implementation, the farm game was composed of four activities:

- collecting strawberries; triggered with any animal using the shake gesture
- laying eggs; triggered with the hen using the jump gesture
- giving milk: triggered with the cow using the jump gesture
- giving wool: triggered with the sheep being placed in the barber's chair.

The next step was to evaluate the four activities with children. At the time, an adult assistant was in charge of asking the children to trigger the activities. However, our aim was to have an autonomous game without adult human intervention. Thus, this was the moment to develop the role of the farmer in order to turn him into a talkative autonomous agent, able to perform the task of asking and guiding the children to carry out all the activities. The question that emerged at this point was 'how detailed should the farmer's instructions be?'

To involve the children in this decision, we developed three different behaviours for the autonomous agent:

- 1 'What to do': the farmer only gives the instruction of what to do (to find strawberries, to lay eggs, to give milk, to give wool).
- 2 'What and where': the farmer also specifies where the toy has to be manipulated (on the plants, nest, bucket, barber's chair), using verbal instructions and moving near the object in the virtual scene.
- 3 'What, where, who, and how': the farmer specifies what to do, with what animal, where and how to do the manipulation (shake, jump...).

In the next school test session, the children played the farm game in pairs. Each pair played with only one behaviour of the farmer. During a full-day test session in the school, seven pairs of children tested the game, so each version was tested at least twice. The trials were video recorded. Also, observation notes were taken down during the trials in order to assist designers in matching the videos and the times.

It was observed that all the children completed all the activities from the beginning to the end in the order of the three farmer roles described above. First, the children listened to the farmer's instructions, and then tried to achieve that goal only (although the game still enabled them to do all the tasks in any order independently of what the farmer was asking for). Only a few children needed help with some tasks, using behaviour 1 as they did not always know how to complete the task after hearing the instructions. Nevertheless, all the children were able to complete the task with behaviours 2 and 3 without adult intervention. In conclusion, it was found that the 'what and where' behaviour retained some exploration and challenge in the game without increasing its difficulty, and this was the behaviour finally implemented for the autonomous agent figure represented by the farmer.

Next, another design question about the farmer emerged: which were the most appropriate verbal expressions to be used? In which situations in the game should the farmer help?

Again, the children were involved in these decisions as informants, adopting a 'peer tutoring' (Höysniemi et al., 2003) approach. In a test session held in a school, designers worked with a class of four-five-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 the farmer (see Figure 15).

The sessions were video recorded and later analysed in order to design the verbal expressions to be used by the virtual farmer and to see at which points help was required. New expressions and terms emerged from this session that were different from those used by the adult designers; e.g. the children described the 'jump' gesture using the verb 'stomp', and this was the term finally verbalised by the autonomous virtual farmer.

Figure 15 Farmer child guiding his friends in the farm game (see online version for colours)



3.3 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 same stage, a final farm game was implemented 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 Figure 16).
- 2 'Hide and seek' minigame. The farmer's son tells the animals to hide in the farm while he counts to 10. The farm scene has some places to hide (a barn, a plant, a hat...) (see Figure 17). The children hide the animals before the farmer's son reaches 10. Then, the farmer's son starts looking for the animals, 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 Figure 18).

All this comprises a functional game that children can use autonomously. As the games approach completion, the children's role changes to that of testers, and near the end of the product design life cycle 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). Sessions with children as users need to focus on the evaluation of the product and its achievement of the five main usability goals: learnability, efficiency of use, ease of retention, error handling and user satisfaction (Nielsen, 1993).

The number of children needed to carry out the evaluations increases in consecutive 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 minimise the 'evaluator effect' (Jacobsen et al., 2003).

Figure 16 'Making a cake' minigame (see online version for colours)



Note: Top: monitor image; bottom: tabletop image.



Figure 17 'Hide and seek' minigame (see online version for colours)

Note: Top: monitor image; bottom: tabletop image.



Figure 18 'Babies go to sleep' minigame (see online version for colours)

Note: Top: monitor image; bottom: tabletop image.

3.3.1 Capture of video data

It is desirable to capture on video everything that happens during test sessions, and not only in relation to game events.

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 (see Figure 19A). 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).

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 (see Figure 19B). If the video camera has a microphone incorporated, children's verbalisations can easily be captured.

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 (Ivory and Hearst, 2001). This is especially useful in tabletop devices, as information is provided about 'what the system is detecting of handlings and gestures'. NIKVision software creates log files automatically for each minigame played, with all the manipulations and events of each minigame. Each movement of the toys is registered, and it also reflects if the system is recognising some specific gestures (like 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 synchronise these log video streams with video recordings of the children (see Figure 19C), giving a complete overview of the test.



Figure 19 Capturing data during the evaluation (see online version for colours)

Note: A: general view of tabletop; B: close view of children playing; C: animated log video streaming.

3.3.2 Usability evaluation

The final step in the analysis of video streams is to find temporal relations from the synchronised streams. Some observed usability problems could be neutralised 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 (Federoff, 2002).

The NIKVision farm minigames were evolved iteratively based on an analysis of videos retrieved during test sessions in schools and nurseries.

The most controversial aspect of the usability of NIKVision was the dual feedback of the device: the vertical monitor and the horizontal table image output.

The videostreams that reflected the faces of the children showed us where they are looking at any moment of the game: at the vertical monitor or the horizontal table surface. We discovered that in the 'making a cake' and 'hide and seek' minigames, the children paid most attention to the vertical monitor as it showed many attractive and fun 3D animations for giving feedback about the actions, and this is where the 3D farmer gives instructions to the children. Consequently, the children only had a quick look at the table surface for locating where to place the toys (see Figure 20). Having to change continuously the focus of attention was a little tiring for very young children, who preferred to focus only on the vertical monitor, making their performance worse for locating the interactive virtual objects in the farm. However, this situation was reversed with the 'babies go to sleep' minigame. The children paid all their attention to the table surface where they had to drag the babies using the toys. The only feedback received on the vertical monitor was how many babies were already sleeping. This minigame had better embodiment, and improved the attention of the children.

Figure 20 Different focus of attention, A: tabletop surface; B: monitor (see online version for colours)



4 Improving toy embodiment and metaphor

With the information retrieved from the usability analysis of the farm game, we decided to design a new generation of toys and games where the image feedback relies completely on the tabletop surface, achieving near embodiment interaction (Ullmer and Ishii, 2000).

Also, we aimed to expand the interactive possibilities of the toys. As seen in the farm game, toys are merely '*Names*' in the game, provided by the addition of printed markers on their base. New toys could be extended with '*Verb*' functionalities using the 'token + constraint' metaphors explained by Ullmer et al. (2005). The toys and games described below use this 'token + constraint' approach to create toys that are at the same time 'Name' and 'Verb', enriching the interaction metaphors of the games.

4.1 Music game

Many traditional children's games are played with little pieces that are physically identical: marbles, caps and all kind of chips in tabletop games. Children play with these in groups on the floor or on a table, using spatial rules defined for each game. These kinds of physical object are named 'Tokens' in tangible interaction (Ullmer et al., 2005). With this approach, we created a music game in which children are able to create drumbeats with plastic tokens (see Figure 21). Music scores can be interpreted as spatial configurations of notes (tokens) over a bi-dimensional surface, where the horizontal axis represents time and the vertical axis defines a sound property. Each colour represents a different drum instrument. The beat is reproduced from left to right. The Music game was tested with eight–nine-year-old children with the aim of explaining music rhythm concepts in a creative and collaborative way.

For use in the Music game, two new toys were designed based on the manipulation of constrained tokens (Ullmer et al., 2005). Constraint toys are confining regions within which tokens can be placed. These regions are mapped to digital operations which are applied to tokens located within the constraint perimeter. Constraint toys can be classified, depending of the relation established between the token and the constraint:

- Associative: a token can only be placed or removed from the confines of a constraint. This way, a relationship is established between the token and the constraint, depending only on the presence or absence of the token. An associative toy is used as a 'beat store' in the 'music game'. It consists of a plastic rectangle with four holes within which a plastic token can be placed and removed (see Figure 22 (up)). Thus, it is an associative toy, where each hole has a meaning in the application. When a drumbeat is composed, the user can place a token in one hole, meaning that this beat is 'stored' in that hole. This way, up to four different beats can be stored in the toy. These beats are reproduced when a token is present in their associated hole, mixing with the physically defined beat on the table. By combining tokens in the 'beat store' toy, children can quickly activate and deactivate beats in a creative way.
- Manipulative: a token is already coupled with a constraint and it cannot be removed. The token can only be manipulated within the confines of its constraint. We designed a manipulative audio fader, which is restricted to moving only on a vertical axis increasing or decreasing the speed of the reproduced beat (see Figure 22 (down)).





Figure 22 Up: associative beat store; down: manipulative audio fader (see online version for colours)



4.2 Asteroids game

Many conventional toys have mechanical structures that add new interactions, e.g. a spaceship toy may have a button that when pressed triggers sound and light to simulate that the ship is firing. Using this concept, a spaceship toy was designed and built for use in the NIKVision tabletop. It has a button on the top that mechanically makes a visual token appear on its base when pressed and disappear when released. The meaning of this action is that the spaceship toy will launch a virtual missile when the token appears. These spaceship toys are used in a tabletop adaptation of the classic videogame 'Asteroids' by Atari. Two children can collaborate to destroy all the virtual asteroids that appear on the active surface, using the physical toys. Each time they press the button on their spaceship toy, a missile launches that may fragment an asteroid on impact (see Figure 23).



Figure 23 Spaceship toys with top fire button (see online version for colours)

4.3 Pirates game

We designed a fan toy with a mechanical constraint that makes a token appear and disappear as the child spins the helix of the fan (see Figure 24). This way, the tabletop device interprets that the fan is spinning when the constrained token is detected, and the system counts how many times per second the token appears and disappears deducing how quickly the fan is spinning.

This toy is used in a 'Pirates' game, where children control a virtual pirate ship by moving the toy and spinning the wheels of the fan. The goal of the game is to attack other ships and to steal their treasure. The collaboration between children is important as one child is in charge of the fan toy while another has to fire the cannons using his/her finger to control the direction of the cannon balls (see Figure 25).

Figure 24 Fan toy (see online version for colours)





Figure 25 Collaboration on Pirates game to sink ships (see online version for colours)

5 Conclusions

The combination of tabletop and manipulative toys described in this paper revealed notable potential for collaborative computer gaming. All the games designed for NIKVision enable more than one child to play at the same time and in some games (especially in the Pirates game) collaboration is essential for achieving the goal. During the testing of the games, children were also engaged in a high degree of physical activity while playing, overcoming one of the most controversial aspects of computer videogames.

Thanks to taking a child-centred approach during the design process, games have evolved from very early concept prototypes to finished products well adapted to children's preferences and needs. 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 analysed data relating to usability and fun in order to iteratively evolve and improve the games, according to the children's mental models. In the early stages of the project, the children informed designers about their preferences in the games and suggested new ways of interaction with tabletop devices. As the development of the games approached the final product, evaluation methods focused on identifying usability problems.

The experience gained in the NIKVision project may contribute to encouraging the use of suitable methods focused on '*letting the children simply use, play and have fun*' with technology, and retrieving data from '*what users do*'. Also, the toys and games designed in this project should open new possibilities for child–computer interaction, combining conventional toys and tangible interaction paradigms with active surface technologies.

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