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NIKVision: Developing a Tangible Application for and with Children

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Abstract: In this paper, the design process of a tangible game for a tabletop device (NIKVision) is presented. NIKVision is intended to give leisure and fun while reinforcing physical manipulation and co-located gaming for 3-6 year old children. Interaction is provided by the handling of conventional toys and computer augmentation on a table surface. The presence of an additional vertical monitor that complements table surface output is a distinguishing feature of NIKVision. By following a engineering design lifecycle, the paper describes the complete process of designing a Farm Game for the tabletop. Children have been involved, for the very starting point, through continuous test sessions in schools and nurseries. The data recovered from these sessions have been essential, not only to detect problems, but to take the more adequate design decisions. Different children-centred design methods have been used, depending on the question to be evaluated or designed, ranging from observation notes to Wizard of Oz, or video-analysis. The paper exposes the results of a final summative evaluation that summarizes the performance of the game in relation to Usability, User Experience and physical and co-located gaming. The experience obtained by the authors from this process has crystalized in a set of reflections about the feasibility of designing with very young children and about the value of the data obtained from them.

Keywords: tangible, children-centred design, tabletop, usability, user experience, evaluation
Categories: H.5.2, H.1.2

1 Introduction

Cognitive and psychomotor development of young children roots on physical manipulation and handling [Piaget, 1952]. Many researchers have been promoting the pedagogical values of object manipulation [Montessori, 1949] since children can investigate the properties and behaviour of physical manipulatives; act and establish relationships with the physical elements, explore and identify them, recognize what

effects they produce, detect similarities and differences, and then can compare and quantify.
Nowadays, computers, laptops, interactive whiteboards and also tabletops have been introduced in school environments. Most computer educative applications oriented to young children use the WIMP (Window, Icon, Menu, Pointer) interaction paradigm and, more recently, multitouch based interfaces, to provide virtual representations that are as meaningful to students as physical objects. Educative computer applications also take advantage of the strong motivation that videogames offer to children [Malone, 1983], combining the motivation with the capabilities of digital technologies to transmit pedagogical content.

Ethnographic research on the use of computers in early years education environments found that digital technologies are in general underused and offer, therefore, a limited experience for most children [Plowman and Stephen, 2005]. Kindergarten teachers consider computers as technical tools with which children should acquaint themselves in preparation for school [Sandberg, 2002]. On the other side, in non-computer activities, lively groups of children play manipulating objects, exploring its properties and using them as an expression tool. Therefore, it should be desirable that computer activities in nurseries would combine the pedagogical benefits of digitally augmenting educative activities [Samara et al., 1996] and co-located learning with small groups of children actively playing with physical materials.

Digital augmented tables are a suitable option for supporting manipulative interaction with small groups of children. The physical affordances of tabletop devices reinforce face-to-face social relations and group learning, showing digital image feedback in the same place where interaction takes place [Morris et al., 2005]. Although the education community are taking especial interest in these devices [Evans and Rick, 2010], multitouch surfaces show important problems when are applied to children in early years education [Mansor et al., 2008]. The adjustment of tabletop devices to them should be possible by redesigning the interaction with an approach more suitable to their psychomotor development. The tangible interaction approach can be seen as a promising alternative for tabletops based on object manipulation. Works carried out by Marshall et al. [2003] and Zuckerman et al. [2005] prove that Tangible User Interfaces (TUI) applied to young children can take benefit of the same pedagogical values as learning with materials. TUI enable children to interact with the physical world, while augmenting it with relevant digital information used to facilitate and reinforce active learning [Price, S. and Rogers, 2004]. However, there is lack of studies about the impact of applying tangible interfaces with very young children (3-6 year old).

Our envision is that an adequate combination of a tabletop computer device with tangible interaction using conventional toys can bridge the gap between digital and physical based educative activities for young children. In this work the benefits that this kind of technology offers to these children are explored, in terms of usability, user experience, and physical co-located playing. For that reason, we decided to create a tangible game for the NIKVision tabletop [Marco et al., 2010], oriented to 3-6 year old children, designed to support co-located gaming around the table with a tangible interaction approach based on toy manipulation. Unlike other papers related with tangible interfaces for children, which either focus in presenting and evaluating a new application or in assessing the effectiveness of a particular Children-Centred

Design method, this paper shows the complete design process of a tangible application for very young children, from the very early concept to the final game with continuous children involvement supported by the use of several Children-Centred Design methods.

Following, in section 2, Related Work that has been the base of our research is presented. In section 3 an overview of the NIKVision design process is given, and its stages, Concept Creation, Prototype and Functional Product are expanded in sections 4, 5 and 6 respectively. Details about the design decisions that appeared during the process, and the different tools and methods used to involve children in the test sessions are discussed. Section 6 ends with the results of a Summative Final Evaluation of the functional game carried out in nurseries and schools. The experience obtained from this process has crystalized in a set of Reflections presented in section 7, focussing on the feasibility of carrying out this kind of research with very young children and on the value of the data obtained from them during the different design stages. Finally Conclusions and Future Work are presented.

2 Related work

In the last years, classrooms are being digitally augmented by promoting conventional blackboards and tables with image projection and multitouch interaction. The education community is taking especial interest in multitouch tabletops for educational purposes [Evans and Rick, 2010]. Many tabletop-based projects have focused on the new possibilities that multitouch active surfaces offer for collaborative learning [Fleck et al. 2009] in school environments.

Nevertheless, some researchers have claimed that many problems emerge when tabletop devices based on multitouch interaction are used by very young children on the grounds that their fine motor skills are not sufficiently developed [Mansor et al., 2008]. Alternatives have appeared based on hybrid physical board-games and computer augmented surfaces [Heijboer and van den Hoven, 2008] that mix conventional physical manipulation with tabletop devices. In this way, traditional play activities and board-games meet with videogames, combining the benefits of co-located gaming and face-to-face social relations [Magerkurt et al., 2005]. Computer augmentation of objects may also open new horizons in interaction design for children [Guerrero et al., 2009]. Hendrix et al. [Hendrix et al., 2009] proposed the use of miniature construction toys on an interactive surface to help shy children aged 9-10 to reinforce collaborative behaviours and sharing of ideas. Moreover, expanding tabletop application with tangible interaction can make computers accessible to children aged 6-11 with disabilities [Li et al., 2008] [Hengeveld et al., 2009]. However, in the light of the state of the art, it can be realized that not only there is a lack of works that adapt tabletop devices to early years education environments but also works that involve young children in designing new tabletop application for them.

Although the involvement of adult users in the design of technological applications has been widely investigated, there are not so many references for the case of very young users. [Druin, 2002] detected four roles of children in design processes, from more to less involvement in design decisions: design partners, informants, testers and users. As design partners, children are involved in

Participatory Design sessions, brainstorming with designers with equalitarian roles. However, many researches considered children's design partner role as too ambitious [Sluis-Thiescheffer et al., 2007], [Mazzone et al., 2008] as the results are very dependant on children social skills.

Children in the role of informants express their preferences and wishes about technology while using prototypes [Scaife et al., 1997] [Xu et al., 2005]. However, involving children as informants requires enough social and verbal skills [van Kesteren et al., 2003] which are already not completely developed in young children.

A more practical and realistic approach would be to focus on the tester and user roles of children, adapting and optimizing methods to recover data from observing them using the prototypes [Abeele 2008]. However, while adult users and testers are conscious of their role during test sessions and, therefore, they acquire some responsibilities in the process, children, and especially the youngest, only would test new products for fun. In fact, children being conscious of their role is not a desirable situation, as they can interpret that they are being tested instead of the product, behaving shy and reticent to play [Hanna et al., 97]. In this context, nurseries and schools can offer an optimal environment for testing. They provide a well-known environment for the children, as well as adult teachers can help to maintain the planned experiment. Moreover, preschool children love to explore new computer games, with the only motivation of having fun [Hanna et al., 97].

NIKVision aims to bridge the gap between computers and physical activities for very young children by designing a system that couples tangible interaction with digital augmentation (according to their development skills) through a tabletop surface. Furthermore, the design of such technology has been carried out involving children through all the process as testers and users during frequent test sessions starting from the early concepts, until their final evaluation.

3 NIKVision design process

One of the main objectives for creating NIKVision has been to take children into account from the very beginning of its design process. Current user-centred design methodologies either are very time and cost consuming due to rigidity and bureaucracy [Abras et al., 2004], or they limit the involvement of end-users to the final evaluation stage [Bergin et al., 2004]. Trying to avoid both problems we decided to follow the generic cascade design process as proposed by Mayhew [Mayhew, 1999], basically due its simplicity. In Figure 1 the NIKVision design process divided into Mayhew‘s three stages are shown:

- The Concept Creation stage comprises the first research issues and very early concepts explored in order to bring tangible interaction to very young children. These first concepts were tested by children in nurseries, where the first usability and user experience features were observed.
- The Prototype stage reflects the many design questions and the final decisions taken during the creation of a tangible application.
- The Functional Product stage describes the integration of all design decisions taken during the prototype stage in a complete game. The final product was evaluated in a nursery and a school with the aim of recovering wide

summative evaluation data of the tangible game, focusing in usability effectiveness and user experience.

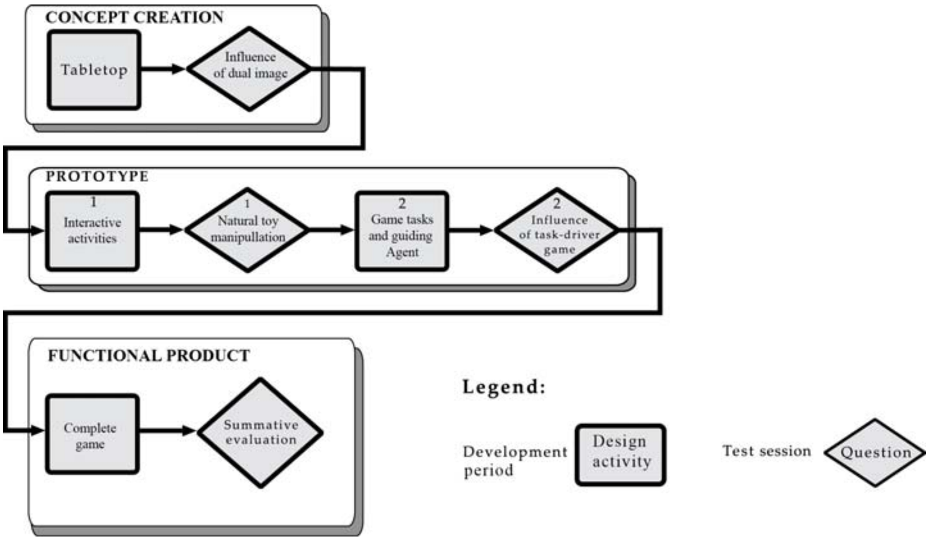

Figure 1: The cascade workflow of NIKVision.

As it can be seen, each stage is composed of various development periods followed by test sessions with children conceived to take the required design decision. From the nature of each decision, a method to retrieve valuable data from children was chosen and applied during a test session; the analysis of these data was taken as a base for the next design iteration. The next sections will give, following the structure of Figure 1, details of each development activity and the subsequent test sessions with children.

4 Concept creation

In order to improve the use of technology in nurseries and preschools classrooms, we started by observing the role of computers in those environments. Usually, children play with computer games as an extra activity in their learning and playing time using conventional computer stations with mouse and keyboard devices. When children play multimedia games, they usually do so in small groups around the computer. As one child can use the mouse and keyboard at a time, the others spend the game looking from below or touching the screen to encourage their friend to act.

4.1 Concept Implementation: NIKVision tabletop

NIKVision concept began with the idea of digital augmenting conventional children activities played on a horizontal surface. In order to do that, the top surface of a conventional table was substituted by a semi-transparent surface, so that any object placed on it could be seen by an infrared light USB camera (fig.2_2) placed underneath the table. Reactivision visual recognition software [Kaltenbrunner and Bencina, 2007] ran in a conventional computer (fig.2_3) to track the position and orientation of toys placed on the surface (fig.2_1), supported by a printed marker attached to their base (see fig.3). Detected manipulations of toys on the table have an effect in the virtual game environment showed in a monitor placed in front of the table (fig.2_6). Image is also showed on the table provided by retro-projection (fig.2_4) through a mirror inside the table (fig.2_5).

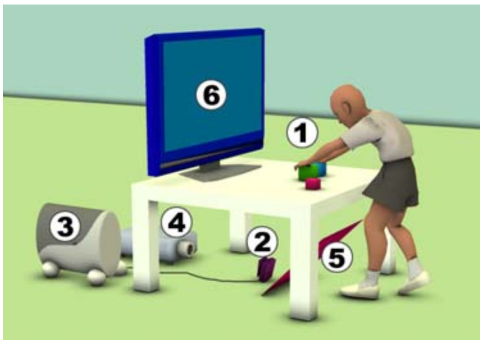

Figure 2: NIKVision tabletop sketch.

Figure 3: Toys with printed marker attached to base.

Observing children playing with toys during their activities, two kinds of interactions were initially implemented for the NIKVision tabletop:

- Move toy on the surface: The software tracks the position and velocity of the toys on the table and these has an effect in the game.
- Rotate toy: The software tracks the orientation of the toys on the table.

There is no limit on the number of toys that can be placed and moved on the desktop, so that more than one child can play at the same time, and therefore the application space is opened to social activities.

In parallel with the construction of the tabletop, different games were explored in order to be implemented for NIKVision. Noticing that farm activities are very popular in toys and multimedia games for very young children, it was decided to create a Farm game for the NIKVision tabletop.

The Farm game concept began with translating a farm toy into a 3D virtual environment showed on the monitor. Four 3D farm animals (a cow, a pig, a sheep and a hen) could be controlled with their corresponding rubber toy. Four bushes were planted in the virtual yard. Each bush had a 3D graphical representation in the monitor (see fig. 4.left) and a corresponding 2D icon in the surface image projection (see fig. 4.right). Children could interact with the bushes by passing an animal toy through them, triggering animation and sound feedback from the interaction.

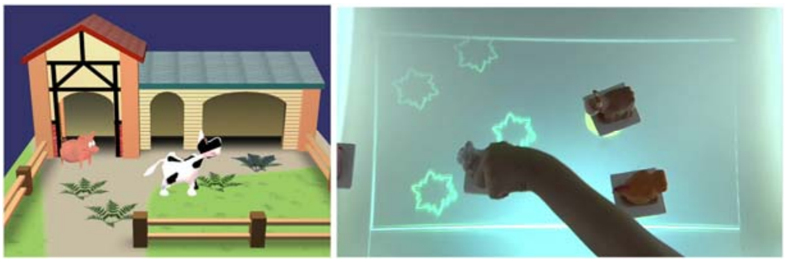

Figure 4: NIKVision Farm game first concept. Left: Monitor output. Right: Table surface output.

An important difference of this game concept from other conventional computer games is the possibility of giving two image feedbacks in different areas, one in 3D in a monitor and another in 2D in the table. Therefore, a test session was arranged to evaluate the influence of both image outputs in the usability of the game.

4.2 Concept Test Session: Influence of dual image feedback

The test session was planned to recover usability data about the impact of the both image feedbacks: on the playable area of the tabletop and on the monitor. Therefore, in this case, the involvement of children consisted in testing two versions of the game, one with only feedback on the monitor and the other adding feedback on the table surface, and comparing both. In Human-Computer Interaction literature there are different methods for capturing children preferences when they use various products, e.g. fun toolkit [Read et al 2008], laddering [Grunet and Bech-Larsen, 2005], “this or that”, “free play” [Zaman and Abeele, 2010]. All these methods require from children to be able to give a qualification or express a preference for each tested product. However, as the age of the tester decreases, children tend to give the maximum qualification to all the products [Read, 2008]. Furthermore, children aged under 8 have not yet enough developed their verbal competences and social skills. With these children, it is not adequate the use of methods that require from them to interact with adult evaluators and verbalize their likes and dislikes about the tested product [Makopoulos and Bekker, 2003]. In this case, observational methods are a very good option since children are merely asked to play with the products which is something they would do anyway [Markopoulos et al., 2008]. But even in that case, the use of observational methods with very young children differs in the way observations are captured and interpreted from testing with adults. Lack of structure of the test and children behaving chaotically during the test (leaving and entering their test and interrupting other's test) have an impact on the validity of in-field observations and in-lab video-recording reviews [Markopoulos and Bekker, 2005]. To minimize this problem, logging methods can provide objective data from children interactions to be analysed in lab [Sanchez and Jorquera, 2000]. Analysis of logs has proved its usefulness in other evaluations in the context of tabletop evaluation with children [Marshall et al, 2009]. For all these reasons, we opted to design a test session using observational methods in a nursery with 12 children aged 3-4 who freely played with both Farm game versions. The game software registered all the manipulations made on the table and stored them in log files. This information could be later graphically represented as paths followed by the children's toys during any game trial. Log data was also complemented with observation notes taken by two evaluators during the trials, paying attention on children's usability differences from both game versions.

In the nursery, the children were grouped in couples. Each couple of children tested both game versions: (A) with only 3D image on the monitor and (B) with both image outputs. Each one tested both game versions, alternating which version was played first. Children were asked to place any animal toy into the bushes of the yard. In this way, the performance of their physical manipulations and their perception of the image outputs could be verified.

After the session in the nursery, log data were retrieved and graphically reproduced in the lab in order to compare both versions of the farm game. The analysis of the paths of the toys revealed that image projection on the surface had a notable impact on children's usability performance. The movements of toys extracted from the log files showed more precise movements when the image projection was present (see fig. 5). However, during the trials, two couples of children had problems to realize that the icons projected on the table surface were mapped to the 3D bushes on the monitor, because they were playing as if there were no image projection, only looking at the monitor. After an adult assistant pointed out to them the meaning of projected icons, they started looking at them to locate the bush positions.

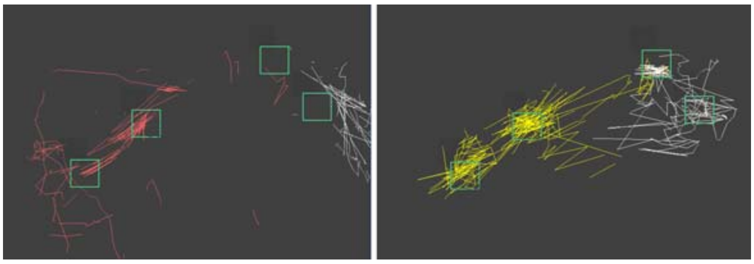

Figure 5: Log data graphically presented as toy paths. Green squares represent location of interactive bushes on the yard. Left: Version A with only 3D monitor image feedback. Right: version B with dual image feedback.

The data obtained from this test session are summarized in table 1.

A. Only 3D environment on the monitor Usability: Children had problems to translate a 2D position of the toy on the surface to the 3D space of the farm virtual environment showed on monitor.
B. Dual image feedback. 3D environment on the monitor and 2D graphics projected on the table surface Usability: POSITIVE: Children easily placed the toys on the interactive areas of the farm, provided by the graphic icons projected on the table surface. NEGATIVE: Some children may not perceive the graphics on the table as their attention goes mainly to 3D environment on monitor.

Table 1: Summary of the Concept Test Session divided in (A) Only 3D monitor image feedback and (B) Dual image feedback farm game versions.

From the analysis of the data recovered in this test session, it was decided to maintain the 3D scenery on the frontal monitor, but also to attract children's attention to the image projection by improving the 2D graphics to be more closely related with the 3D virtual yard showed in the monitor.

5 Prototype

The prototype stage focussed on enriching the interaction of the Farm game. Many questions arose during this stage. The nature of these questions falls in one of these categories:

- Capture of children preferences.
- Evaluation of the impact of a new feature in the prototype.

Each category requires different methods to recover valuable data during the test sessions to support the design decisions that trigger the next development iteration. Usability and user experience data from children were retrieved using observational methods, while children preferences were retrieved with the support of the Wizard of Oz [Höysniemi et al., 2004] method.

5.1 First prototype implementation: interactive activities

In order to offer children a richer experience, the farm game was improved adding new physical and virtual elements, associated to specific farm activities:

- Physical toys: besides the animals used in the previous stage (pig, cow, hen and sheep), a toy bucket was added to be used in a new activity in which the cow can give milk in the bucket.
- Interactive virtual elements:
    - 3D elements: four plants were included for the activity of finding strawberries inside them (see fig.6 left).

- 2D icons: a nest and a barrel were added in relation with two new activities: laying eggs (hen toy) and giving wool (sheep toy). The 2D graphics icons projected on the table surface were also enhanced to attract the attention of the children and to support them placing the toys on the interactive areas of the game (see fig. 6 right).

Figure 6: First Prototype iteration: Farm game prototype with more activities and enhanced 2D (right) and 3D (left) graphics.

At that moment, it was necessary to decide the physical manipulations that children should use to interact with the toys and the virtual objects. Usually, in early prototype tests, it is common to ask the user to “figure” or “imagine” that some system functionalities are implemented, but this is not viable with children. It is important to remember that children are not really “testing” the prototype, they are playing, and they will only do so for fun. A Wizard of Oz method [Höysniemi et al.,2004] can be helpful to maintain the illusion in children of playing a functional game. Instead of implementing algorithms to detect specific gestures on the tabletop, it was decided that a Wizard of Oz adult assistant would be in charge of activating game feedback using keyboard strokes. In this way, an early test of the new elements of the game could be carried out with minimal codding effort.

5.2 First prototype test session: natural toy manipulation

The aim of this test session was that children informed us about their preferences when manipulating toys in the Farm game. However, as stated in section 2, the informant role of children relies in their verbalization and social skills. For that reason, we planned this test session based on a Wizard of Oz method that, ultimately, led children to inform us of their preferences without verbalization. To do so, and previous to the test session, the game had to be prepared: animations and sound of the virtual plants, nest, barrel and bucket were activated with keyboard stokes.

The test session was carried out in a school classroom with 14 children aged 4-5. An adult assistant was in charge of triggering the feedback and responses of the game according to children’s manipulations (see fig. 7) and other assistant was in charge of the video-recording and taking observation notes. Children play in couples and they were asked to use the hen to lay eggs, the cow and the bucket to give milk, the sheep to give wool and all the animals to look for strawberries in the plants. No instructions were given about how they must perform each action, as indeed the NIKVision software did not recognise any gesture of the toys on the table. The children's manipulations were observed by the Wizard of Oz, who triggered the animations using the keyboard when a child performed a manifest action with the toy: the children were really receiving feedback from the game which motivated and encouraged them to continue playing.

Figure 7: First prototype test session: Using a Wizard of Oz method.

To minimize biased effects during the evaluation of the observations recovered during the test, we followed the method proposed by Höysniemi et al. [2004]. The in-lab analysis of the Wizard of Oz test session consisted in collecting a "gesture corpus" with the most common toy manipulations carried out by the children. The adult evaluator reviewed the video-recording and the observation notes taken in the classroom to write down a list of gestures and the farm activity in which they were made. Table 2 shows the results of the most common gestures.

Gestures identified:

- "Jump": Children made quick jumps with the toys over the icons projected on the table surface.
- "Shake": children made quick drags imitating to shake the plants (specifically in the plants icons).
- "Mount": Children tried to combine two toys (the cow and the bucket) one over the other to perform an action (to give milk).

Problem identified:

- Children were not able to understand the shear activity, so no gestures were identified.

Table 2: Summary of the first prototype test session.

Based on these results, algorithms for detecting the "jump" and "shake" gestures were decided to be implemented; the log files collected during the test session were useful to implement precise detection algorithms for both gestures. On the contrary, it was not possible to implement the “mount” gesture because of technical limitations, given that the tabletop video camera was not able to “see” a toy if it was not directly placed on the table surface. In consequence, the bucket toy was discarded and the milk activity was redesigned with a virtual bucket in the 3D yard and a new graphical icon on the tabletop surface where the children could jump with the cow to give milk.

The shear activity also presented problems. Children expressed confusion when the shear animation was triggered. No one understood the relationship between the barrel and the sheep when they were asked to give wool with the sheep and they were not able to interpret the barrel animation as a shear action. Therefore, a new shear activity was ideated, based on a more familiar situation for very young children in which the sheep goes to the barber to get her hair cut.

5.3 Second Prototype Implementation: Game tasks.

From the results of the previous test session, the script of the farm game was designed including four interactive activities:

1. Collecting strawberries (see fig. 8.a): children have to find hidden strawberries in four plants in the yard. Any animal can be used for being shaken or jumped on a plant. The children have to collect five strawberries to complete the task.
2. Laying eggs (see fig. 8.b): only the hen toy can trigger this activity. The children have to jump with the hen on the nest and with each jump one virtual egg appears in the nest until four eggs are laid.
3. Giving milk (see fig. 8.c): similar to the eggs activity, the cow has to jump on the virtual bucket. With each jump, the bucket fills a little with milk. After four jumps, the bucket is filled up.
4. Giving wool (see fig. 8.d): the children have to place the sheep toy on a virtual barber chair, where it gets a haircut.

Figure 8: Different goals of the farm game: a/ collecting strawberries. b/ laying eggs. c/ giving milk. d/ giving wool.

As the farm game was intended to be completely autonomous, with no adult intervention, it was decided to introduce an autonomous character with the function of guiding the children through the activities. Therefore, a 3D farmer character was modelled, animated and embedded in the 3D farm scenery (shown in fig. 8). The aim of the virtual farmer is to provide tasks to the children and to ensure that all features of the game are addressed. However, in the context of videogames, research has shown that task-driven games may negatively influence user experience [Vermeeren et al., 2007], affecting fun and the exploration and discovery benefits of games. To retrieve information about the influence of the farmer character two different versions of the game were developed:

A. Free game: the farmer character is silent and does not give instructions. It only collects the strawberries, eggs, milk and wool that the children produce playing freely. In consequence, the children can do the activities out of order.

B. Task guided game: In this game version, the farmer takes part in the game giving verbal instructions to carry out the tasks in a fixed order: strawberries, eggs, milk and wool. Additionally, three different behaviours were modelled to give instructions:

1. "What to do": the farmer only says 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 put (plants, nest, bucket, barber chair), with verbal instructions and moving near the object in the virtual scenery.
3. "What, where, who and how": the farmer specifies what to do, with what animal, where and how to do the manipulation (shake, jump…).

5.4 Second prototype test session: influence of task-driven game

The aim of this test session was to evaluate the impact of introducing a new feature in the prototype: an autonomous agent to guide the game. For this purpose the plan was to compare the way children played with the non-task-driven farm game and with one completely task-oriented with a virtual farmer and retrieve the differences, not only in the game usability, but also in the children experience. Also, it was important to detect the influence of different levels of explanation in the task-driven game. To retrieve these data, the test session was planned with observational methods supported by observation notes, video-recordings and log files.

20 children aged 4-5 year of a school classroom participated in the test session. Teachers organized the children in pairs and evaluators assigned each one either the "non-task-driven" version (A) or the "task-driven" version (B) of the game with one of the three different farmer behaviours. During the full day test session in the school, ten pairs of children tested the game, so each version was tested at least twice. Before starting playing, all couples of children received the same explanation about the game with independence of which version they were going to play. No instructions were given, only that they would have to use the toys on the table to play.

The trials were video-recorded and observation notes were written, paying especial attention to the order in which each task was carried out and which tasks were not completed. Also, the log tool was improved to retrieve the instant when each gesture (shake, jump) was recognised by the system and to store farmer's movements and verbalizations.

After the test, when analysing the videos, logs and notes collected in the trials, an important difference emerged between both versions: Behaviour of children playing with the "non task-driven" game version can be described as exploratory. Children started playing by picking one toy randomly and explored the yard by dragging the toy on the table surface and usually they discovered the different activities accidentally. On the other side, regarding the "task-driven" game version, it was observed that all children completed all the activities from beginning to end in the correct order suggested with the three farmer behaviours. The children quietly listened to the farmer's instructions and then tried to achieve only that goal (although the game still allowed them to do all the tasks in any order independently of what the farmer was asking for).

Regarding with the different levels of farmer explanations, in the level of less explanation a pair of children asked for help from adults or friends in the egg and milk tasks, as they did not know how to complete them after hearing the instructions. In the other behaviours, all the children were able to complete the tasks without intervention and with no significant differences. Moreover, the redesigned "giving wool" activity was understood by the children, who found very funny to sit the sheep in the barber chair and see how she gets a haircut.

On the other hand, reviewing the videos of the session in order to retrieve user experience data, it was observed that children showed more fun in the "non task-driven" version of the game, with more laughs and frequent verbalizations between both children exploring and sharing what they discovered on the game. In contrast, in "task-driven" versions of game, it was observed that usually only one child played at one time trying to complete the assigned task, while the other partner just kept observing and waiting to the next task.

Results from the analysis of the videos, logs and notes collected in the trials, are summarized in the table 3.

A. Non task driven game	**Usability**: only tasks that covered a wide or centred area of the tabletop (strawberries and milk) were discovered by all children, while those with less area of interaction (eggs and wool) were never accessed. **User experience**: Children showed more fun and interaction between partners while exploring and discovering the game activities.
B. Task driven game	**Usability**: each task is carried out in the assigned order. Levels with less explanation of farmer confused children, who preferred to ask adults assistants that trying to discover by themselves. **User experience**: group playing was limited, as each task was carried out by one child at a time, in detriment of fun and social interaction between children.

Table 3: Summary of the second prototype test session.

As a conclusion of the test, the non task-driver game version promoted explorative and social activities in children, but children missed some goals of the game as they never discovered them. By using an autonomous character to guide children through all the game goals, children completed them, though children interaction became more rigid. The Farm game was not created with a specific educative objective, but thinking in using NIKVision in educational environments, completion of tasks of the game should be important for transmitting all the pedagogical content of a future educative videogame application. For that reason, the task-driven approach was kept and a compromise was reached between the usability and the user experience with the "what and where" level of explanation.

6 Functional product and final evaluation

The iterative nature of the prototype stage helped us to take all the design decisions needed to complete the Farm game as a totally functional product to be used as a ludic activity. The work in this stage focussed on achieving a complete product, aimed to be used in early-year education environments and to provide fun and playful physical and co-located activities to young children. It was decided to integrate the collecting strawberries, eggs and milk activities in a game with one objective: help the farmer to find the ingredients needed to make a cake.

The fully functional game prototype was evaluated in nurseries and schools. The evaluation was aimed to recover wide summative data of the tangible game, focusing in the following usability issues:

- Those related with a videogame application: game task completion, paying especial attention to the influence of the autonomous character.
- Those related with the tabletop tangible device: promotion of physical activity through toy manipulation, and co-located gaming through groups of children actively playing with the game.
- Those related with user experience: engagement of children in a playful and funny activity.

In the following sections, the tools used to evaluate the functional game are described and the summative analysis of the recovered data is presented.

6.1 Evaluation tools

The plan for the final evaluation was to install the tabletop and the Farm game in nurseries and schools to recover data of their use by children minimizing adult evaluator's intervention. In order to do that, evaluation methods based on Usability Testing were used with children involved as mere users, playing freely with the game. Data were retrieved from video-recording and automatic log files. Summative data were extracted by software tools that analysed all the log files and gave statistical measures of:

- Task completion: percentage of tasks completed related to the total number of trials of the tasks.
- Influence of the autonomous character: percentage of tasks completed in the order driven by the farmer character, to the total number of tasks completed; and percentage of tasks in which children gave additional ingredients (eggs or milk) that just the amount asked by the farmer, to the total number of tasks completed.

- Physical activity and co-located gaming: they are measured by the number of manipulations and different toys used on the table during a time unit and graphically represented with their evolution during the time of the trial.

To capture the fun and children engagement, sessions were video-recorded by two cameras. One camera was placed under the monitor to capture children faces. This video-stream allows transcribing children gestures and verbal expressions while interacting with each other, as well as engagement from retrieving the point of attention of children. The other camera was placed in order to capture all the tabletop surrounding area. By placing the camera high up on a tripod, a view of the tabletop surface and children's manipulations on it can be captured. This video-stream helps to identify usability problems during the game (problems in carrying out a task, difficulties in performing the physical gestures, etc.) that log analysis is not able to detect. Interaction between children was also retrieved with the camera (to see if children played independently or helped each other, or if some child stopped playing to watch his/her partner).

In the analysis phase, both video-streams were synchronized together with a graphical animated representation of the log file. The complete video-stream composed of the three views (see fig. 9) was used to relate all game events to the fun and the engagement of groups of children during the game.

Figure 9: Three video-streams synchronized. Left: face camera. Central: tabletop camera. Right: log video-stream.

6.2 Summative analysis

The data of the final evaluation were retrieved from two sessions: one carried out in a nursery with 3-4 year-old children and the other in a school classroom with 4-5 year old children. The initial plan was to analyse both sessions together but, even with this small age gap, there are important differences in cognitive and motor skills in children [Piaget, 1952]. Moreover, the nursery and school environments showed important differences that may influence in the results. In the nursery, NIKVision was available simultaneously with the rest of the activities. Toddlers came in groups of three to play freely with the game. On the contrary, in the school NIKVision was installed in the library, not in a classroom. Adult intervention was not as minimized as in the nursery, since the teacher brought groups of two or three children to play with the game and adult assistants introduced the game and encouraged the children to start playing. It can be deduced that children in the nursery did not feel of being tested and played completely disinhibited; but in the school, children had the feeling of being tested, behaving shy when entering the library, and sometimes even asking for permission to start playing. For this reason, the analysis is presented separated from the origin of data: nursery or school.

The “Making a cake” game starts with the farmer asking the animals to help him to make a birthday cake. For this purpose, he first asks for 5 strawberries which appear randomly within the plants: the children can use any animal toy to pick strawberries. Then, the farmer asks for 4 eggs, and only the hen toy can do this activity. Finally, the farmer asks for milk, which is obtained by jumping with the cow four times on the bucket. When one of those tasks is completed, the farmer announces that he does not need more and asks for the next ingredient. Anyway, children can continue laying eggs and giving milk if they want to.

Ten trials of the “Making a cake” game were obtained from the nursery session and twenty from the school. Figure 10 shows the summative analysis extracted from the log files.

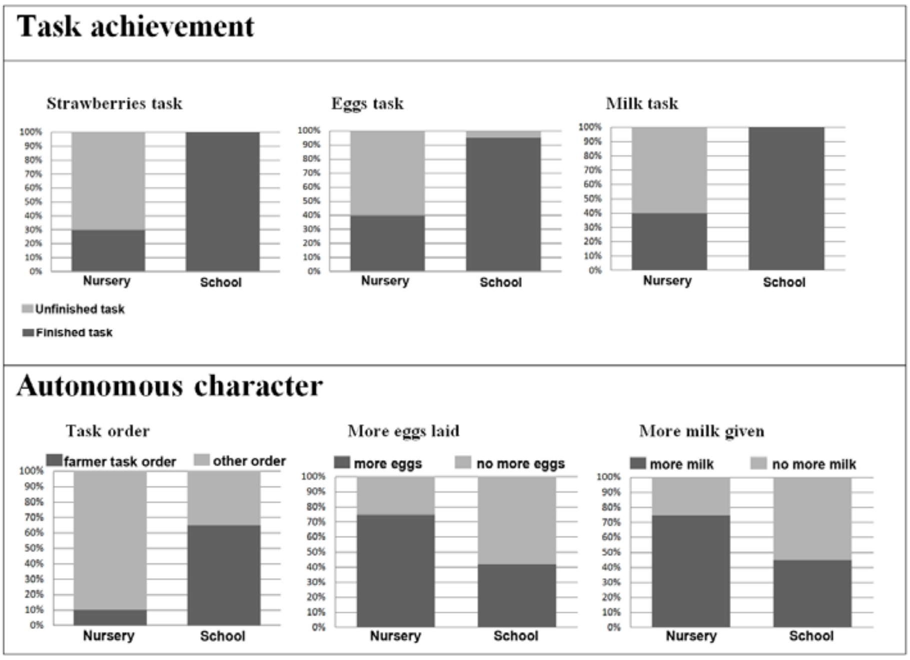

Figure 10: “Making a cake” game: Task completion rates and impact of farmer autonomous character.

In the school test nearly all groups finished all the game goals, in contrast with the nursery where most of the children did not finish the tasks. The video-analysis of the nursery data showed that carrying out the tasks did not seem too challenging for the toddlers. They were able to shake the bushes and to stomp with the cow and the hen to give milk and eggs without any difficulty. But their motivation was merely exploration, so they did not worry about the amount of strawberries, eggs, and milk needed to complete the task. The toddlers explored the yard freely, not paying attention to the farmer’s verbal instructions. Indeed, the chaotic and noisy environment of the nursery did not help the farmer to be heard. This is confirmed by analysing the order in which the tasks were carried out (see fig. 10): while in the school most of the children carried out the tasks in the order asked by the farmer, nearly no trial in the nursery was made following farmer instructions. Also, in most of the nursery trials, toddlers also laid more eggs and gave more milk that the amount asked by the farmer. Therefore, it can be concluded that the farmer had almost no influence during the nursery test. On the other side, in the quiet environment of the school library, the farmer was easily heard and the children played mostly following the order proposed by the farmer. However, the school measurements show that nearly half of the groups that had already finished the eggs and milk tasks, continued repeating them as there was no limit to the eggs and milk they could produce, pointing that children in the school wished to carry out the activities beyond the farmer commands.

Regarding the game performance in promoting physical and co-located gaming, figure 11 shows the graphs of the evolution of these measurements during a trial of the game comparing nursery and school sessions. As each trial game has a different time length, all the game trials were divided in 30 time segments, to obtain the statistics.

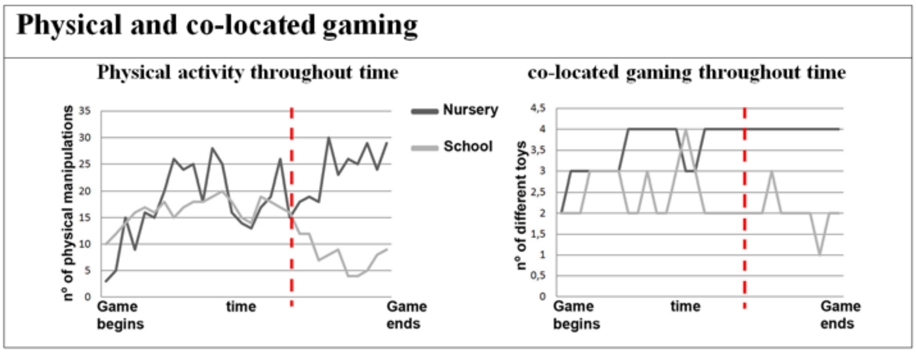

Figure 11: "Making a cake" game: Physical and co-located gaming.

The school trials show high physical and co-located gaming during the first 2/3 of the game (until the red line in the graphs), decreasing to the end of the trial. As the school trial was more task-driven, it shows that the strawberry task (the first task requested by the farmer) engaged children in a more intense physical and co-located activity than the eggs and milk tasks which can only be carried out by one toy (hen and cow respectively). This was confirmed by the video-streams, where more than one child could be seen trying to find strawberries on the bushes at the beginning of the game but, when the strawberries task finished, only one child carried out the eggs and milk tasks while the other partners looked away. In contrast, in the nursery, physical and co-located gaming measurements show nearly inverted results: these rates increase continuously during the trials and are higher than in the school. Looking at the videos, it can be observed that toddlers behaved rather shy at the beginning of the game, not knowing how to play. But soon, they discovered how to interact with the yard elements, and physical and co-located gaming increased to a maximum until the end of the game, even with one child manipulating two toys at the same time table.

Fun and engagement of children in the game was extracted from video-streams. Children attention went to the monitor most of the time. Laughs and expressions of fun were always related with 3D animations and sounds. Children only looked at image projection on table surface during very short periods of time when they needed to locate the strawberries in the plants and the nest and bucket. But once they placed the toy on the spot, they performed the gesture looking at the monitor, and laughed when the strawberries were dropt, the eggs were laid and the milk filled the bucket (see fig. 12).

Figure 12: Four year old girls playing. Top: seriously manipulating toys on table surface Bottom: having great fun seeing animations on monitor.

This evaluation shows results, not only about the impact in usability of a guiding autonomous agent, but also the influence that the design of tangible tabletop activities and toy roles have in promoting physical and co-located gaming in young children.

7 Discussion: designing tabletop games for young children

From the experience gained during the design process and the final evaluation of the Farm game developed for our tangible tabletop device, some lessons might be extracted that could be useful for developing future tabletop games for very young children.

- The addition of a conventional vertical monitor, complementary to the active image shown on the table surface, has notable impact in fun, as had been assessed with the analysis of video-recordings of the sessions: children expressed fun and engagement in the game while looking at the animations in the 3D scenery on the monitor. This benefit should be exploited with an adequate distribution of visual feedback between monitor and tabletop projection. While the first should be in charge of engaging children in the game, using an attractive scenery, funny animations and autonomous characters, the second should give visual feedback about task completion and guide children to locate the interactive spots where toys are manipulated.

- The inclusion of a virtual character and its role in the game must be carefully considered depending on the game objectives. In games where children need to go throughout all the tasks so that pedagogical content is transmitted, the use of an autonomous character to provide instructions and precise commands is determinant. In a task-driven approach with a guiding character imposing the order of task completion, children get a clear understanding of each task objectives and end conditions. However, interaction with the game may become rigid, with less fun and spontaneous moments. On the other hand, a free game with no autonomous character giving instructions may support better explorative behaviours in children, enhancing physical and co-located gaming. The use of a virtual character in this kind of scheme may still have benefits in engaging children, if its behaviour is oriented to inform children of their progress through positive and negative feedback.
- Guidelines extracted from previous literature about videogames and children [Malone and Lepper, 1987] may be useful, but designers should consider new ways of TUI interaction closer to non-digital toys and gaming. In other words, the potential of a tangible tabletop to promote physical playing is better exploited when the classical videogame model (with task and objectives to be sequentially achieved) is avoided, and children are left to freely explore and discover how to activate sound and animations. In this scheme is where a guiding virtual character could help to engage children in the exploration of the game.
- A tabletop device which supports co-located gaming does not grant this issue by itself. The design of the game tasks is decisive to engage groups of children to actively play with the toys. By giving balanced roles to each toy throughout the game, children can take any toy at any moment and start exploring its interactions in the virtual environment of the game, promoting co-located gaming.
- Psychomotor and cognitive development of children should always be considered when designing any game task: will children understand that a sheep can be sheared to give wool? When children are asked to shake or stomp with the toys, will they all perform the gesture in the same way? Observation of children playing with the games helps to solve this kind of questions, and with an iterative design process the game can be refined and adapted to children capabilities.

There are some important considerations that designers and developers interested in receiving help from young children have to take into account during the process of creating a new technology:

- The most important decision is to define the role of children in the project from the beginning. Higher involvement children roles, like design-partners and informants, may be very useful to detect children needs and preferences, but are not adequate for very young children, as their social and cognitive development is not enough for a natural relation with adult evaluators. Furthermore, these roles require more structured evaluation sessions, which can compromise the value of the data obtained. In fact, our experience during the evaluation sessions with very young children shows that the more structured the session, the less useful the data obtained. One possible explanation would be that the great amount of instructions that is necessary to give to them before they start, reducing their naturalness and spontaneity when playing. An additional risk in this kind of structured sessions is that the child may have the impression of being tested. On the contrary, those sessions in which the game becomes one more classroom activity among others, provide more reliable, honest and valuable data to evaluators. Additionally, the use of log files and video-streams allows to face the evaluation in an objective and exhaustive way.

- Regarding which are the most adequate place to carry out the evaluation sessions, nurseries and schools are very versatile environments for developing projects involving adult designers and children. Toddlers have difficulties in adapting to new environments and new people. Therefore, children may have unpredictable reactions in laboratory test sessions, added to which it is difficult to arrange frequent visits to the lab and usually only small groups of children can enter the lab at a time. On the other hand, many teachers are willing to collaborate with researchers offering their classrooms and time, provided, of course, that all ethical questions about testing with children have been carefully considered and permissions from parents have been granted. For designers, classrooms provide a sufficient number of users for formative and summative evaluation, as well as being a favourable environment for inspiration and creativity.

To conclude, the most important thing to consider when planning a test session is that children are using the product just for fun.

8 Conclusions

The feasibility and impact of bringing digital technologies based on tangible interaction to early years environments have been explored in the present work. A tabletop device and a tangible game were created with the aim of engaging groups of children in a physical and co-located ludic activity by manipulating conventional toys on a digital augmented table. From the very early concepts of the game, children have been involved in every design decision evaluating the impact of new game element, or to decide the more natural gestures and interactions. In order to do that, several Children-Centred Design methods have been used to capture usability and user-experience data from children playing with the game prototypes. The methods used during each test session were selected according to the kind of data needed to capture. However, due to the young age of children, methods based on children expressions or verbalizations of their thoughts were avoided. Instead, Usability Testing methods, like observation notes, automatic logging and video-recording were used. These methods have proven to be very useful to compare different versions of the prototype and, combined with other methods of children involvement like Wizard of Oz in order to capture their natural gestures to be implemented in the game.

The final version of the Farm game was summatively evaluated focusing on game task completion and physical and co-located activity of children while playing freely with the game.

The experience obtained during this process has been summarized in a set of general guidelines and reflections about the design of new digital activities for children based on tangible interaction and the involvement of very young children in this kind of projects.

9 Future work

From the final evaluation of NIKVision several improvements have emerged that will trigger a new iteration of the Farm game in the next future, and will set the base for the design of new NIKVision toys and games. These new games will add a new objective to the tangible interaction: collaboration between children. Also, we will work on the development of a “smarter” autonomous character farmer able to play a role as helper and guide in a non task-driven farm game.

Children with different cognitive disabilities also come within the scope of NIKVision’s future work. We intend to explore the benefits that these tabletop technologies can provide in the education of children with special needs. In this context, there is a huge research field in adapting the methods exposed in this paper to retrieve usability and user experience from children with especial cognitive needs.

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