Hybrid Games: Designing Tangible Interfaces for Very Young Children and Children with Special Needs

Eva Cerezo, Javier Marco and Sandra Baldassarri

Abstract During recent years, our group has been combining tabletop devices and Tangible Interaction in several experiments in nurseries, schools and special education schools. The development of tangible tabletop games for children involves the integration of physical, virtual and social aspects, thus introducing new challenges to their design, implementation and evaluation processes. This chapter describes the complete process of creating a tangible tabletop game for kindergarten children. The role of the children in every step of the process is discussed, and the different evaluation methods used are shown. The frequent evaluation sessions have provided us with valuable information such as the kind of gestures to be recognized, the benefits of using an additional monitor, or the convenience of using a virtual agent to guide the game. These and other lessons extracted from our experience are presented and discussed in the chapter. An evaluation of the game in a special education environment is also described. Owing to the particular social and cognitive characteristics of these children, conventional well-known usability and user-experience evaluation methodologies are not suitable. Findings from these evaluations are also shared and discussed in order to help in the challenging task of designing tangible tabletop games for all.

Keywords Tangible interfaces · Children-centered design · Tabletop hybrid games · Children with special needs

E. Cerezo · J. Marco (✉) · S. Baldassarri
Advanced Computer Graphics Group (GIGA), Computer Science Department, Engineering Research Institute of Aragon (I3A), University of Zaragoza, Ed. Ada Byron. Campus Río Ebro, C/María de Luna N.1, 50015 Zaragoza, Spain
e-mail: javi.marco@unizar.es

E. Cerezo
e-mail: ecerezo@unizar.es

S. Baldassarri
e-mail: sandra@unizar.es

A. Nijholt (ed.), *More Playful User Interfaces*, Gaming Media and Social Effects,
DOI 10.1007/978-981-287-546-4_2

1 Introduction

One of the emerging research fields in human–computer interaction (HCI) is concerned with innovative interaction techniques that aim to provide a more seamless bridge between the physical and digital worlds. Tangible user interfaces (TUI) aim to give physical form to digital information by coupling physical manipulations of conventional objects with computational systems (Ishii and Ullmer 1997). TUI are envisioned as an alternative to conventional desktop computers (monitor + keyboard + mouse) that would bring some of the intuitiveness of the interaction with conventional objects back into our interaction with digital content.

Games and entertainment computer applications are especially prolific in putting into practice the TUI paradigm, giving rise to a new generation of hybrid games which combine traditional physical playing based on the manipulation of toys and playing pieces, with the new possibilities of digitally augmenting the player's area with computer images and audio feedback.

Large horizontal interactive surfaces (or tabletop devices) are emerging as an ideal environment for these innovative hybrid games (Heijboer and van den Hoven 2008; Leitner et al. 2010). Tabletop devices are of particular interest for reinforcing face-to-face social relations (Rogers and Rodden 2003) and group activities (Morris et al. 2005). However, most current child-oriented applications for tabletops are based on tactile interaction. This poses important problems when applied to very young children or children with physical and cognitive disabilities since this kind of interaction requires fine muscle coordination. This problem can be avoided in the Tangible Interaction approach, investigating how objects and digital content could be more intuitively coupled and how to better apply TUI to children. Recent studies carried out by Marshall et al. (2003) and Zuckerman et al. (2005) proved that applying the Tangible Interaction approach to young children can take advantage 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 and Rogers 2004). However, there is a lack of studies about the impact of Tangible Interaction with very young children (3–6 years of age). Moreover, the application of alternative ways of interacting with digital contents has also recently revealed important benefits for special needs children (Bevan 2003; Piper et al. 2006). New interactive devices are not only more physically accessible but also offer a more direct and flexible form of showing digital information to the child. However, the lack of specific studies in this area is particularly noticeable.

In recent years, our group (the AffectiveLab at the University of Zaragoza, Spain) has been combining tabletop devices and Tangible Interaction in several experiments in nurseries, schools and special education schools. Our approach is that an appropriate combination of a tabletop computer device with Tangible Interaction can bridge the gap between digital- and physical-based activities for young children and/or children with cognitive disabilities. The objective of our work is to explore the benefits that this kind of technology offers to these children in terms of usability, user experience and physical co-located playing. In this context, we decided to create the NIKVision system, which consists of a tabletop device and a set of tangible games (Marco et al. 2010a) designed to support co-located gaming around the table with a Tangible Interaction approach based on toy manipulation. To achieve an optimal design for the NIKVision tabletop and games, the development process was undertaken with the active involvement of children right from the very early conceptual stage (Marco et al. 2010b, 2013a). The participation of children in the technological design of products oriented to them is always desirable, but it involves many challenges (Raisamo et al. 2006). The very considerable variation in their needs and social skills depending on their age and even among children of the same age has to be taken into account as well as the ethical questions involved (Farrel 2005). Even though useful guidelines have been provided by researchers such as Read et al. (2002), Markopoulos (2008) and Druin and Hanna (1999), the best way of selecting the role of children in a project and the most suitable testing method in every step still remains an open question. Besides, the consideration of children with special needs, in particular, with cognitive disabilities makes the evaluation issue even more difficult but opens the door to the challenge of designing TUIs for all.

This chapter is organized as follows. Section 2 describes the state of the art. Section 3 presents our tabletop NIKVision. Section 4 describes the complete process of developing a tangible game for kindergarten children from the creation of the concept to the final evaluation, as well as the lessons learned. In Sect. 5, an evaluation of the game with special needs children is presented. Finally, Sect. 6 is devoted to the conclusions.

2 Related Work

The work described in this chapter relates to two main research areas: computer-augmented surfaces for very young and special needs children and the evaluation of interactive applications with children. The most relevant works in both areas are summarized below.

2.1 *New Technologies for Very Young and Special Needs Children*

In recent years, classrooms have been digitally augmented by replacing conventional blackboards and tables with computer-augmented surfaces provided with image projection and multitouch interaction. The educational community is taking a special interest in creating pedagogical content for multitouch-based tables (or tabletops) (Utani 2012). Many tabletop-based projects have focused on the new possibilities that multitouch active surfaces offer for co-located learning (Scott et al. 2003; Cappelletti et al. 2004; Morris et al. 2005). 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; Harris et al. 2009). Alternatives have appeared based on hybrid physical board games and computer-augmented surfaces, keeping playing pieces in the players' physical environment (Mandryk and Maranan 2002; Heijboer and van den Hoven 2008), and thus reinforcing the emotional impact of the game (Magerkurth et al. 2005; Hengeveld et al. 2009). This way, traditional play activities and board games meet with video games, combining the benefits of co-located gaming and face-to-face social relations (Iwata et al. 2010). The handling of conventional toys on an interactive surface may also open new horizons in interaction design for children. 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 behaviour and the sharing of ideas. Also, tangible educative materials such as cards have been used on computer-augmented tabletop surfaces to reinforce the learning of reading skills (Sluis et al. 2004) and maths (Khandelwal and Mazalek 2007) for 5-to-7-year-old children. Expanding tabletop applications with Tangible Interaction can make computers accessible to children with cerebral palsy (Li et al. 2008) and to children with social disorders (Pipper et al. 2006; Battocchi et al. 2010; van Veen 2009). These studies have provided promising results about the accessibility and benefits of this technology. However, studies that combine tabletop devices and Tangible Interaction applied to children with cognitive disabilities remain scarce and of a preliminary nature (Hengeveld et al. 2009; Pontual Falcão 2010).

In the light of the state of the art, it can be seen that there is a lack of works that adapt tabletop devices to very young and special needs children using Tangible Interaction with the aim of achieving the seamless integration of computers with conventional physical games and activities.

2.2 Evaluating with Children

Young children are users of technology and are thus entitled to be involved in user-centred design projects. However, many products for children are still analytically evaluated only by adult experts (Buckleitner 1999), but it is not easy for an adult to step into a child's world, and therefore, expert evaluation can miss important problems that could emerge when the final product is used by children (Druin and Hanna 1999).

Well-known evaluation methods for adult users are also applied in evaluations with children, but the special characteristics of the child's development stage may require substantial adaptations of these methods. Some such methods may even need to be discarded when working for children belonging to specific age groups (Rounding et al. 2013). It should be remembered that young children are less able to read, verbalize, concentrate and perform abstract logical thinking than adults (Markopoulos and Bekker 2002). Their undeveloped ability for translating experiences into verbal statements and for formulating compound and abstract tasks could pose problems, as their abstract and logical thinking abilities are not yet fully developed and they are not skilled in keeping multiple concepts simultaneously in mind. Inquiry methods which rely on these skills are therefore not suitable for very young children.

Observational methods seem to be the most appropriate for product evaluation involving children, although some techniques of observational evaluation that work with adults may not necessarily work with children. Hanna et al. (1997) suggest that children's frowns and yawns are more reliable indicators of lack of engagement than their responses to questions. Read et al. (2002) propose that children's engagement could be measured by observing the occurrence of a set of behaviours including smiles, laughing, signs of concentration, excitable bouncing and positive vocalization, while lack of engagement could be measured through frowns, signs of boredom (ear playing, fiddling), shrugs and negative verbalization. Formative evaluation methods of children's products must look not only for usability problems, but also for positive factors such as magic (Xu et al. 2009) and fun (Pagulayan 2003; Sim et al. 2006). Usability and fun are closely linked. If the game has a goal too easy to achieve, children might get bored; but if it is too difficult, children may get frustrated. Usability and fun problems will occur during the test and will influence each other, but after the test, it may be necessary to distinguish between them as they may require different solutions.

In the case of children with cognitive disabilities, all the aforementioned problems become even more marked so that observational methods and expert evaluation are the only possibilities (Lepisto and Ovaska 2004). But even these methods should take into account such children's difficulties in adapting themselves to a testing environment, interacting with the facilitator, following some procedures and, in general, contributing to the evaluation by reporting on their experiences. Methods based on the structured analysis of video sequences captured during test sessions may be carried out without requiring active participation in the evaluation process, leaving the children to interact in a natural way (Van Kesteren et al. 2003). These methods may be adapted to the consideration of usability issues such as fun and user experience (Barendregt 2006) and accessibility matters that go beyond hardware concerns, incorporating broader concepts such as children's understanding, digital feedback and adult support during the interaction (Hasselbring and Glaser 2000).

In conclusion, the evaluation of applications with very young children still remains an open question. In the case of testing with cognitive disabled children, the difficulties and challenges markedly increase and require specific efforts and studies.

3 The “NIKVision” Tabletop

The NIKVision tabletop (Marco et al. 2009) uses well-known techniques for multitouch active surfaces (Schöning et al. 2010), but its design is mainly focussed on Tangible Interaction and therefore in the handling of physical objects on the table surface. It is easily mountable and dismountable and, because it is oriented to kindergarten children, robust and safe (Fig. 1).

Children use NIKVision by manipulating conventional toys on the surface (Fig. 2a). A USB video camera is placed inside the table, capturing the surface from below (Fig. 2b). Visual recognition software runs in a computer station (Fig. 2c) which also handles the game software and the tabletop active image provided by a video projector under the table (Fig. 2d) through a mirror inside the table (Fig. 2e). The image output is also shown on a conventional computer monitor (Fig. 2f)

Fig. 1 NIKVision tabletop

Fig. 2 NIKVision sketched components

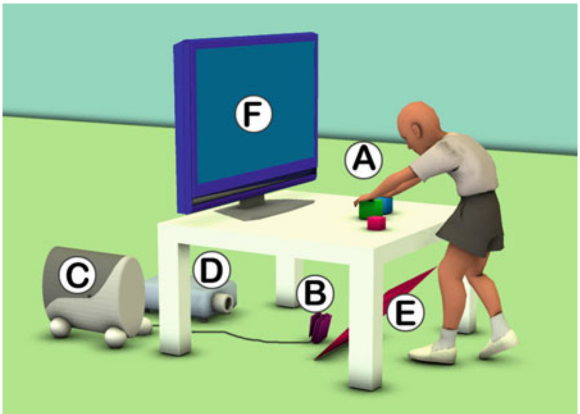


Fig. 3 Toys with printed marker attached to base

adjacent to the table; this is a distinguishing factor of NIKVision. Visual recognition and tracking of objects manipulated on the table is provided by the reacTIVision framework (Kaltenbrunner and Bencina 2007). A printed marker attached to the base gives each toy a digital "*Name*" (Fig. 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: 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: 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 on the tabletop and a virtual 3D car on the monitor will move in the same way as in the game.

Several games have been designed and developed for the NIKVision tabletop, with the involvement of children (Marco et al. 2010a). In the next section, the complete process of developing a game for NIKVision is presented. Children involvement techniques, evaluation strategies and the difficulties encountered are discussed.

4 Getting Down to Work: Developing a Farm Game for Nikvision

The engineering life cycle adopted for developing NIKVision games (Marco et al. 2013a) starts out from the Mayhew (1999) usability life cycle. This cycle takes users into account and reflects the iterative nature of the design of interactive

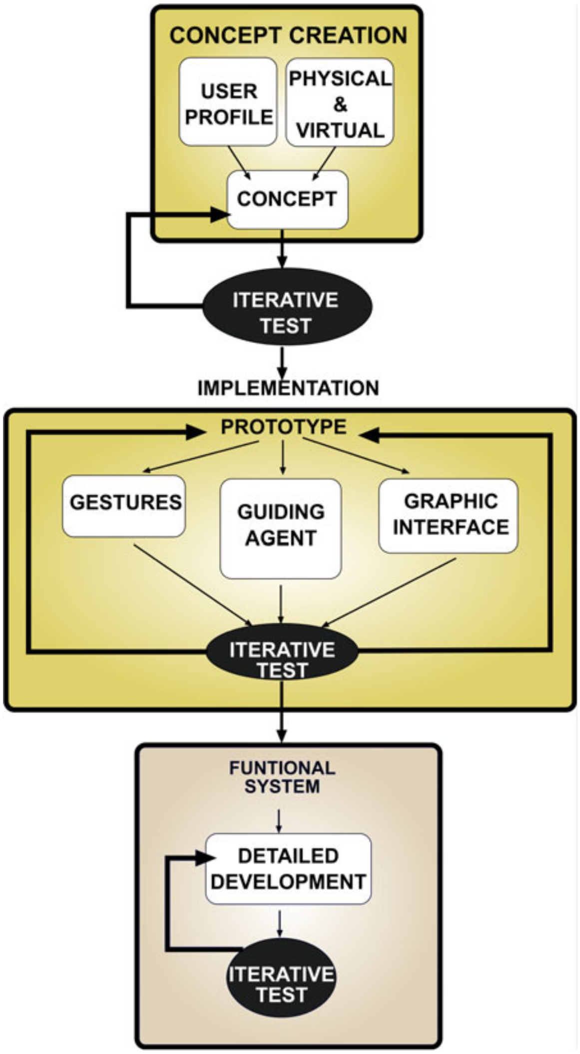


Fig. 4 Usability engineering life cycle used in NIKVision adapted from Mayhew (1999)

technologies. We have adapted the Mayhew engineering life cycle to reflect the dual character of tangible interactive applications (Fig. 4), 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* and considering the best combination of *physical and virtual* aspects. 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, the *prototype phase* requires to implement gesture recognition to identify children's manipulations of objects and provide feedback through a graphic interface and other virtual elements, such as a virtual agent in charge of providing guidance to children through the game. Developed by successive iterations, the prototype evolves into a product with all its functionalities implemented. During *the functional system* stage, the product is iteratively refined and fixed in order to achieve an error-free finished product ready to be commercialized or installed in its intended environment. In our case, life cycle iterations are guided by *test sessions* with the involvement of children. This means that from the concept creation through to the prototyping and functional system stages, the design of games for the NIKVision tabletop involves children at every step. 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 a specific NIKVision game.

4.1 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 preschool children's education. In order to start researching this question, we first needed to know our users, the 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.

4.1.1 User Profile

When intending to create a new product for users with very particular characteristics, such as 3-to-6-year-old children, it is important to have a detailed user profile in relation to the benefits that the new product can offer them. As described by Piaget (1952), children between 3 and 6 years are in the preoperational stage in which they begin to develop the symbolic function (language, symbolic games, mental image, imitations), 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 (1936) 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-computerized children's toys are played on horizontal surfaces such as a table or floor (Fig. 5). In fact, these are "non-computer-enriched" tabletop games.

Fig. 5 **a** MB Lucky Ducks™, **b** Goula Domino™ and **c** Playmobil™

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 3. The observation of children playing computer games in their nurseries shows that they usually play in little groups around the computer station. However, as there is only 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.

4.1.2 Physical Versus Virtual

Tangible tabletop concept ideation should be based on an appropriate combination of the "*physical versus virtual*" nature of tangible interfaces. In this way, designers can start from a virtual concept (pre-existing multimedia game based on keyboard or mouse) and enrich it with physical embodiment, or 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 (Fig. 6a). A tabletop game concept was thus created based on a virtual farm, where the animals

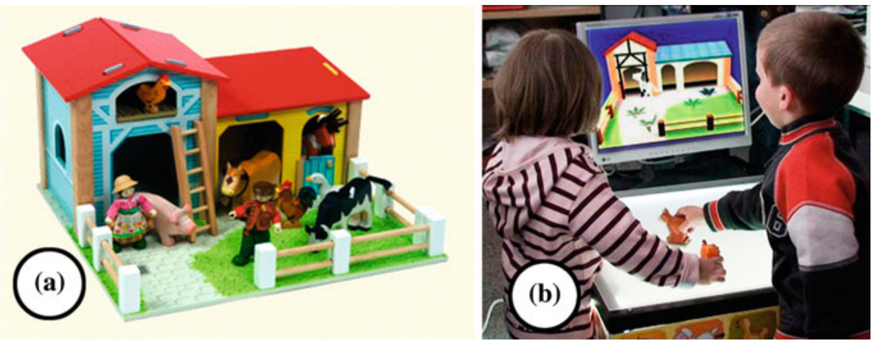


Fig. 6 **a** "Le Toy Van"™ wooden farm toy and **b** tabletop concept for farm game

were physical toys interacting with each other and with virtual elements in a 3D farm scene (Fig. 6b).

During the *concept creation* 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. 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.

4.2 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 (such as tabletop interaction) implies prototyping the *graphical interface* (images, animations, sounds, feedback, etc.) in a similar way to any conventional game, but also *gesture recognition* for physical interactions must be prototyped and the guidelines to be given by the *virtual agent* must be specified.

4.2.1 Gesture Prototyping

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.

Fig. 7 Farm game in NIKVision tabletop

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.

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, etc. and a virtual farmer character that collected the objects gathered by the animals (Fig. 7).

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

A test session was planned in a school with 4-to-5-year-old children who were brought into play in pairs with the farm prototype. Three pair of children participated in the session. They were asked to feed the animals with strawberries (Fig. 8a), to use the toy hen to lay eggs (Fig. 8b), or to give milk or wool with the cow and sheep, respectively, 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 (Fig. 9). 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.

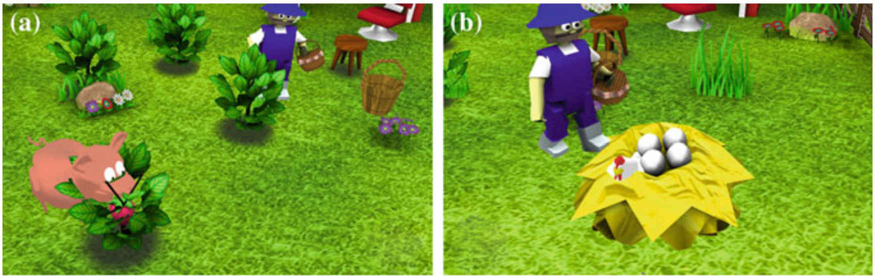


Fig. 8 **a** Virtual pig looking for strawberries and **b** Virtual hen laying eggs

Fig. 9 Adult "Wizard of Oz" observes children playing and triggers game events with a keyboard

The first couple of children started playing with the game without using the toys. They touched with their fingers on the different areas of the tabletop surface. Obviously, they understood the tabletop device as a tactile tablet device. We needed to explain them that the game has to be played handling the toys on the table surface. After that, they stated to manipulate the toys, but they played in turns; i.e., they did not tried to play with two toys at the same time. First, they tried to feed the animals with strawberries. They used a tilt gesture to lower the toy head until it touched the table surface, simulating the toy was eating the virtual strawberry. Then, they handled the hen on the nest. To simulate the hen putting eggs, they slowly jumped up and down the toy on the nest.

The second couple understood the game as a competition. They simultaneously handled and moved the toys on the surface with lots of energy. They used a very quick "shake" gesture to pick up the hidden strawberries from the plants. Once the strawberries task was completed, they stopped competing and carried out the other tasks in turns. They also used a jump gesture to put eggs with the hen, but they perform it more strongly compared to the previous couple.

The third couple took different roles to play the game; one handled the toys, and the other helped her partner by pointing on the table surface where she should place the toys. This child also simulate the toys were eating the strawberries by tilting the toys on the table surface, and they also used the jump gesture to put eggs with the hen.

After the session, we coded these gestures to be recognized by the NIKVision software, and they proved to be very viable actions in later test sessions. However, not all the actions proposed by the children were finally used. For example, the tilt gesture used to "feed the animals" task could not be implemented because the system cannot technically detect this gesture and consequently the feed gesture was discarded from the game.

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

4.2.2 Guiding Agent

The developers implemented algorithms to automatically recognize the shake and jump gestures. After this implementation, the farm game was composed of three 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.

The next step was to evaluate the 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 an autonomous talking 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:

- "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).
- "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.
- "What, where, who, and how": the farmer specifies what to do, with what animal, where and how to do the manipulation (shake, jump, etc.).

In the next school test session, the children played the farm game in pairs. Each pair played with only one of the three roles 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 "What to do" 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 "what and where" and "what, where, who, and how" 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 4-to-5-year-old children, taking them in groups of three but letting one of them learn how to play before the other two. It was explained to the first child that later he/she would help other children to play the game. The child was given a farmer's hat to encourage him/her in the role of the farmer (Fig. 10).

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

Fig. 10 Farmer child guiding his friends in the farm game

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 verbalized by the autonomous virtual farmer.

4.3 Functional System 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 for young children. It was decided to integrate the collecting strawberries, eggs and milk activities in a game with one objective: to 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 at collecting a wide range of summative data from the tangible game, focusing on the following usability issues:

- Those related with a video game application: game task completion, paying special 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 fun activity.

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

4.3.1 Evaluation Tools

The plan for the final evaluation was to install the tabletop and the farm game in nurseries and schools to recover data relating to their use by children, minimizing the adult evaluator's intervention. In order to do this, 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 given by the farmer character compared to the total number of tasks completed; and percentage of tasks in which children gave greater quantities of

the ingredients (eggs or milk) than the amount requested by the farmer compared to the total number of tasks completed.
- Physical activity and co-located gaming: measured by the number of manipulations and different toys used on the table during a time unit and graphically represented during the time of the trial.

To capture the degree of fun and the children's engagement, the sessions were video recorded by two cameras. One camera was placed under the monitor to capture the children's faces. This video stream allows the children's gestures and verbal expressions while interacting with each other to be transcribed, as well as showing to what degree the game caught the children's attention. The other camera was placed so as to capture all the area surrounding the tabletop. By placing the camera high up on a tripod, a view of the tabletop surface and the 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. The 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 (Fig. 11) was used to relate all game events to the degree of fun and the engagement experienced by the groups of children during the game.

4.3.2 Summative Analysis

The data of the final evaluation were retrieved from two sessions: one carried out in a nursery with 3-to-4-year-old children and the other in a school classroom with 4-to-5-year-old children. The initial plan was to analyse both sessions together but, even with this small age gap, there are significant differences in cognitive and motor skills in children (Piaget 1936). Moreover, there were differences between the nursery and school environments that may influence the results. In the nursery,

Fig. 11 Three video streams synchronized. **a** face camera, **b** tabletop camera and **c** log video-stream

NIKVision was available simultaneously with the rest of the activities. Toddlers came in groups of three to play freely with the game. However, 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 that they were being tested and they played completely uninhibited, whereas in the school, the children had the feeling of being tested. They were shy when entering the library and sometimes even asked for permission to start playing. For this reason, the analysis is separated according to the origin of the 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, which can only be provided by the hen toy. Finally, the farmer asks for milk, which is obtained by jumping the cow four times on the bucket. When one of these tasks is completed, the farmer announces that he does not need more and asks for the next ingredient. In any case, the 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.

In the school test, nearly all groups finished all the game goals (98 %), in contrast with the nursery where most of the children did not finish the tasks (only 36 % finished 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: while in the school, most of the children carried out the tasks in the order asked by the farmer (65 %), hardly any trials in the nursery were carried out following the farmer’s instructions (10 %). Also, in most of the nursery trials, the toddlers laid more eggs and gave more milk than the amounts asked for by the farmer (75 %). Therefore, it can be concluded that the farmer had almost no influence during the nursery test. In contrast, 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 if there were no limit to the eggs and milk they could produce, indicating that the children in the school wished to carry out the activities beyond the farmer’s commands.

Regarding the game performance in promoting physical and co-located gaming, Fig. 12 shows the graphs of the evolution of these measurements during a trial of

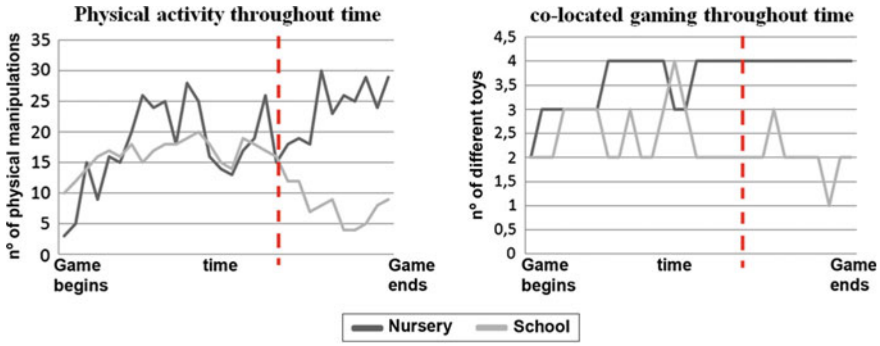


Fig. 12 "Making a cake" game: physical and co-located gaming

the game comparing the nursery and school sessions. As each trial game has a different time length, all the game trials were divided into 30 time segments to obtain the statistics.

The school trials show active physical and co-located gaming during the first two-thirds of the game (until the red line in the graphs), decreasing to the end of the trial. The school trial was more task driven, and it can be seen that the strawberry task (the first task requested by the farmer) engaged the 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 had 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 almost the opposite results: these rates increased continuously during the trials and were higher than in the school. Looking at the videos, it can be observed that the toddlers were rather shy at the beginning of the game, not knowing how to play. But they soon 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.

The degree of fun and the engagement of the children in the game were extracted from the video streams. The children's attention was attracted to the monitor most of the time. Laughs and expressions of fun were always related with 3D animations and sounds. The children only looked at image projections on the 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 had placed the toy on the spot, they performed the gesture looking at the monitor and laughed when the strawberries were dropped, the eggs were laid and the milk filled the bucket (Fig. 13).

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

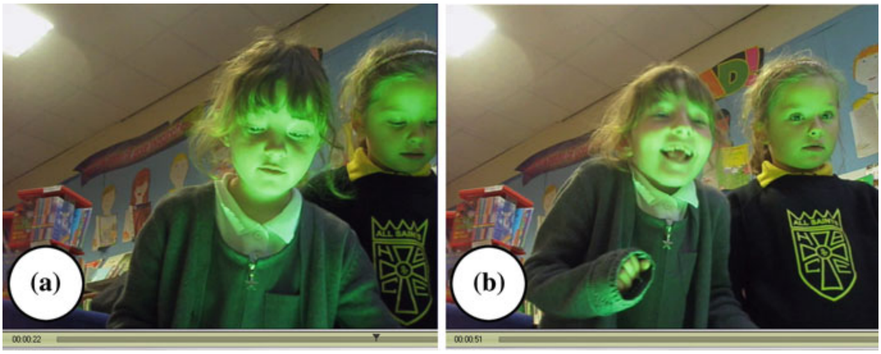


Fig. 13 Four-year-old girls playing, **a** seriously manipulating toys on table surface, **b** having great fun seeing animations on monitor

4.4 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.

- Analysis of the video recordings showed children expressed their sense of fun and engagement in the game while looking at the virtual characters and animations running at the conventional monitor. This benefit should be exploited with an appropriate distribution of visual feedback between monitor and tabletop projection. While the first should be responsible for engaging children in the game, using attractive scenery, funny animations and autonomous characters, the second should provide visual feedback about task completion and guide children to locate the interactive spots where toys are to be manipulated. As a consequence, children attention during the game is divided in two different locations. Feedback events should be wisely distributed in different moments, providing children with guidance on the tabletop surface while carrying on the task and, once the task has been completed, rewarding them with funny animations on the conventional monitor.
- 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 perform all the tasks so that pedagogical content is transmitted, the use of an autonomous character to provide instructions and precise commands is essential. In a task-driven approach with a guiding character imposing the order of task completion, children gain a clear understanding of the objectives and end conditions of each task. However, interaction with the game may become rigid,

with less fun and fewer spontaneous moments. In contrast, a free game with no autonomous character giving instructions may encourage greater exploratory behaviour 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 informing children of their progress through positive and negative feedback.

- Guidelines extracted from previous literature about video games and children (Malone 1984) may be useful, but designers should consider new methods 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 video game model (with tasks and objectives to be sequentially achieved) is avoided, and children are left to freely explore and discover how to activate sound and animations. In such a scheme, 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 in itself produce such gaming. The design of the game tasks is decisive for engaging 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, and thus, co-located gaming is encouraged.
- Psychomotor and cognitive development of children should always be considered when designing any game task: for example, 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 these kinds of questions, and with an iterative design process, the game can be refined and adapted to children's 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 new technology applications:

- The most important decision is to define the role of the children in the project from the beginning. Roles requiring a high degree of involvement, such as design partners and informants, may be very useful for detecting children's needs and preferences, but they are not suitable for very young children whose social and cognitive development is not sufficiently developed 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 large number of instructions that have to be given before they start reduced the children's naturalness and spontaneity when playing. An additional risk in this kind of structured session is that the child may have the impression of being tested. In contrast, those sessions in which the game is just 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 the evaluation to be conducted in an objective and exhaustive manner.

- As regards the most appropriate places 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 laboratory and usually only small groups of children can enter the laboratory at a time. On the other hand, many teachers are willing to collaborate with researchers by offering their classrooms and time provided, of course, that all ethical questions about testing with children have been carefully considered and permission from parents has 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.

5 Tangible Tabletops for All? Evaluating the Farm Game with Children with Special Needs

The principles of universal accessibility have made possible a great advance in the application of digital technologies to the learning of disabled children. In the case of physical disabilities, accessibility is achieved with specific hardware and software to allow access to digital contents. In the case of children with cognitive disabilities, accessibility problems come from the difficulty of understanding the information given by the computer application.

Thanks to a collaboration project with a special education school, we were given the opportunity to test the NIKVision tabletop and games with children with cognitive disabilities (Marco et al. 2013b). As stated in the introduction, studies focusing on Tangible Interaction applied to children with cognitive disabilities are still very scarce. The aim of our tests was to investigate the suitability of our tangible tabletop for this kind of child. Would they understand how to play? What should be the role of the virtual character? What role should the teacher assume during the game? In fact, studies carried out to analyse the use of computers in classrooms with cognitively disadvantaged children have shown a strong dependence on teacher intervention (Bunninga et al. 2010). Studying these issues in depth required a more meticulous video analysis of the data retrieved during the test session, as explained in the following sections.

5.1 Testing Sessions and First Results

The test sessions took place in one of the school classrooms with the participation of three pairs:

- Pair 1: one multidisabled boy aged 8 and a girl aged 6 with West syndrome.
- Pair 2: two boys aged 9 and 11 with Down syndrome.
- Pair 3: a boy aged 7 with attention deficit and a boy aged 8 with autism.

During the sessions, the pair of children, two school teachers and two evaluators were present in the classroom. The game was briefly presented to the children, and they were encouraged to play, but they were not told exactly how to do this. The teachers only intervened when the children became blocked and did not know how to advance the game. Each pair played twice so that every child could carry out all the tasks (the laying eggs and giving milk tasks can only be done with one of the animals), and therefore, six "Making a cake" games were played in total.

In this case, besides the video recordings and the logs, a usability test was conducted by the evaluators with the aid of the teachers who answered at the end of the test a simple questionnaire with opinions and suggestions about the performance of the game. After the session, the video and log files were recovered and paired up (Fig. 14). The log files were exported as video sequences and synchronized with the recordings of the children playing. In this way, a complete reconstruction of every game carried out in the classroom was achieved.

The first analyses were similar to those carried out in the regular school tests, examining task completion, task order (an indicator of the impact of the virtual farmer), physical activity (through the number of manipulations over time) and co-located playing (through the number of toys manipulated).

As regards task completion, results are very similar to those obtained from the previous school tests. The tasks were completed in all trials (100 %), the task order followed the instructions given by the farmer in most trials (65 %), and nearly half of the children continued the egg and milk tasks after completion. The explanation may lie in the similarities of both environments: in both cases, the children had the feeling of being tested which pushes them to follow instructions and complete the

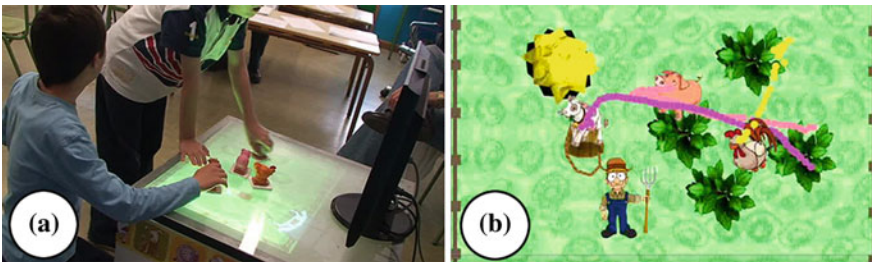


Fig. 14 **a** Video sequence captured in the classroom and **b** graphical reconstruction from the log file

tasks. But the way this behaviour is achieved is quite different in both environments. In the regular school, the farmer's instructions are sufficient to ensure task completion and task order. In the case of the special education school, the farmer's instructions are often not enough: many children have difficulties in paying attention to the farmer's instruction even if they are periodically repeated. On many occasions, it is necessary for the teacher to intervene to ensure that children continue with the task. In spite of the teacher's interventions, there were some shifts in the task order and some tasks were continued after having been completed. The shift in order always occurred in the pair's second game: thanks to the knowledge gained during the first game, the children went directly to the tasks they liked most.

Besides comments referring to the farmer's role, the questionnaire filled out by the teachers revealed a new problem. The children did not really know whether they had completed a task or not, because they did not know how many eggs or how much milk was needed. This explains why they so frequently persisted with the tasks. Therefore, more attention should be paid by game developers to ensure children understand the game. Appropriate feedback should be added to motivate children to continue, rewarding them when the task is finished. In fact, educators suggested using the virtual farmer to reinforce positive feedback by means of laughs, applause, dancing, etc. and not only by spoken words.

As regards physical activity and co-located playing (Fig. 15), the analysis shows results very similar to those obtained in the nursery tests. Physical activity shows an ascending tendency during the game. Again, at the beginning, children behaved very shyly and appeared reluctant to play. The teachers' motivation and explanations encouraged the children to start playing. Co-located playing also shows very high ratios, with all the toys being used all the time. Analysing the videos, it was realized that the children loved to have all the toys on the table and while one child was carrying out the task, the other took advantage to explore the environment with the other toys. In the second game of the same pair, the roles were reversed, and the tasks were then performed by the child who had devoted the previous game to exploring. Therefore, it can be concluded that special needs children like to actively explore the farm with the toys, similar to toddlers in the nursery environment, but

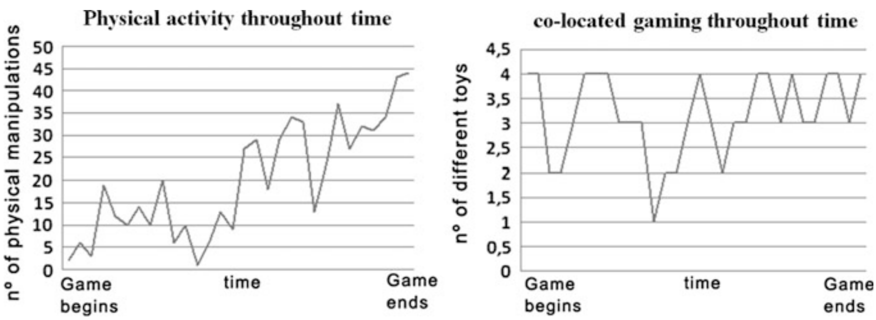


Fig. 15 Evaluating the "making a cake" minigame: physical and co-located gaming with special needs children

they still need the support of educators to begin playing and to continue moving the game forward.

From these results, it was clear to teachers and evaluators that the children's comprehension of the game needed to be studied in more detail. The impact and usefulness of feedback in the application and educators' interventions during the test sessions also required further examination. A more detailed video analysis of the games was therefore carried out, as explained in the following section.

5.2 Detailed Video Analysis

To perform a more detailed analysis, the DEVAN (DEtailed Video ANalysis) method proposed by Vermeeren et al. (2002) was chosen and adapted. The DEVAN method is based on the structured analysis of video material captured during user tests and was developed to detect usability problems in task-based products for adults. When used for evaluation with children, this method can be adjusted for the detection of usability and fun problems (Barendregt 2006) in computer games. It is a very time-consuming method: the interaction is analysed in detail to locate events that indicate an occurrence of a problem, i.e. the evaluators have to detect and code the behaviours that may indicate a problem, which are called "breakdown indications". The breakdown indications have to be grouped into problems, as there can be multiple indicators for the occurrence of one problem. The result of this stage of the analysis is a list of pairs of time stamps and behavioural categories.

In our case, the aim of the video analysis was to relate the usability breakdowns found during the sessions with the children's comprehension problems and their relationship with game feedback and adult interventions. A graphic dictionary of indicators (Table 1) was drawn up. The indicators were grouped in two categories:

- Child **behaviour indicators** that mark game moments in which the child's action is *correct* (allowing moving forward to task achievement), *incorrect* (the child shows the intention of achieving the task, but the action performed is not correct), *exploratory* (the child does not show any intention of completing the task but has a good time exploring the virtual farm scenario) and *system problem* (the action is correct but the system misses it).
- **Feedback indicators** that mark those game moments when information is given to the child through the **virtual farmer** (asking the child to complete a task and giving instructions on how to do it), through **graphics and animations** visualized in the farm scenery that indicate the degree of task achievement (egg laid, bucket filled, etc.) and through **teacher intervention** at those moments when the child becomes blocked and is not able to continue with the task.

The indicator icons are used to label, by means of a video editing tool, those moments when the evaluator observes the appearance of one of the events defined in the dictionary (Fig. 16).

Table 1 Dictionary of indicators used to label the test session video recordings

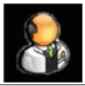
Child behaviour			
			
Correct	Incorrect	Exploratory	Correct action but system problem
Feedback			
			
Verbal indications given by virtual farmer	Visual feedback	Adult intervention	

Fig. 16 Different labels on video streams, **a** a child discovers how to lay eggs while exploring the game, **b** a child tries to collect strawberries when the task has already ended and **c** a child is making a jump gesture which the system does not recognize

After the labelling process, each game is graphically shown as a timeline where the children's actions are related to feedback events (Figs. 17 and 18). Each event is depicted as a rectangle of the corresponding indicator colour and with a width proportional to the duration of the event. These time graphs are of great help when trying to correlate children's behaviour with system or adult feedback. For example, Fig. 17 shows a child carrying out a milk task. At the beginning, the farmer gives instructions about how to perform the task (Fig. 17a). The child tries it, but he has not really understood the farmer's instruction and makes the wrong action. Afterwards, an adult intervenes, and consequently, the child succeeds (Fig. 17b) in partly filling the bucket with milk. Nevertheless, the child has not fully understood the task and keeps repeating it incorrectly in spite of the adult's interventions (Fig. 17c). Finally, there is a longer teacher intervention explaining how to perform the task (Fig. 17d), and the child correctly completes it, completely filling the bucket.

In the laying eggs task, the same child shows a very different behaviour (see Fig. 18). The timeline shows that the child has definitely understood the task: after listening to the farmer's instructions, he lays an egg correctly (Fig. 18a). Subsequently, his actions are exploratory and he has fun playing with another toy

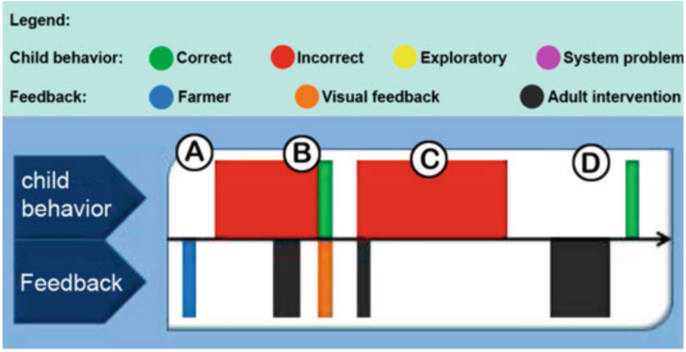


Fig. 17 “Giving milk” task timeline

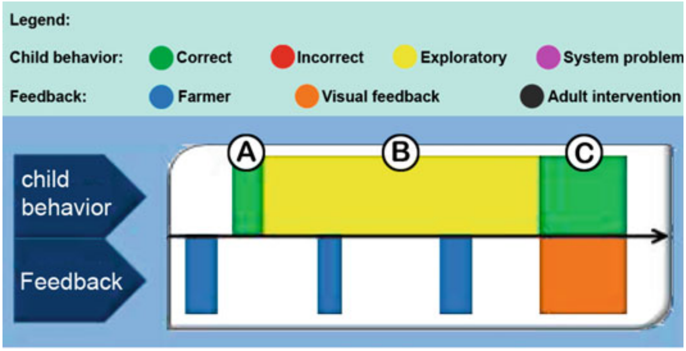


Fig. 18 “Laying eggs” task timeline

without realizing that he has to lay three more eggs to successfully complete the task. Meanwhile, the farmer keeps telling him to finish the task (Fig. 18b), and finally, the child realizes and correctly lays the rest of the eggs (Fig. 18c).

The results from the video analysis show the intrinsic difficulty of designing computer feedback for children with cognitive disabilities. Figures 17 and 18 reflect two very similar game activities carried out by the same child, resulting in very different adult interventions and child understanding.

These tests have highlighted important issues to be taken into account in our future work, as discussed in the next section.

5.3 Discussion: Designing Tabletop Games for All

The evaluation of the farm game in the special education school has resulted in some findings similar to those found in the school and nursery environments:

children have fun playing with the tabletop and have no problems in interacting with it. However, specific issues have arisen related to the autonomy of children in special education environments:

- In these environments, children's activities strongly depend on teacher support. Virtual characters, which can be very effective in regular educational environments, should not be developed as a substitute for motivating and guiding role of teachers. This has to be taken into account not only when developing the game but also when assessing it. Evaluations in nurseries and schools have to be planned minimizing adult intervention in order to observe children's natural interaction. In a special education classroom, however, educators should have an important role in encouraging and helping children during the test and supporting evaluators with their perceptions and opinions about the performance of the technology after the test.
- Virtual characters may have an important role giving positive and negative feedback to children's actions and rewarding the children after fulfilling the tasks. Feedback should be emotional: that is, appearing sad for negative feedback, and laughing and dancing for positive feedback.

6 Conclusions

The feasibility and impact of developing digital technologies based on Tangible Interaction for young children and those with special needs have been shown. In particular, our NIKVision system with its combination of tabletop and manipulative toys has considerable potential for collaborative computer gaming. During the testing of the games, children played together and engaged in a high degree of physical activity, thus overcoming one of the most controversial aspects of computer video games (i.e. lack of social and physical activity).

Child-centred design methods have to be used to capture usability and user-experience data from children playing with the game prototypes. The methods used during each test session must be selected according to the kind of data to be captured. However, due to their young age, methods based on children's expressions or verbalizations of their thoughts should be avoided. Instead, usability testing methods are a good option, for example observation notes, automatic logging and video recording. These methods have proved to be very useful for comparing different versions of our prototype and have been combined with other methods of child involvement such as Wizard of Oz techniques in order to capture their natural gestures for implementation in the game.

Acknowledgments We want to thank all the children, parents, nurseries and schools that participated in the NIKVision tests. We also thank the staff of the ChiCI Group from the University of Central Lancashire (UK), the staff from Colegio Público de Educación Especial Alborada de Zaragoza (Spain) and the students of the University of Zaragoza (Spain) who participated in the project. This work has been partly financed by the Spanish Government through the DGICYT contract TIN2011-24660.

References

Alibali, M.W., diRusso, A.A.: The function of gesture in learning to count: more than keeping track. Cogn. Dev. **14**, 37–56 (1999)

Barendregt, W.: Evaluating fun and usability in computer games with children. Ph.D. thesis, Eindhoven University of Technology, Eindhoven (2006)

Battocchi, A., Ben-Sasson, A., Esposito, G., Gal, E., Pianesi, F., Tomasini, D., Venuti, P., Weiss, P.L., Zancanaro, M.: Collaborative puzzle game: a tabletop interface for fostering collaborative skills in children with autism spectrum disorders. J. Assistive Technol. **4**(1), 4–14 (2010). (themed issue on autism and technology. Guest-edited by Sarah Parsons)

Bevan, R.: Another way on? A search for an alternative path into learning for people with a learning disability. Br. J. Spec. Educ. **30**(2003), 100–106 (2003)

Buckleitner, W.: The state of children's software evaluation—yesterday, today and in the 21st century. Inf. Technol. Child. Educ. Ann. **1999**, 211–220 (1999)

Bunninga, K., Heatha, B., Minniona, A.: Interaction between teachers and students with intellectual disability during computer-based activities: the role of human mediation. Technol. Disabil. **22**(2010), 61–71 (2010)

Cappelletti, A., Gelmini, G., Pianesi, F., Rossi, F., Zancanaro, M.: Enforcing cooperative storytelling: first studies. In Proceedings of the IEEE International Conference on Advanced Learning Technologies (ICALT '04), pp. 281–285. IEEE Computer Society, Washington, DC, USA (2004)

Chao, L.L., Haxby, J.V., Martin, A.: Attribute-based neural substrates in posterior temporal cortex for perceiving and knowing about objects. Nat. Neurosci. **1999**, 913–919 (1999)

Druin, A., Hanna, L.: The Design of Children's Technology. Moran Kaufmann Publishers, Inc, Massachusetts (1999)

Farrell, A.: Ethical Research with Children. McGraw-Hill International, New York (2005)

Hanna, L., Risden, K., Alexander, K.: Guidelines for usability testing with children. ACM Interact. **4**(5), 9–14 (1997)

Harris, A., Rick, J., Bonnett, V., Yuill, N., Fleck, R., Marshall, P., Rogers, Y. (2009). Around the table: are multiple-touch surfaces better than single-touch for children's collaborative interactions? In: 9th International Conference on Computer Supported Collaborative Learning, vol. 1, pp. 335–344. (2009)

Hasselbring, T.S., Glaser, C.H.: Use of computer technology to help students with special needs. Future Child. **10**(2), 102–122 (2000)

Heijboer, M., van den Hoven, E.: Keeping up appearances: interpretation of tangible artifact design. In: Proceedings of the 5th Nordic conference on Human-computer interaction: building bridges (NordiCHI '08), pp. 162–171 (2008)

Hendrix, K., van Herk, R., Verhaegh, J., Markopoulos, P. Increasing children's social competence through games, an exploratory study. In: Proceedings of the 8th International Conference on Interaction Design and Children, pp. 182–185. ACM, NewYork (2009)

Hengeveld, B., Hummels, C., Overbeeke, K., Voort, R., van Balkom, H., de Moor, J. Tangibles for toddlers learning language. In: Proceedings of the 3rd International Conference on Tangible and Embedded Interaction (TEI '09), pp. 161–168. ACM, New York (2009)

Höysniemi, J., Hämäläinen, P., Turkki, L.: Wizard of Oz prototyping of computer vision based action games for children. In: 2004 Conference on Interaction Design and Children, pp. 27–34 (2004)

Höysniemi, J., Hamalainen, P., Turkki, L.: Using peer tutoring in evaluating usability. Interact. Comput. **15**, 203–225 (2003)

Ishii, H., Ullmer, B.: Tangible bits: towards seamless interfaces between people, bits and atoms. In: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems, pp. 234–241. ACM, New York (1997)

Iwata, T., Yamabe, T., Poloj, M., Nakajima, T.: Traditional games meet ICT: a case study on go game augmentation. In: Proceedings of the Fourth International Conference on Tangible, Embedded, and Embodied Interaction (TEI ‘10), pp. 237–240 (2010)

Kaltenbrunner, M., Bencina, R.: reacTIVision: a computer-vision framework for table-based tangible interaction. In Proceedings of the 1st International Conference on Tangible and Embedded Interaction (pp. 69–74). ACM, New York (2007)

Khandelwal, M., Mazalek, A.: Teaching table: a tangible mentor for pre-k math education. In: Proceedings of the 1st International Conference on Tangible and Embedded Interaction TEI ‘07, Baton Rouge, Louisiana, 15–17 Feb 2007

Leitner, J., Haller, M., Yun, K., Woo, W., Sugimoto, M., Inami, M., Cheok, A.D., Been-Lirn, H. D.: Physical interfaces for tabletop games. Comput. Entertain. **7**(4), 61 (2010)

Lepisto, A., Ovaska, S.: Usability evaluation involving participants with cognitive disabilities. In: Proceedings of the Third Nordic Conference on Human-Computer Interaction (NordiCHI ‘04), pp. 305-308. ACM, New York, USA (2004)

Li, Y., Fontijn, W., Markopoulos, P.: A tangible tabletop game supporting therapy of children with cerebral palsy. In: Markopoulos, P., Ruyter, B., Ijsselsteijn, W., Rowland, Duncan (eds.) Proceedings of the 2nd International Conference on Fun and Games, pp. 182–193. Springer, Berlin (2008)

Montessori, M.: In: Carter, B.B. (ed.) The Secret of Childhood. Orient Longmans, Calcutta (1936)

Magerkurth, C., Cheok, A.D., Nilsen, T.: Pervasive games: bringing computer entertainment back to the real world. ACM Trans. Comput. Entertain. **3**(3), 4a (2005)

Malone, T.W.: Heuristics for designing enjoyable user interfaces: lessons from computer games. In: Thomas, J.C., Schneider, M.L. (eds.) Human Factors in Computer Systems, pp. 1–12. Ablex, Norwood (1984)

Mandryk, R.L., Maranan, D.S.: False prophets: exploring hybrid board/video games. In: CHI ‘02 Extended Abstracts on Human Factors in Computing Systems (Minneapolis, Minnesota, USA), CHI ‘02, pp. 640–641. ACM, New York, 20–25 April 2002

Mansor, E.I., De Angeli, A., De Bruijn, O.: Little fingers on the tabletop: a usability evaluation in the kindergarten. In: Horizontal Interactive Human Computer Systems, 2008. 3rd IEEE International Workshop on TABLETOP 2008, pp. 93–96. IEEE (2008)

Marco, J., Cerezo, E., Baldassarri, S., Mazzone E., Read J.C.: Bringing tabletop technologies to kindergarten children. In: BCS-HCI ‘09 Proceedings of the 23rd British HCI Group Annual Conference on People and Computers: Celebrating People and Technology, pp. 103–111 (2009)

Marco, J., Cerezo, E., Baldassarri, S.: Playing with toys on a tabletop active surface. In: Proceedings of the 9th International Conference on Interaction Design and Children, IDC ’10, pp. 296–299. Barcelona, Spain, 09–12 June 2010. ISBN 978-1-60558-951-0. (2010a)

Marco, J., Baldassarri, S., Cerezo, E., Xu, D.Y., Read, J.C.: Lifelong interactions: let the experts talk: an experience of tangible game design with children. Interactions **17**(1), 58–61 (2010b)

Marco, J., Baldassarri, S., Cerezo, E.: NIKVision: developing a tangible application for and with children. JUCS **19**(15), 2266–2291 (2013a)

Marco, J., Cerezo, E., Baldassarri, S.: Bringing tabletop technology to all: evaluating a tangible farm game with kindergarten and special needs children. Pers. Ubiquit. Comput. **17**(8), 1577–1591 (2013b)

Markopoulos, P., Bekker, M.M.: How to compare usability testing methods with children participants. In: Workshop Interaction Design for Children, Proceedings of the IFIP 9th International Conference on Human-Computer Interaction—INTERACT ’05 Rome, pp. 153–158. Shaker Publishing, Maastricht (2002)

Markopoulos, P., Read, J.C., MacFarlane, S.J., Höysniemi, J.: Evaluating Children’s Interactive Products. Morgan Kaufmann, Burlington (2008)

Marshall, P., Price, S., Rogers, Y.: Conceptualising tangibles to support learning. In: Proceedings of IDC 2003, pp. 101–109. ACM Press, New York (2003)

Mayhew, D.J.: The usability engineering lifecycle. In: CHI’99 Extended Abstracts on Human Factors in Computing Systems, pp. 147–148. ACM, New York (1999)

Morris, M.R., Pipper, A.M., Cassanego, A., Winograd, T.: Supporting cooperative language learning: interface design for an interactive table. Technical report, Computer Science Department, Stanford University (2005)
Pagulayan, R.J., Keeker, K., Wixon, D., Romero, R., Fuller, T.: User-centered design in games. In: Jacko, J., Sears, A. (eds.) Handbook for Human-Computer Interaction in Interactive Systems, pp. 883–906. Lawrence Erlbaum, Mahwah (2003)
Piaget, J.: The Origins of Intelligence in Children. International Universities Press, New York (1936/1952)
Piper, A.M., O'Brien, E., Morris, M.R., Winograd, T.: SIDES: a cooperative tabletop computer game for social skills development. In: Proceedings of the 2006 20th Anniversary Conference on Computer Supported Cooperative Work, pp. 1–10. ACM, New York (2006)
Pontual Falcão, T.: The role of tangible technologies for special education. In: Proceedings of the 28th of the International Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '10), pp. 2911–2914. ACM, New York, USA (2010)
Price, S., Rogers, Y.: Lets get physical: the learning benefits of interacting in digitally-augmented physical spaces. Comput. Educ. **43**(1), 137–151 (2004)
Raisamo, R., Hippula, A., Patomäki, S., Tuominen, E., Pasto, V., Hasu, M.: Testing usability of multimodal applications with visually impaired children. IEEE Multimedia **13**(3), 70–76 (2006)
Read, J.C., MacFarlane S.J., Casey C.: Endurability, engagement and expectations: measuring children's fun. In: Proceedings of the International Workshop on Interaction Design and Children, pp. 189–198. Shaker Publishing, Eindhoven, The Netherlands (2002)
Rogers, Y., Rodden, T.: Configuring spaces and surfaces to support collaborative interactions. In: Public and Situated Displays, pp. 45–79. Springer, Netherlands (2003)
Rounding, K., Tee, K., Wu, X., Guo, C., Tse, E.: Evaluating interfaces with children. Pers. Ubiquit. Comput. **17**(8), 1663–1666 (2013)
Scaife, M., Rogers, Y.: Kids as informants: telling us what we didn't know or confirming what we knew already. In: Druin, A. (ed.) The Design of Children's Technology, pp. 27–50. San Francisco, CA, Morgan Kaufmann (1999)
Schöning, J., Hook, J., Bartindale, T., Schmidt, D., Oliver, P., Echtler, F., von Zadow, U.: Building interactive multi-touch surfaces. In: Tabletops-Horizontal Interactive Displays, pp. 27–49. Springer, London (2010)
Scott, S., Mandryk, R., Inkpen, K.: Understanding children's collaborative interactions in shared environments. J. Comput. Assist. Learn. **19**(2), 220–228 (2003)
Sim, G., MacFarlane, S., Read, J.: All work and no play: measuring fun, usability, and learning in software for children. Comput. Educ. **46**(3), 235–248 (2006)
Sluis, R.J.W., Weevers, I., Van Schijndel, C.H.G J., Kolos-Mazuryk, L., Fitrianie, S., Martens, J. B.O.S.: Read-it: five-to-seven-year-old children learn to read in a tabletop environment. In: Proceedings of the 2004 Conference on Interaction Design and Children: Building a Community, pp. 73–80. ACM, New York (2004)
Sluis-Thiescheffer, W., Bekker, T., Eggen, B.: Comparing early design methods for children. In: 6th International Conference on interaction Design and Children, pp. 17–24 (2007)
Utani. http://www.utani.org. Accessed 10 March 2012
Van Kesteren, I.E.H., Bekker, M.M., Vermeeren, A.P.O.S., Lloyd, P.A.: Assessing usability evaluation methods on their effectiveness to elicit verbal comments from children. In: Proceedings of the Interaction Design and Children Conference 2003, Preston UK, pp. 41–49. ACM, Inc., New York, July 2003
van Veen, M.: Improving collaboration with racketeer: development of a serious game with multi-touch interaction for teaching children with PDD-NOS collaboration. Student Doctoral thesis. Rijksuniversiteit Groningen (2009)
Vermeeren, A.P.O.S., den Bouwmeester, K., Aasman, J., de Ridder, H.: DEVAN: a detailed video analysis of user test data. Behav. Inf. Technol. **21**, 403–423 (2002)
Xu, D.Y., Read, J.C., Sim, G., McManus, B., Qualter, P.: Children and 'smart' technologies: can children's experiences be interpreted and coded? In: Proceedings of the 2009 British Computer

Society Conference on Human-Computer interaction, Cambridge, United Kingdom, pp. 224-231. British Computer Society Conference on Human-Computer Interaction. British Computer Society, Swinton, UK, 01–05 Sept 2009

Zuckerman, O., Arida, S., Resnick, M.: Extending tangible interfaces for education: digital Montessori inspired manipulatives. In Proceedings of CHI '05, pp. 859–868. ACM Press, New York (2005)