Pers Ubiquit Comput (2013) 17:1577–1591
DOI 10.1007/s00779-012-0522-5

ORIGINAL ARTICLE

Bringing tabletop technology to all: evaluating a tangible farm game with kindergarten and special needs children

Javier Marco · Eva Cerezo · Sandra Baldassarri

Received: 11 October 2011 / Accepted: 17 November 2011 / Published online: 25 April 2012

Abstract The tangible interaction approach has in recent years become a promising alternative to multitouch tabletops for very young children. Children learning with tangible user interfaces can benefit from the same pedagogical values as learning with materials in physical play. The NIKVision tabletop and games have been designed to provide leisure and fun while reinforcing physical manipulation and co-located gaming for young children (3- to 6-year-olds). Interaction is provided in NIKVision by the handling of conventional toys and computer augmentation on a table surface. First of all, the paper sets out the results of a summative evaluation carried out in nurseries and schools summarising the performance of the tabletop in terms of usability, user experience and physical and co-located gaming. Secondly, the paper presents an evaluation carried out in a special education school with children with cognitive disabilities, in an attempt to widen the range of possible beneficiaries of tangible interfaces. The challenge in this case is to ensure children's comprehension of the game and to adequately combine feedback on the application with teacher interventions. In fact, the initial results reinforce the idea of not trying to substitute but rather to assist teachers and emphasise the possibilities offered by the tabletop as a tool to promote student autonomy.

Keywords Tangible · Tabletop · Usability · User experience · Evaluation · Children with special needs

1 Introduction

Nowadays, technology is present throughout our lives from the first years of our education (3–6 years old). However, conventional computer stations and interactive applications based on mouse and keyboard are not appropriate for the cognitive and psychomotor development of young children [13] and do not offer benefits in fundamental aspects of their development such as group activities, physical playing and manipulative learning [31].

Ethnographic research on the use of computers in early years education environments has found that digital technologies are in general underused and, therefore, most children have a limited experience of them [33]. Kindergarten teachers consider computers as technical tools with which children should acquaint themselves in preparation for school [38]. On the other hand, non-computer activities involve lively groups of children playing by manipulating objects, exploring their properties and using them as tools to express themselves. Children build their mental image of the world through action and motor responses and, with physical handling, they become conscious of reality [6]. Therefore, it is desirable that computer activities in nurseries should combine the pedagogical benefits of digitally augmenting educative activities [39] and co-located learning with small groups of children actively playing with physical materials.

J. Marco (✉)
Advanced Computer Graphics Group (GIGA), Computer Science Department, Universidad de Zaragoza, Ed. Ada Byron, C/María de Luna n. 1, 50015 Zaragoza, Spain
e-mail: javi.marco@unizar.es

E. Cerezo · S. Baldassarri
Advanced Computer Graphics Group (GIGA), Computer Science Department, Engineering Research Institute of Aragon (I3A), Universidad de Zaragoza, Ed. Ada Byron, C/María de Luna n. 1, 50015 Zaragoza, Spain
e-mail: ecerezo@unizar.es

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

Computationally enhanced 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 [28]. Although the educative community is taking a special interest in these devices [9], multitouch surfaces pose important problems when applied to children in the first years of education [23] since this kind of interaction requires fine muscle coordination that is not usually achieved until around the age of seven. The adjustment of tabletop devices to very young children requires 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. [27] and Zuckerman et al. [48] prove that tangible user interfaces (TUI) applied 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 [35]. However, there is a lack of studies about the impact of using tangible interfaces with very young children (3- to 6-year-olds).

Recently, the application of alternative ways of interacting with digital contents has revealed important benefits for special needs children [3, 32]. New interactive devices are not only more physically accessible but offer a more direct and flexible form of showing digital information to the child. However, the lack of specific studies is in this area is particularly noticeable.

Our approach is that an adequate combination of a tabletop computer device with tangible interaction can bridge the gap between digital- and physical-based educative 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 education environments. The use of virtual autonomous agents and their usability impact also comes within the scope of our work. In this context, we decided to create the NIKVision system, which consists of a tabletop device and a set of tangible games [24] 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 [25].

The paper is organised as follows. Section 2 describes related work constituting the basis of our research. Section 3 provides a brief description of the NIKVision tabletop and farm game. Section 4 details the evaluation carried out in nurseries and schools and outlines the fundamental conclusions drawn. Section 5 describes the evaluation performed in a special needs school and, finally, our conclusions and future work are presented in Sect. 6.

2 Related work

The work described in this paper relates to two main research areas: the application of computer augmented surfaces in educative environments and the evaluation of interactive applications with children. The most relevant works in both areas are summarised 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 image projection and multitouch interaction. The educative community is taking a special interest in creating pedagogical content for multitouch-based tables (or tabletops) [43]. Many tabletop-based projects have focused on the new possibilities that multitouch active surfaces offer for co-located learning [7, 28, 40].

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 [11, 23]. Alternatives have appeared based on hybrid physical board games and computer augmented surfaces [14, 22] that combine 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 [21]. The handling of conventional toys on an interactive surface may also open new horizons in interaction design for children. Hendrix et al. [15] 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 learning of reading skills [42] and maths [18] for 5- to 7-year-old children. Expanding tabletop applications with tangible interaction can make computers accessible to children with cerebral palsy [20] and children with social disorders [2, 32, 45]. 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 preliminary [16, 34].

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 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. Many products for children are still analytically evaluated by adult experts only [4]. However, 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 [8].

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 important adaptations of these methods, or even discard some of them when working for children belonging to specific age groups [37]. It should be remembered that young children are less able to read, verbalise, concentrate and perform abstract logical thinking than adults [26]. 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 that 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. [10] suggest that observing children's frowns and yawns are more reliable indicators of lack of engagement than their responses to questions. Read et al. [36] 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 vocalisation, while lack of engagement could be measured through frowns, signs of boredom (ear playing, fiddling), shrugs and negative verbalisation.

Formative evaluation methods of children's products must look not only for usability problems, but also for positive factors such as magic [47] and fun [30, 41]. 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 [19]. 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 [44]. These methods may be adapted to the consideration of usability issues such as fun and user experience [1] and accessibility matters that go beyond hardware concerns, incorporating broader concepts such as children's understanding, digital feedback and adult support during the interaction [12].

In conclusion, the evaluation of applications with very young children and the selection of the most suitable testing method still remain 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 NIKVision tabletop and tangible farm game

The NIKVision tabletop design aims to bridge the gap between computers and physical activities for very young children by means of a system that couples tangible interaction with digital augmentation (according to the child's development skills) using a tabletop surface. Furthermore, the design of this technology has been carried out involving children throughout the process as testers and users of the device and games during frequent test sessions starting from the early conceptual stage [25].

The NIKVision tabletop was originally designed to be used in nurseries and schools by 3- to 6-year-old children. It is based on the physical manipulation of traditional toys over the table surface (Fig. 1-1). There is active image output on the table surface, and a conventional computer monitor (Fig. 1-6) adjacent to the table is also used to bring tabletop games closer to the conventional multimedia graphics approach that looks attractive and fun to little children. Technically, NIKVision uses visual recognition software (Fig. 1-3) to track the position and orientation of toys placed on the surface, provided by a printed marker attached to their base (see Fig. 2) [17]. An infrared light USB camera (Fig. 1-2) captures video from underneath the table and streams it to the computer station that executes the visual recognition and game software. Active image projection on the table is provided by retro-projection (Fig. 1-4) through a mirror inside the table (Fig. 1-5).

The tangible interaction is achieved by manipulating the tangible toys. During play, the children move the toys on

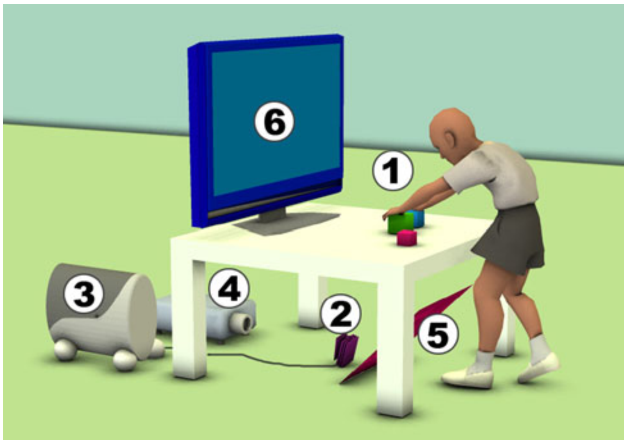

Fig. 1 NIKVision tabletop

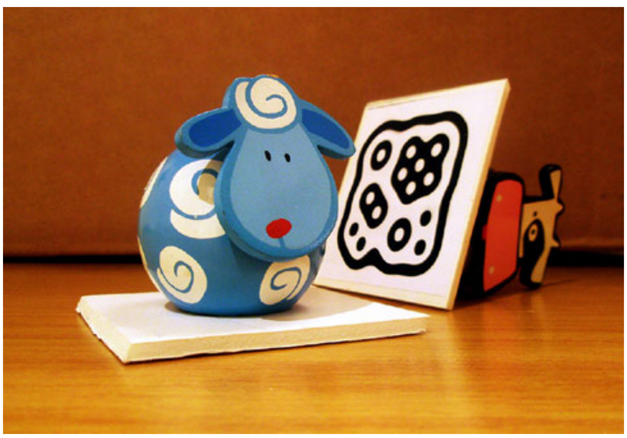

Fig. 2 Toys with fiducial marker attached to base

the translucent surface of the table, putting the base of the toy in contact with the table to enable the camera to see the markers located under its base (see Fig. 2). There is no limit on the number of toys that can be placed and moved on the desktop (providing there is free space on the table). This enables more than one child to play at the same time and opens up the application space to social activities.

Several manipulative games have been developed for NIKVision [24]; the evaluation presented in this paper has been carried out with a tangible farm game. It consists of a virtual farm with a virtual autonomous character (a farmer) and several physical farm animals to be manipulated by the children. The farm animals (a hen, a cow, a sheep and a pig) are plastic animal toys with fiducials attached to their bases. Every time a child puts an animal on the table, its 3D representation appears in the farm scenario shown on the monitor. Interactive 2D virtual elements are shown on the tabletop surface to help children with the activities (see Fig. 3).

The farm game is composed of different minigames. Here, we will focus on the one analysed in the tests, the “Making a cake” minigame. In this game, the farmer asks the animals to help him make a cake. Three strawberries, four eggs and a bucket of milk are needed to bake the cake. The strawberries are hidden in four plants (see Fig. 4a). Any animal toy can be used to shake a plant. If the plant has a strawberry, it jumps from the plant and a funny sound is heard. Eggs are laid by jumping the hen up and down on the yellow nest (see Fig. 4b). With each jump, an egg appears in the nest. Milk is given by jumping the toy cow on the bucket icon (see Fig. 4c). Two jumps are needed to fill the bucket. The virtual farmer is in charge of asking for the ingredients: first the strawberries, second the eggs and finally the milk. When an ingredient is obtained, he takes it and asks for the next one. The children can in any case continue laying eggs and getting milk if they want to. If 30 s pass without collecting any ingredient, the farmer keeps insisting and gives instructions about the action that children have to perform.

4 Evaluation with kindergarten children

4.1 Evaluation objectives and tools

Thanks to a collaboration project with the ChiCI Group at the University of Central Lancashire (UK), the NIKVision farm game was evaluated in a nursery and a school. The evaluation was aimed at collecting a wide range of summative data relating to the tangible game, focusing on the following usability issues:

- Those related with a **videogame 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 the game.
- Those related with **user experience**: engagement of children in a fun play activity.

The plan for the evaluation was to install the tabletop and the farm game in local nurseries and schools to obtain data about their use by children, minimising 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 recordings and automatic log files, and a subsequent summative analysis of these data was performed in the laboratory.

Capture and analysis of usability data from **log files** were made automatically. Each time a minigame was played, a new log file was created. The log files contained all the events occurring in the game: toy manipulations, actions with interactive virtual objects and farmer

Fig. 3 Tangible farm game with enhanced 3D (*left*) and 2D graphics (*right*)

Fig. 4 “Making a cake” minigame tasks. **a** Picking strawberries. **b** Laying eggs. **c** Giving milk

instructions, all with their time stamps. A software tool was used in the laboratory to retrieve all the log files and extract summative data about the following:

- **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 in relation to the total number of tasks completed, and percentage of tasks in which children gave additional ingredients (eggs or milk) to the amount asked by the farmer in relation to the total number of tasks completed.
- **Physical activity and co-located gaming**: measured by the number of manipulations (movements of any toy on the tabletop surface) and different toys used on the table during a time unit, respectively.

To capture the degree of **fun and 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 allowed the children’s gestures and verbal expressions while interacting with each other to be transcribed, as well as their engagement by means of observing the focus of the children’s attention (see Fig. 5). The other camera was placed high up on a tripod in order to capture all the area surrounding the tabletop, with a view of the tabletop surface and children’s manipulations on it. This video stream helped 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 the children was also retrieved with this camera (to see whether the children played independently or helped each other, or whether some child stopped playing to watch his/her partner).

In the analysis phase, both video streams were synchronised together with a graphical animated representation of the log file. The complete video stream composed of the three views (see Fig. 6) was used to relate all game events to the fun and the engagement experienced by groups of children during the game and to locate usability problems.

Table 1 summarises the NIKVision evaluation objectives with their respective indicators and the usability testing tools used in the evaluation.

4.2 Data analysis

The data from 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 the nursery and school environments were so different that it was decided to analyse them

Fig. 5 Different focus of attention, *left* tabletop surface, *right* monitor

Fig. 6 Three video streams synchronised. *Left* face camera. *Central* tabletop camera. *Right* log video stream

Table 1 Final evaluation: objectives, indicators and tools

Evaluation objectives	Indicator	Tool
Game task completion	% of task completed/total trials	Statistics from log
Influence of autonomous character	% of task carried out in the order commanded by the farmer/total number of tasks completed	Statistics from log
	% of additional ingredients collected after completion of the task/total number of tasks completed	
Promotion of physical activity	Rates of toy manipulations per time throughout the game	Statistics from log
Promotion of co-located gaming	Number of different toys manipulated simultaneously per time throughout the game	Statistics from log
Fun and engagement	Laughs and expressions related with fun and evidence of children engaged with the game	Video analysis

separately as statistics showed that environmental conditions have a notable influence on game usability. In the nursery, the NIKVision was available simultaneously with the other activities. Due to the noisy environment of the nursery, the children did not listen to the farmer's instructions. The children played in groups of three until they completed the goals, or they got tired and went to play something else; at that moment, the game was restarted, and another group of three children came to play. In contrast, in the school, the NIKVision was installed in the library, not in a classroom. Adult intervention was not as minimised 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. In the quiet environment of the library, children paid attention to the farmer's instructions. It can be deduced that children in the nursery did not feel that they were being tested and they played without the guidance of an autonomous agent. However, in the school, the children had the feeling of being tested, appearing shy when entering the library and sometimes even asking for permission to start playing. Their interaction during the game was oriented by the farmer character. For this reason, the analysis of the farm game is presented separately according to the origin of the data: nursery or school. The impact of the use of an autonomous character in the game was also studied.

Ten trials of the "Making a cake" minigame were obtained from the nursery session and twenty from the school. Figure 7 shows the summative analysis of task completion and autonomous character influence in this game.

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. 7): while in the school, most of the children carried out the tasks in the order asked by the farmer, scarcely any trial in the nursery followed the farmer's instructions. Also, in most of the nursery trials, the toddlers also laid more eggs and gave more milk than the amount asked for by the farmer. Therefore, it can be concluded that the farmer had almost no influence during the nursery test. On the other hand, 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. Therefore, it can be concluded that the use of the farmer character has a positive impact on task completion rates. 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, suggesting that the children in the school wished to carry out the activities beyond the farmer's commands.

Regarding the game performance in terms of promoting physical and co-located gaming, Fig. 8 shows the graphs of the evolution of these measurements during a trial of the game comparing nursery and school sessions. As each trial game lasted for different periods of time, all the game trials were divided into 30-time segments to obtain the statistics. As can be observed, the degree of physical and co-located gaming is always higher in the nursery environment except in the first moments. Looking at the videos, it can be observed that toddlers behaved rather shyly 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

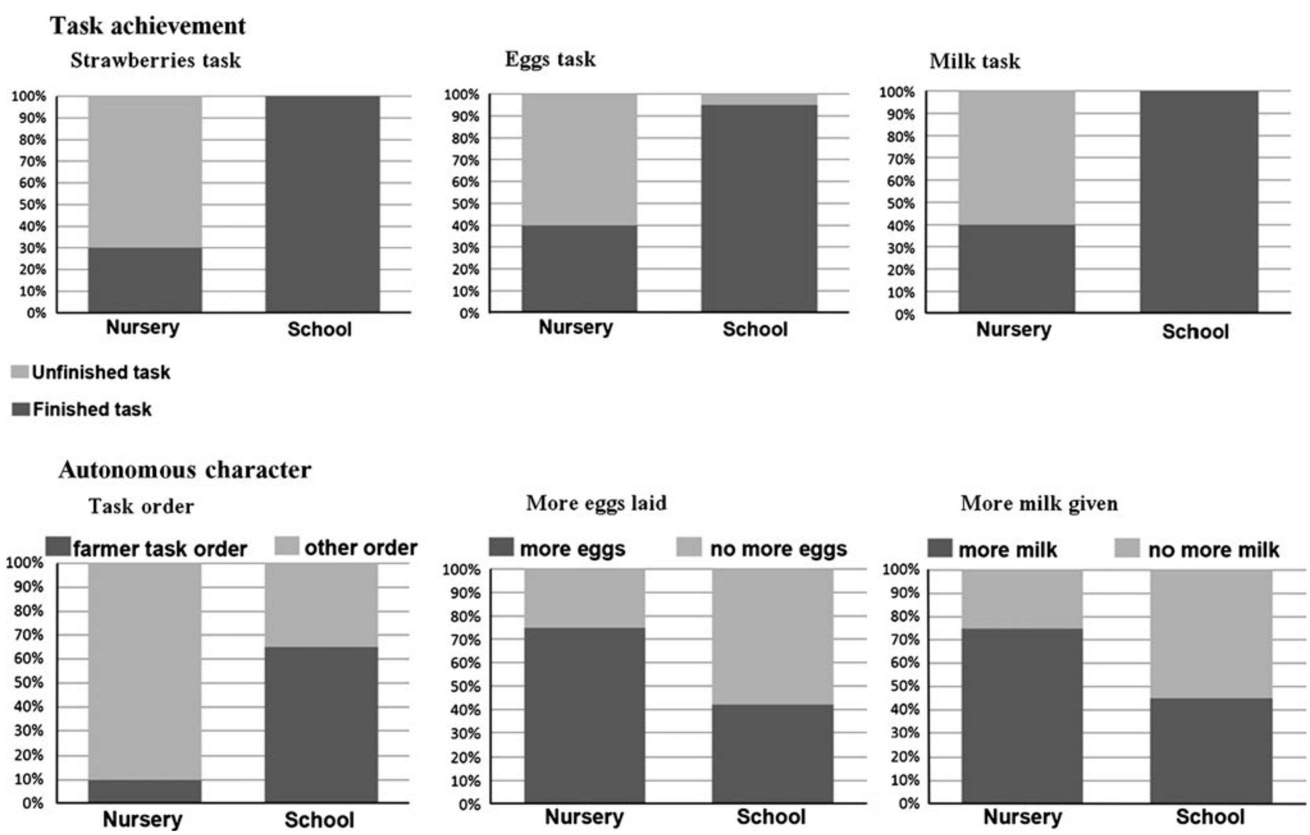

Fig. 7 "Making a cake" minigame: task completion rates and impact of the farmer autonomous character

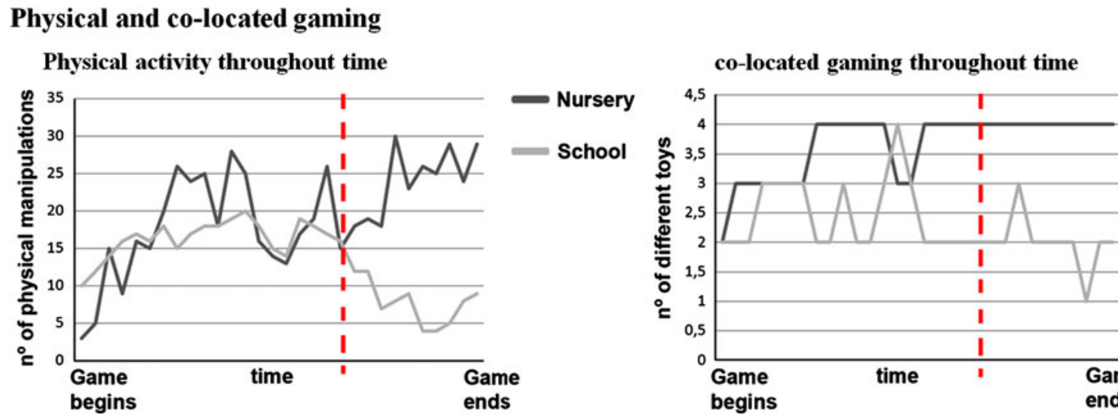

Fig. 8 "Making a cake" minigame: physical and co-located gaming

until the end of the game, even with one child manipulating two toys at the same time. In contrast, the school trials show an abrupt drop in physical and co-located gaming in the last 1/3 of the game (after the discontinuous vertical line in the graphs). 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 egg and milk tasks that 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, once the strawberry task was finished, only one child carried out the egg and milk tasks while the other partners looked away. Two main conclusions can be derived from these results:

- Even though the farmer character has a positive impact on task completion rates, he may have a negative impact on the physical and co-located gaming rates. This assumption should be taken with some precaution, due to the different environmental conditions in the nursery and the school.
- The co-location potential of the tabletop can be fostered with correctly designed activities (collecting strawberries) or wasted by not so good ones (collecting eggs and milk).

The degree of fun and engagement experienced by the children in the minigame was extracted from the video streams. The children's attention was on the monitor most of the time. Laughs and expressions of fun were always related with 3D animations and sounds shown on the monitor. The 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 or the nest and the bucket. Once they placed the toy on the correct 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. The combination of both outputs seems to have been a success, helping the children to perform their tasks (tabletop) and to have a good time looking at the 3D animations.

4.3 Discussion: tabletop games and young children

Various lessons useful for developing future tabletop games for very young children have been learned from the evaluation of the tangible farm game in the school and the nursery:

- NIKVision complements active images on the table surface with images on a vertical monitor, which is rare but not unique [29]. In our case, the vertical position of the monitor has been used to give a more attractive view of the virtual farm environment, in contrast with the less appealing top views characteristic of virtual environments normally shown on tabletop surfaces. This design decision had a notable impact on the degree of fun, as confirmed by the analysis of the video recordings of the sessions. The children expressed a sense of fun and engagement in the game while looking at the 3D animations on the 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 a set series of tasks (and **complete** the **game**) to benefit from the pedagogical content, the use of an autonomous character to give instructions and commands is fundamental. In a task-driven approach with a guiding character imposing the order of task completion, children get a clear understanding of each task objective and the end conditions. However, interaction with the game may become rigid, with less fun and spontaneity.
- **Physical** play can be better exploited by avoiding rigid structures (like those of traditional videogames), letting

children freely explore and discover for themselves and taking advantage of the new forms of interaction offered by TUI. The use of a virtual character may again have a strong impact: a free game with no autonomous character giving instructions may result in better explorative behaviour in children, enhancing physical and co-located gaming. Relaxing the task-driven orientation of the character by limiting it to providing help when needed and to giving positive and negative feedback seems a good solution for reinforcing explorative gaming.
- A tabletop device does not in itself support co-located gaming. The design of the game tasks is decisive in order 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.

Lastly, the different psychomotor and cognitive development states of small children of the same age represent a challenge when designing any game task. When children are asked to shake or stomp with the toys, Will they all understand the instruction equally? Will they perform the gesture in the same way? How precise or exact should children's manipulations be in order to make a challenging game but not an impossible task? These issues become critical when the range of possible players is extended to children with cognitive disabilities, as discussed in the next section.

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. Nevertheless, in the case of cognitive disabilities, the accessibility problem is not rooted in physical barriers but in the comprehension on the part of the child of 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. As stated in Sect. 2.2, 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 the way 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 [5]. 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 how to do it. The teachers only intervened when the children became blocked and did not know what to do 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. The log files were exported as video sequences and synchronised with the recordings of the children playing. In this way, a complete reconstruction of every game carried out in the classroom was achieved (Fig. 9).

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, Fig. 10 shows very similar results to those obtained from the previous school tests. The tasks were completed in all trials, the task order followed the instructions given by the farmer in most trials, 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, children had the feeling of being tested which pushes them to follow

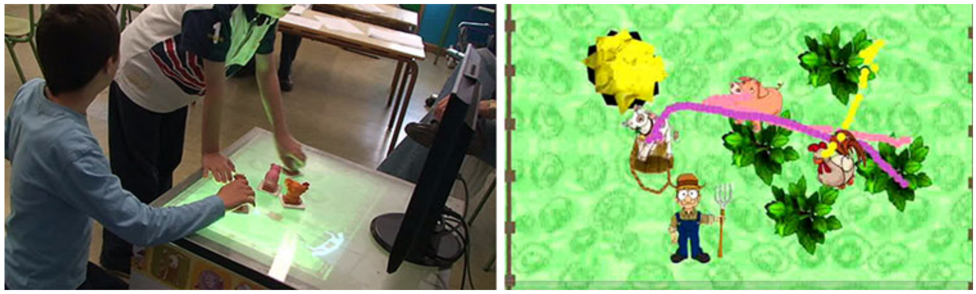

Fig. 9 Video sequence captured in the classroom (*left*) and graphical reconstruction from the log file (*right*)

instructions and complete the 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 teachers' interventions, there were some shifts in the task order and some tasks were continued after having been completed. The order shift 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. 11), 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 realised 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 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. [46] 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 [1] 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, that is, 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 (see Table 2) 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

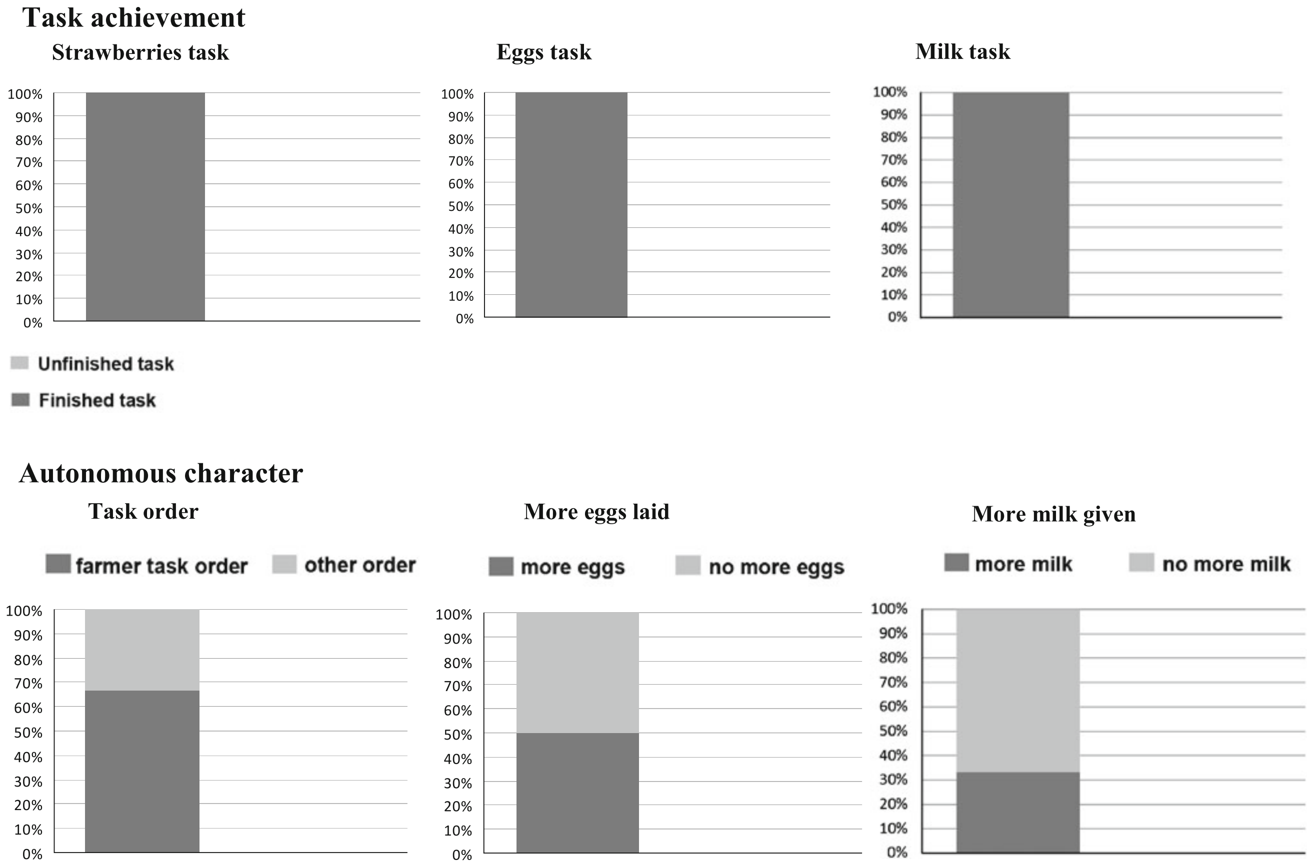

Fig. 10 Evaluating the "Making a cake" minigame: task completion rates and impact of the autonomous farmer character with special needs children

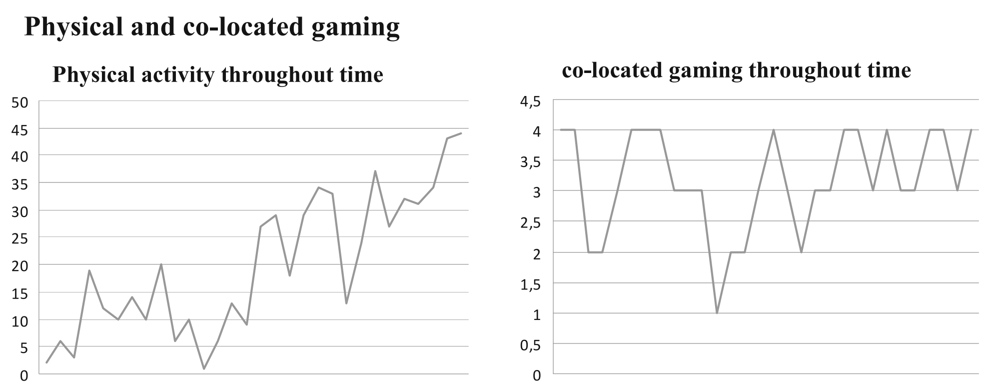

Fig. 11 Evaluating the "Making a cake" minigame: physical and co-located gaming with special needs children

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** visualised 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 (see Fig. 12).

After the labelling process, each game is graphically shown as a timeline where the children's actions are related

Table 2 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. 12 Different labels on video streams. *Left* a child discovers how to lay eggs while exploring the game. *Centre* a child tries to collect strawberries when the task has already ended. *Right* a child is making a jump gesture which the system does not recognise

to feedback events (see Figs. 13, 14). 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. 13 shows a child carrying out a milk task. At the beginning, the farmer gives instructions about how to perform the task (Fig. 13-1). 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. 13-2) 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. 13-3). Finally, there is a longer teacher intervention explaining how to perform the task (Fig. 13-4), 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. 14). The timeline shows that the child has definitely understood the task: after listening to the farmer's instructions, he lays an egg correctly (Fig. 14-1). Subsequently, his actions are exploratory and he has fun playing with another toy without realising that he has to lay three more eggs to successfully complete the task. Meanwhile, the farmer keeps telling him to finish the

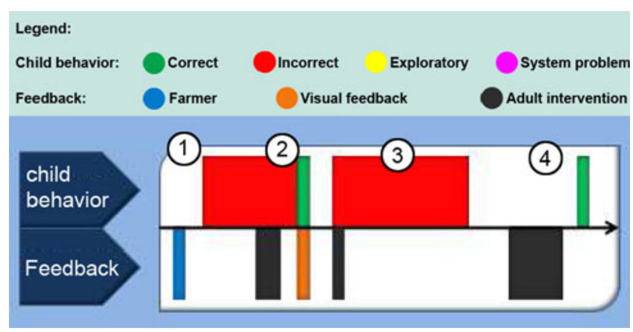

Fig. 13 "Giving milk" task timeline

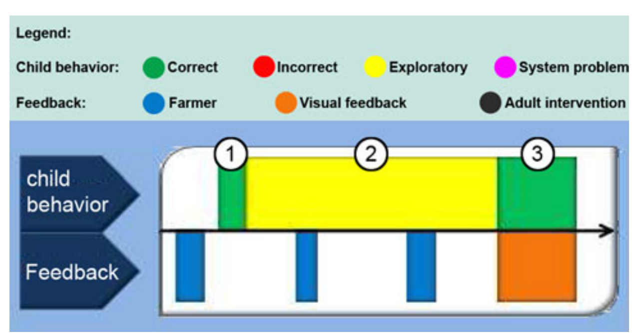

Fig. 14 "Laying eggs" task timeline

task (Fig. 14-2) and, finally, the child realises and correctly lays the rest of the eggs (Fig. 14-3).

The results from the video analysis show the intrinsic difficulty of designing computer feedback for children with cognitive disabilities. Figures 13 and 14 reflect two very similar game activities carried out by the same child, resulting in very different adult interventions and child understanding.

These tests, although preliminary, 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, that can be very effective in regular educational environments, should not be developed as a substitute for the motivating and guiding roles of teachers. This has to be taken into account not only when developing the game but when assessing it. Evaluations in nurseries and schools have to be planned minimising adult intervention in order to observe children's natural interaction. In a special education classroom, however, educators should have an important role 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 and future work

In this work, a tabletop and a game based on tangible interaction have been evaluated in three educational environments: a nursery with 3- to 4-year-old children, a school with children aged 4–5 and a special education school with 7- to 11-year-old children. The game was created with the aim of engaging groups of children in a physical and co-located recreational activity by manipulating conventional toys.

Due to the young age of the children in the nursery and the school, and the cognitive skills of the children in the special education classroom, evaluation methods based on children's expressions or the verbalisation of their thoughts were avoided. Instead, usability testing methods were used such as automatic logging, video recording and questionnaires aimed to collect educators' observations. These methods proved to be very useful for collecting summative and formative data in the three environments. They have also been shown to be very versatile for gathering and analysing different usability data and in adapting to the different evaluation conditions of the three aforementioned environments.

The analysis of the data obtained from the evaluation sessions shows a positive impact of these technologies in terms of physical and co-located playing, revealing very similar behaviour in the early years and special education environments. Tangible interaction has proved to be equally accessible for both types of children. Differences emerge when the context and the level of teacher intervention are considered. In early year education environments, the activity can be designed as an autonomous recreational activity based on exploratory behaviour guided by a virtual character without teacher intervention. On the other hand, in special education environments, the activity strongly depends on the teachers' presence in order to facilitate game comprehension and to organise the activities according to the specific characteristics of the child. In this environment, the game should act as a motivational strengthening of the activities that the teacher proposes to the children. The role of the virtual characters should shift to providing emotional feedback and rewarding successful task completion.

Moreover, the promising results of the evaluation with special needs children have opened the door to the development of new recreational and educative activities specially designed for special education schools. In particular, teachers are convinced that a tool like NIKVision can be of great use as a flexible training tool for the reinforcement of the communicative skills of children with cognitive disabilities.

Acknowledgments We want to thank all the children and parents that participated in the NIKVision tests, the staff of the ChiCI Group at the University of Central Lancashire (UK) and the Alborada Special Education School of Zaragoza. This work has been partly financed by the Government of Aragon through Cooperation projects between University Departments and Secondary Schools and the Spanish DGICYT (contract no. TIN2011-24660).

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