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Evaluating simultaneous visual instructions with kindergarten children on touchscreen devices

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Abstract.

A myriad of educational applications using tablets and multi-touch technology for kindergarten children have been developed in the last decade. However, despite the possible benefits of using visual prompts to communicate information to kindergarteners, these visual techniques have not been fully studied yet. This paper therefore investigates kindergarten children's abilities to understand and follow several visual prompts about how to proceed and interact in a virtual 2D world. The results show that kindergarteners are able to effectively understand several visual prompts with different communication purposes despite being used simultaneously. The results also show that the use of the evaluated visual prompts to communicate data when playing reduces the number of interferences about technical nature fostering dialogues related to the learning activity guided by the instructors or caregivers. Hence, this work is a starting point for designing dialogic learning scenarios tailored to kindergarten children.

Keywords. Multi-touch interaction, kindergarten, semiotics, user interface design, interactive learning environments, tablet computers

1 Introduction

In recent years a great deal of attention has been paid to the use of touch-based devices such as tabletops and tablets. The direct-touch that these devices enable is preferred by children over other mediated pointing devices like the mouse and keyboard, as it provides a more direct way of selecting options on the screen (Hourcade, 2007). Moreover, different studies have pointed out that using multi-touch is a more intuitive way of interaction (Smith, Burd, & Rick, 2012) (Jokisch, Bartoschek, & Schwering, 2011); (Ioannou, Zaphiris, Loizides, & Vasiliou, 2013). Hence, as this technology involves a natural interaction style requiring little training (Fernández-López et al, 2013), tablet-based games have already been tested with children who have demonstrated preference for this option in educational activities (Furió et al, 2013). These devices have brought new opportunities to create other forms of interactive media to engage kindergarten children in beneficial educational activities (Nacher, Garcia-Sanjuan, & Jaen, 2016). With the goal of assessing the suitability of multi-touch tablet devices and to fully exploit its potential to design educational applications targeted to kindergarten children, several works have focused on evaluating the way in which kindergarten children interact with these devices. In this respect, Nacher et al (Nacher, Jaen, Navarro, Catala, & González, 2015) show that even children aged 2 to 3 are able to perform a basic set of multi-touch gestures (tap, scale up, scale down and rotation) on a tablet without assistance and they are able to perform more complex gestures (such as double tap and long press) when using some assistive techniques (Nacher et al., 2014). In this line, Vatuavu et al (Vatavu, Cramariuc, & Schipor, 2015) also showed that children aged 3 to 6 are able to perform touch gestures on small devices such as tablets and smartphones. Accordingly, kindergarten children have become frequent users of multi-touch devices such as smartphones and tablets being confronted with this technology even before they fully develop oral communicative functions (Rideout, 2011); (Plowman, Stevenson, Stephen, & McPake, 2012); (Cristia & Seidl, 2015). However, this growth in the use of multi-touch technology by kindergarten children and the study and evaluation of the gestures that they can successfully perform has not been matched with the study of appropriate techniques to communicate information about the applications tailored to their development. Several studies have shown that including instructions in the form of a short text or video clips is suitable for primary school children (Kähkönen & Ovaska, 2006) (Niemi & Ovaska, 2007) (Van Der Meij & Van Der Meij, 2014) but kindergarteners do not have the abilities required to read and understand text messages or complex verbal video instructions. In this sense, the design process of these techniques is especially challenging because kindergarteners are in the process of early language development and the younger they are the more scaffolding of technical nature they need (Neumann, 2017), including these special communication strategies when using touch screen devices. Hence, designers of educational applications targeted to kindergarten children need adequate graphic strategies to enable them to interpret different and diverse information about the applications, such as the gestures to be performed at a given time, the actions needed to go ahead, or information about the spatial location of objects in the virtual world. Therefore, the design of appropriate visual cues must be addressed since multi-touch interfaces can facilitate dialogic learning scenarios in which the dialog is centered around the learning activity itself rather than on the interactions the children are expected to perform each time (Derboven, De Roeck, & Verstraete, 2012).

Considering this, designing visual prompts that avoid the need of continuous external technical scaffolding (i.e. the gestures to be performed, the direction in which a game character should move, etc.) is crucial when developing games or applications targeted to young children. The design and usage of visual prompts tailored to kindergarten children abilities and development will help caretakers to concentrate more on giving cognitive scaffolding (i.e. the learning content to be acquired by the children) since children will get the other information through the integrated prompts. Moreover, in other scenarios in which children can interact collaboratively, the use of visual prompts understandable by all the children involved in the game is a key point for them to share information and plan collaboratively the actions to take by referring to visual elements that indicate the possible available actions to perform contributing to a more satisfying and successful group educational experience.

Therefore, in this paper we evaluate several visual prompts in co-existence in a real educational application in order to find out whether the cluttering of different visual prompts and several interactive elements in a virtual world has an impact in the understanding of these semiotics with kindergarten children. In addition, we also aim to test whether kindergarten children are ready to use an application which requires sequences of different multi-touch gestures to complete the task with the same success than when performing these gestures in isolation.

The contributions of this work are manifold. The first contribution is the experimental confirmation that kindergarteners are able to effectively understand two different types of visual prompts displayed simultaneously and communicating data with several purposes. The second contribution relies on the fact that using visual prompts to communicate data about the gestures to be performed and to provide directional awareness fosters dialogues related to the learning activity and reduces the number of interferences about the interaction mechanisms expected each time by the application. The third contribution is the experimental confirmation that despite the task asks kindergarten children to perform sequences of different multi-touch gestures; their performance is not negatively affected. Finally, in this work we have gamified a multimedia application adapting it to kindergarteners' development and skills and the results show that they are ready to use it and that the use of this game fosters dialogues with caretakers about the learning content to be acquired.

2 Related work

In the literature, several studies evaluating the suitability of multi-touch technology with pre-kindergarten children can be found.

For example, Nacher et al (Nacher et al., 2015) showed that even children aged two and three years old are able to perform properly a basic set of multi-touch gestures including tap, drag, scale (up & down) and one finger rotation. Moreover, more complex gestures such as double tap and long pressed can also be performed by them when using some assisted strategies (Nacher et al., 2014). The work by Vatavu et al (Vatavu et al., 2015) also pointed out that children aged three to six years old are able to perform the tap, double tap and single hand drag and drop gestures properly. However, not only basic gestures can be done by young children but also gestures that require movement of contacts with high accuracy at the termination of the gesture (such as drag and drop) and more complex gestures (such as the one finger rotation and scales) (Nacher & Jaen, 2015) suits with young children's skills. Other studies evaluated the interaction needed to play with four applications (Aziz, Batmaz, Stone, & Paul, 2013)(Aziz, Mat, Batmaz, Stone, & Paul, 2014). These applications required the use of gestures such as tap, drag, rotation, drag and drop, pinch, spread and flick. After evaluating them with children aged from 2 to 4, the results showed that children aged 4 were able to perform all the set of evaluated gestures and those aged 3 only had problems with the spread task. Finally, 2-year-olds were less effective with the more complex gestures such as drag and drop and pinch but were able to perform the tap and drag gestures properly and quickly learnt to perform the flick gesture. Moreover, children's preference for educational tablet-based games has already been demonstrated in real educational applications targeted to transmit knowledge (Furió et al, 2013) because it involves a natural interaction style which requires little training (Fernández-López et al, 2013).

These previous studies reveal that the use of multi-touch technology fits perfectly with young children and point out some guidelines to design and develop the interactions to be included in touch applications specially tailored to kindergarten children skills and development. However, only few and diverse studies can be found addressing the issue of communicability of information to kindergarten children in multi-touch screen devices. Hence, there is no standard way of communicating information to children. In this sense, several works have evaluated different ways of providing children with instructions about the required interaction. For example, Niemi & Ovaska (Niemi & Ovaska 2007), explored an interaction design process with children aged 6 years old when instructions are given and their results showed that instructions in the form of animations to show the correct use of complex tools were the best option understood but only if these animations were accompanied by spoken instructions. These results are obvious and expected since applications for young children cannot rely on written text to give instructions due to their lack of reading skills. Similarly, animations and written instructions to provide instructions in applications targeted at 5-6 year-old children with desktop computers were explored by Kähkönenet et al (Kähkönen & Ovaska, 2006). The results showed that despite communicability being especially challenging with young children, following some design guidelines was effective in supporting the communication process and also showed that providing help in the form of audio messages could overcome some of the limitations of written instructions. These guidelines recommended giving visual cues to trigger children's attention in order to help them finding new content and textual instructions adapted for them and providing separated video instruction so that they can focus on a specific explanation. Another example is the work by McKnight and Fitton (McKnight & Fitton 2010) in which they performed a test on common touch-screen terminology in which English-speaking children aged between 6 and 7 were asked to perform a basic set of touch gestures from audio and written instructions. The obtained results showed most of the instructions were understandable by children and they completed the task easily. Moreover, as can be expected, giving accompanying textual instructions was useful. However, they pointed out that it was hard to establish a consistent link between a specific term and a touch gesture making the design of the given children instructions a critical phase due to their limited vocabulary and reading skills.

Baloian et al. (Baloian, Pino, & Vargas, 2013) evaluated the use of metaphors to communicate multi-touch gestures to 5-6-year-olds. In their approach, they used metaphors for each of the application's gestures avoiding the use of common names of gestures used by adults. Hence, each gesture was associated to a specific "recallable" character (e.g. a jumping grasshopper for a double tap, a walking ladybug for a drag gesture or a hovering butterfly for a tilting gesture) and these words and pre-recorded audios were used to ask users to identify and perform different gestures. However, the results showed no strong correlations between performance and the behavior of the characters that the children liked or disliked the most.

All the previous works used a combination of text, audio and/or visual cues to give instructions to children aged 5 to 7 and showed that they are ready to use this type of communication despite having some minor issues. However, applications for younger children cannot rely on written text to give information due to the lack of reading skills. Moreover, there is no standardized way to name touch gestures, so using audio cues may present several understandability problems.

Other works have addressed the communicability of touch gestures avoiding text and audio cues. Hiniker et al (Hiniker et al., 2015) evaluated prompts such as in-app audio, on-screen demonstrations (with hand demos or changing the visual state of the item) and instructions by an adult model for eliciting gestures such as double tap, horizontal and vertical swipe and shaking the tablet with children aged between 2 and 5. Their results showed that although the most effective technique was adult guidance, children aged 3 years or older were able to follow other types of cues. Nacher et al (Nacher et al., 2014) (Nacher et al., 2017) analyzed the communicability of three types of touch gestures (in-place, one-contact dynamic & two-contact points dynamic gestures) comparing three visual prompts with children aged 2 to 3. Despite their results showed that the iconic approach designed for adults was not appropriate for young children, the two animated approaches (using the image of a hand and changing the visual state of the item to be manipulated) had high success rates (reaching 90%) when communicating gestures which involve movement (drag, rotation & scales). Hence, these works showed that the basic reasoning related to the interpretation of moving elements on a surface can be effectively performed during early childhood despite the fact that kids develop spatial reasoning during middle childhood (Levine, Huttenlocher, Taylor, & Langrock, 1999) (Piaget, 1973).

Although the previous results showed that these approaches are feasible and understandable for these users, the studies focus on semiotics for giving instructions to children but not for giving any type of application information, such as spatial information, application goals, etc. Only a recent study has addressed the issue of communicability of spatial awareness about the elements included in a virtual world with children aged between 4 and 7 years old (Nacher, Jurdi, Jaen, & Garcia-Sanjuan, 2019). Three different visual prompts to communicate directional awareness (a mini-map, using thumbnails on the screen borders & using an arrow to guide the direction in which the main character should be moved) were designed and evaluated. The mini-map resulted the most problematic technique, whereas the border-floating thumbnails and the arrow techniques reached success rates of over 99%.

In conclusion, several works have showed that using visual prompts is a feasible technique to communicate information about the game/application to young children fostering dialogues about the content and reducing dialogues about the interaction to be performed. However, these works have evaluated these techniques in isolation and in tasks specially designed to test the suitability of the designed visual prompts. In this work we therefore evaluate whether kindergarten children are able to interact/play with applications in which two different types of visual prompts coexist giving cues with information from different sources (i.e. the gestures to be performed and spatial awareness about the digital world of the application). Moreover, the evaluation of the different visual prompts is carried out in a real application targeted to kindergarten children. Hence, the results obtained in this work should be a step forward in the process of obtaining effective semiotic systems understandable by kindergarten children that could be used in educational applications based on multi-touch technology.

3 Study context

The overall goal of our study was to test the suitability of using two visual prompts simultaneously to communicate different types of information about the virtual world in which kindergarten children have to complete a task by moving a character and performing different sequences of gestures on the objects scattered in the virtual world and to evaluate their effectiveness and efficiency.

Hence, using the GQM (Goal Question Metric) template (Basili, Caldiera, & Rombach, 1994), our goal can be defined as follows: *analyze* the impact of having two different types of visual prompts with different purposes each one cohabiting in the same virtual world *for the purpose* of evaluating their suitability *from the viewpoint* of effectiveness and efficiency *in the context of* providing both spatial awareness of the objects in a digital game world and the gestures to be performed by kindergarten children to complete the task.

3.1 Visual prompts

In the game, two different visual prompts are used to communicate information to children; visual prompts designed to give directional awareness and visual prompts to point out which gestures are required to complete an action.

The visual prompts used to point out the required gestures consist of a Mickey Mouse animated hand to represent a hand with one finger extended. Hence, the object to be manipulated with a multi-touch interaction is accompanied by the animated virtual hand (or hands if more than a contact is needed) that provides visual cues about the trajectory of the gesture to be carried out. This animated technique has been previously tested and resulted effective to communicate dynamic gestures such as *drag, rotation, scale up* and *scale down* with success rates of up to 90% with children aged between 2 and 3 years old (Nacher et al., 2017). The gestures to be performed are drag, scale down, scale up and rotation.

On the other hand, the visual prompts used to give directional awareness to children is a *Border-Floating thumbnails* technique in which miniatures of the objects that are not visible on the surface appear at the border of the screen. The position where the miniature is shown is the intersection between the vector that links the character to the corresponding object and the screen border (see **¡Error! No se encuentra el origen de la referencia.**). The miniatures positions are dynamically updated according to the relative character's position at a given moment. With this technique, the visual prompts only represent the objects that are outside of the current screen display. This technique has been previously evaluated in isolation reaching success rates of over 99% when guiding young children's movements to reach different targets in a 2D digital world (Nacher et al., 2019).

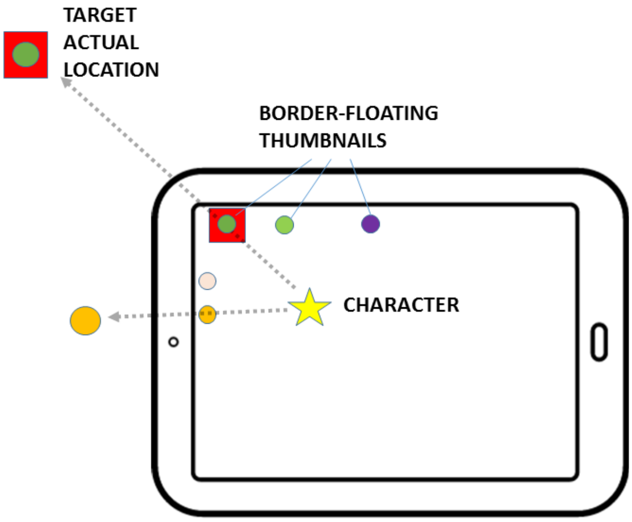

Figure 1. Representation of the thumbnail visual prompts.

3.2 Participants

Seventy-five children aged from 4 to 6 years old took part in the experiment (Mean (M) = 60.24 (months), Standard Deviation (SD) = 6.5) with a gender distribution of 34 males and 41 females.

The children were split up into two balanced age groups, i.e. they were grouped by age, with each age group comprising the ages [4, 5[and [5,6[. The distribution of the age groups were 39 children in the 4-years age group and 36 children in the 5-years age group.

The 4 to 6 year age range was chosen in order to assess whether the usage of different type of visual prompts working at the same time and the requirement of different types of gestures to be performed in sequence for different purposes is affordable for children in the earliest stage of development. The youngest users were children aged 4 years because in previous studies (Nacher, Ferreira, Jaen, & Garcia-Sanjuan, 2016), children were found not to be able to move/guide a character in a 2D world using indirect drag techniques with acceptable success when they are aged less than 4 . Parental and children consent was obtained before carrying out the study.

3.3 Equipment

The interaction framework for the experiment was implemented in Java using the LibGDX framework. The devices used for the experiment were BQ Aquaris M10 tablets with Android 5.1. The tablets were equipped with capacitive multi-touch screens with a 1280x720px resolution.

3.4 Task

The task designed is in context with the educational goals of the school where the activity took place. In this respect, teaching animal conservation and care topics was an educational goal for children in this early childhood. This educational topic is becoming more and more important because children are infrequently in touch with the natural world as pointed out by (Willis, Weiser, & Kirkwood, 2014). Hence, educating on environmental care values is necessary for children to start developing responsible behaviors regarding the natural environment (Louv, 2008). Environmental education is usually addressed through the basic premises of scientific inquiry: exploring, observing, communicating, organizing, applying, relating and inferring (Arce, 2013) so the task has been designed to evaluate children' preferences and engagement when taking part in activities of different nature. The task has been split up in three different stages corresponding to different cognitive processes that educators wanted to develop. The first one relies on an adventure game style in which free exploration of a virtual world is allowed fostering curiosity and discovery. In this part of the task children explore a 2D world simulating a natural ecosystem with different animals scattered around the digital world. The second part of the task consists in a problem-solving reasoning activity in which children have to "help" a specific animal performing different care actions. Finally, in the third stage of the task, children will be able to carry out an observation activity by visualizing a real video of the type of animal that has been cared.

In the following, each stage of the game is explained in detail and, in addition, an example of the game usage with these three stages has been recorded in order to facilitate the task explanation[2].

Exploration & Curiosity

The first part of the task relies on an adventure game style in which children have to control the movements of a character to explore the available open 2D space in search of animals to take care of. The choice of this type of game style is because it stimulates curiosity (Collins & Stevens, 1981) (Malone, 1981) and can potentially facilitate a range of different learning styles such as tutoring, practice and self-learning (Dempsey, Rasmussen, & Lucassen, 1994). Moreover, this type of activity fosters learning discovery which is a technique that helps learners to create and organize their knowledge, since they draw upon past knowledge and experience to infer underlying strategies and gain understanding of concepts (Honomichl & Chen, 2012). Knowledge discovery is also beneficial for students' motivation, since those

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[2] https://goo.gl/trjB2i

who discover information for themselves are more motivated to achieve educational goals and more likely to remember the information learned (Bruner, 1960). Taking this into account, the task begins in the *Exploration & Curiosity* stage in which children can move a vehicle in a virtual 2D world (see Figure 2). The vehicle can be moved using four arrow-shaped buttons symbolizing the four basic directions (i.e. up, down, left and right). These buttons are placed at the bottom-center of the screen and allow users to move the target by tapping and holding one finger on the button that symbolizes the desired direction. This indirect drag technique has been evaluated previously showing that children aged 4 years and older are able to use it with high success and reducing the number of undesired collisions respect to other indirect techniques (Nacher, Ferreira, et al., 2016).

In the task, children move the vehicle over the virtual world in order to visit the animals they want to help and watch. In order to develop problem-solving skills educators proposed that the animals should be surrounded by water that the vehicle cannot cross; however, malleable bridges are placed in each water point (see Figure 2). These bridges need to be rotated and/or scaled in order to fit with the water size and shape. This task was also proposed by educators in order to develop geometric interpretation skills. Once the bridge is fitted the water disappears and the vehicle can go through to reach the animal. The gestures to be performed in order to fit the bridges are scale down, scale up and rotation. Some bridges require only one of these gestures to be fitted and others need a sequence of them (rotation and scale up/down). The prompts about the gestures to be performed will only be visible when the main character is close to the bridge location in which case the bridge will be enabled to be manipulated.

Figure 2. Example of the game in the *Exploration & Curiosity* stage with an active bridge and the visual prompts representing a scale up gesture.

In order to evaluate the interface under two different levels of visual information density (low and high), two different scenarios varying the information density are used. The first one corresponds to a setting with low density, hence, three animals to be cared of are used. The second setting has six animals to visit being a scenario with a high visual information density. Each child is randomly assigned with one setting.

When the vehicle finally reaches the location of an animal, the second stage of the game is launched in which children have to take actions to care this specific animal.

Problem-solving Reasoning

In this stage, children are told to take care of an animal who is not feeling well by giving it food, medicine or cleaning it. Children aged between 4 and 5 years begin to understand inference as a source of knowledge and around the same time they evidence an understanding of knowledge gained through perception and communication (Keenan, Ruffman, & Olson, 1994), hence, this part of the task aims to help children to infer that taking the appropriate medicines, having good hygienic habits and having a proper diet will make them healthy. The design of the activity resulted from a discussion with educational experts who decided that a matching activity should be proposed at this stage. Therefore, in this part of the game, three images of the animal, the one reached in the previous exploration stage, appear on the right side of the screen and three different images representing care actions to be dragged appear on the left side. The three images of the animal are tailored to represent three different states; a sick animal, a hungry animal and a dirty animal (see Figure 3). The three images to be moved are objects that the animal needs; medicines, food and a sponge to be cleaned. These objects have to be matched with the animal that requires the corresponding action. An animated semiotic using a moving hand is used to point out to children that a drag interaction is needed. Once an object is brought to the correct animal, the characterization disappears and the animal appears with a green background denoting that it is fine (healthy, clean or without hunger). When the three images are matched with the corresponding image of the animal, a video of the animal is automatically played in full screen starting the third phase of the game.

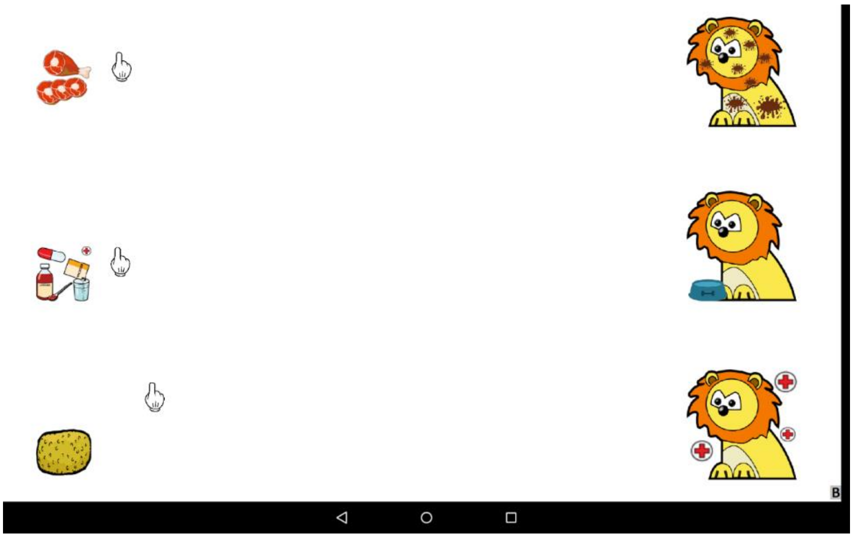

Figure 3. Example of the game in the *Problem-solving Reasoning* stage for the lion.

Observation

Children are able to learn from video visualization since the early childhood (Allen & Scofield, 2010; Pecora, Murray, & Wartella, 2009), hence, in this stage of the task, children visualize a video related to the animal that they have helped previously (see Figure 4). Children are able to quit the video whenever they want and they are able to go forward or backward in the video as they wish. With the help of educators, the videos were previously selected when designing the game from a set of available videos in the Youtube platform.

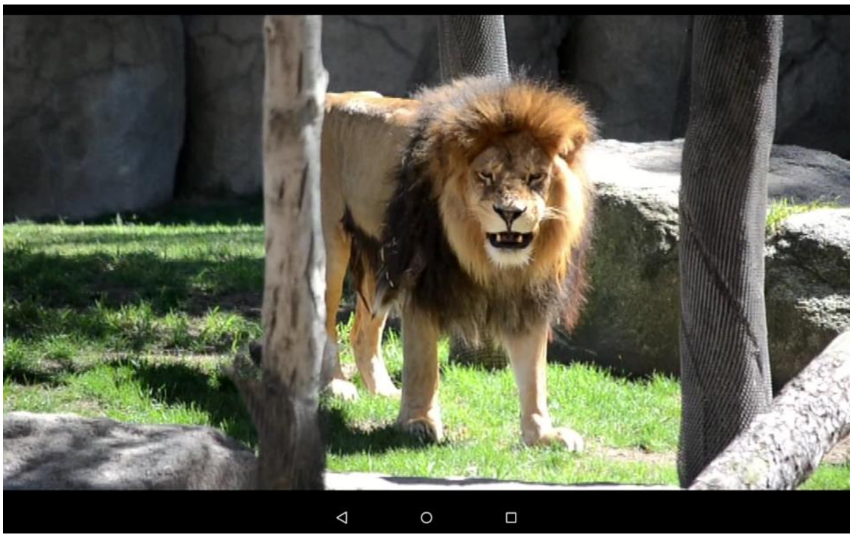

Figure 4. Example of the *Observation* stage for the lion.

3.5 Procedure

The children participated in the experiment one day. At the beginning, the instructors explained the task to children telling them that the task consists of a game in which they have to move a vehicle to visit and take care of different animals that appear in the game and, then, as a reward visualize a video of the animals after being helped. The children were given a 1-minute learning phase with an instructor in order to explain the button based technique to move the vehicle and the visual prompts used (i.e. the border-floating thumbnails technique for the spatial awareness and the moving-hands technique to communicate the gestures to be performed). Then the game begins in the Explore stage and children are free to visit (or not) the animals they want. Each child plays in a setting randomly assigned so they have three or six animals to visit depending on the setting assigned. An instructor is accompanying children all the time and can eventually help them if they ask for it. Around 15 minutes are given to each children to play the game. The experimental platform registered the times dedicated by the children in each of the three stages (*Exploration & Curiosity*, *Problem-solving Reasoning* and *Observation*), the number of times a given animal is visited and the gestures performed by children to fit the bridges. Moreover, a qualitative analysis is also carried out from the notes taken by the instructors during the experimental sessions.

3.6 Research questions

The research questions of this work are formulated as follows. The first research question is about the engagement of the game:

- RQ1: Is the game attractive to children and engage them along the duration of the task?

Then, five research questions are stated and will be answered for each factor F_i considered (where *i=Semiotic density*, *Age* and *Gender*)

- RQ2: Is the time spent in the *Exploration & Curiosity* stage affected by the factor F_i?
- RQ3: Is the time spent in the *Problem-solving Reasoning* stage affected by the factor F_i?
- RQ4: Is the time spent in the *Observation* stage affected by the factor F_i?
- RQ5: Is the spatial exploration scope affected by the factor F_i?
- RQ6: Is the effectiveness of the gestural semiotic affected by the factor F_i?

3.7 Design

Six dependent variables were defined: percentage of Explore & Curiosity time, percentage of Problem-solving Reasoning time, percentage of Observation time, percentage of the available animals visited, total animals visited and percentage of gestures correctly performed. A between-subject ANOVA (with an $\alpha = 0.05$) was carried out with the factors: *semiotics density* with two levels (low vs high), *age group* with two levels (4 years vs. 5 years) and *gender* (Male vs. Female).

4 Results

4.1 Time dedicated by stage

With the purpose of evaluating children preferences when playing, the time spent by each user in each of the three stages of the game were registered. The time spent in each stage respect to the total time of the task is expressed as a percentage in Figure 5 and the times by each of the factors evaluated are shown in Table 2, Table 3 and Table 4.

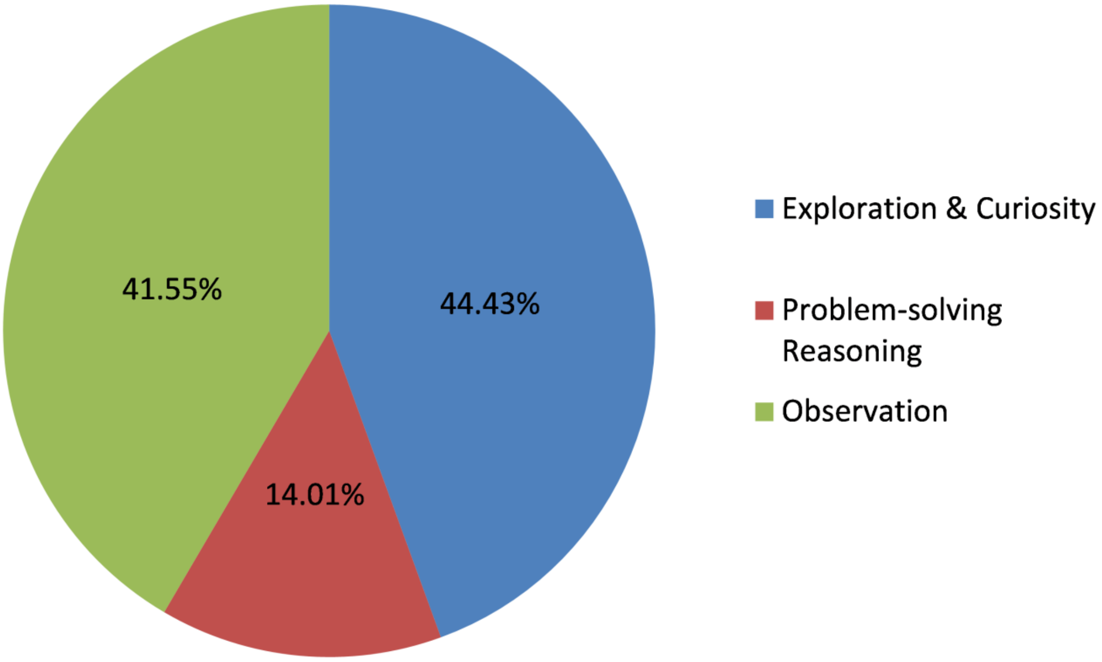

Figure 5. Time spent in each stage of the task in percentage.

A three-way between-subject ANOVA with the independent variables *gender*, *age group* and *semiotic density* and the dependent variables *percentage of Exploration & Curiosity time, percentage of Problem-solving Reasoning time* and *percentage of Observation time* was applied. The statistical analysis revealed significant differences in the between-subject factors *age group* and *semiotic density* (see Table 1). The differences between the age groups in the distribution of time can be seen in Figure 6, children aged 4 years spent significantly more time than those aged 5 years in the *Exploration & Curiosity* stage ($M_{4\text{-years}}$ = 48.40% vs $M_{5\text{-years}}$ = 40.03%). However, those aged 5 years, spent significantly more time visualizing the videos than the younger age group ($M_{4\text{-years}}$ = 37.31% vs $M_{5\text{-years}}$ = 46.26%). No differences were found in the *Problem-solving Reasoning* stage with both age groups spending around a 14% of the total time.

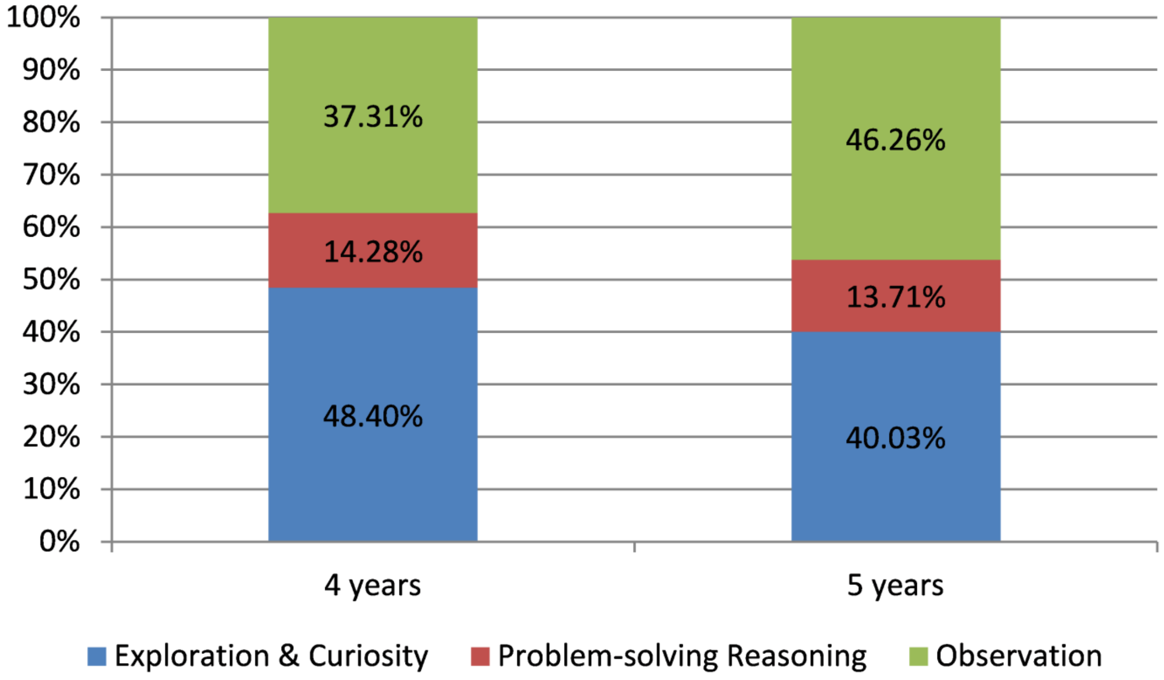

Figure 6. Percentage of time spent in each stage by age group.

On the other hand, the *semiotic density* has an impact too in the time distribution between the stages being significantly higher the time spent in the *Observation* stage when the semiotic density was low (i.e. three animals are available) (M_{low}= 44.79%) than when it was high (i.e. six animals were disposed in the game) (M_{high} = 39.07%). Moreover, as it was expected, the time spent by children in the *Explore & Curiosity* stage was significantly lower when the semiotic density was low (M_{low} = 41.46%) than when it was high (M_{high} = 46.72%) (see Table 1). No differences were found between the two semiotic density settings in the *Problem-solving Reasoning* stage of the game.

Finally, the analysis demonstrated that the time spent in each stage of the game was not significantly influenced by gender (see Table 1).

4.2 Spatial exploration scope

To evaluate the effectiveness of the spatial awareness semiotic and its ability to effectively communicate the relative position of different targets with respect to the current position of the main character, the number of times that an animal is visited was registered.

4.2.1 Virtual space covered

In order to assess the effectiveness of the semiotic to provide spatial awareness of all the animals scattered along the virtual world, the percentage of available animals that has been visited during the task is depicted in Figure 7 by age group, semiotic density and gender. The detailed data can be seen in Table 2, Table 3 and Table 4.

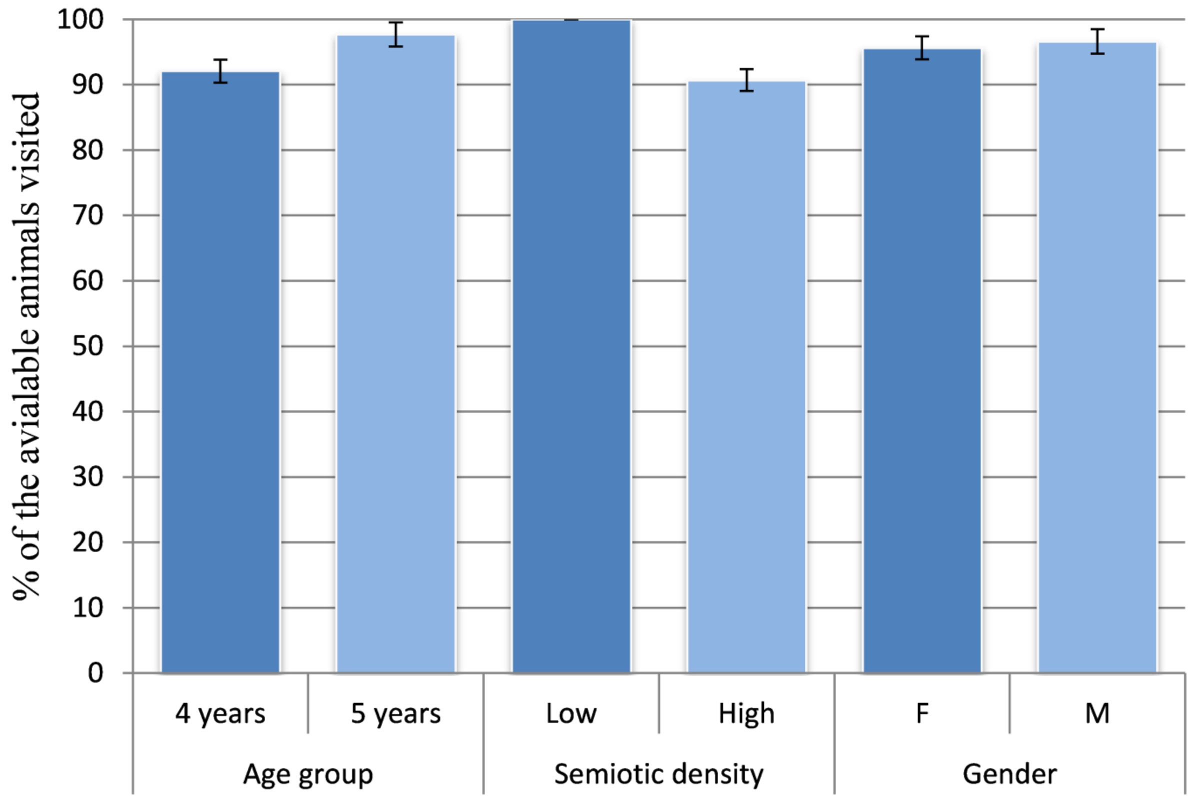

Figure 7. Percentage of the available animals visited during the experiment by age group, semiotic density and gender.

The ANOVA did not reveal significant effects on the percentage of available animals visited of the *gender* and *age group* factors (see Table 1). On the other hand, the statistical analysis revealed significant effects on the percentage of the available animals visited of the factor *Semiotic density*, being the percentage 100% when it was low (i.e. three animals were available in the task) and 90.70% when the semiotic density was high (i.e. six animals available to visit). However, despite this difference, the average percentage of the available animals that have been visited during the task is over 90% showing that the spatial awareness semiotic fulfills effectively its function communicating to children where the animals are located in the virtual open 2D world independently of the semiotic density.

4.2.2 Exploration efficacy

The total number of animals visited was analyzed too in order to assess the efficacy of the visual prompts to reach different points of the virtual game several times and to find out whether children revisit elements of interest in a fifteen minutes play. The total number of animals visited is shown in Figure 8 by age, gender and semiotic density.

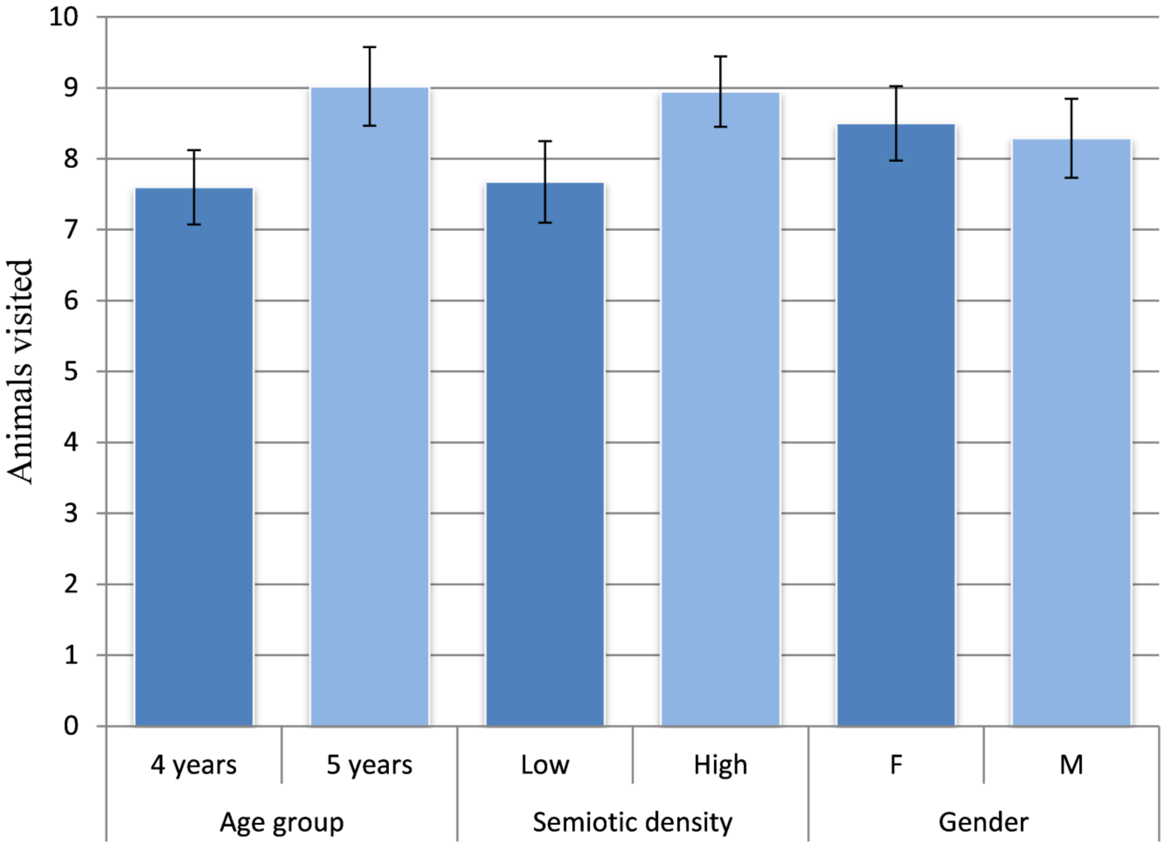

Figure 8. Total animals visited in the task by age, semiotic density and gender.

The analysis revealed that none of the evaluated factors (*age*, *semiotic density and gender*) have a significant impact on the total number of animals visited by children during the task (see Table 1). On average they visit a number of animals between seven and nine in the fifteen minutes that they were playing with the game, hence, children visited an animal approximately every two minutes of playing. This data shows that kindergarten children are ready to complete the task without having big handicaps.

4.3 Gestural interaction visual prompts effectiveness

In order to assess whether the need to perform sequences of gestures has an impact on the success rates of children and whether the prompts used to communicate the gestures to be performed are effective with kindergarten children when the virtual space is also cluttered with the directional awareness visual prompts, the sequence of gestures to be performed by children for each “bridge” was predefined in order to compare the total number of gestures fitted by each children (i.e. 4 gestures were needed to be performed to fit all the bridges when the semiotic density was low and 8 gestures were needed when the semiotic density was high). Hence, the percentage of gestures fitted respect to the total number of gestures previously set is evaluated. This percentage is shown in Table 2, Table 3 and Table 4 and graphically in Figure 9.

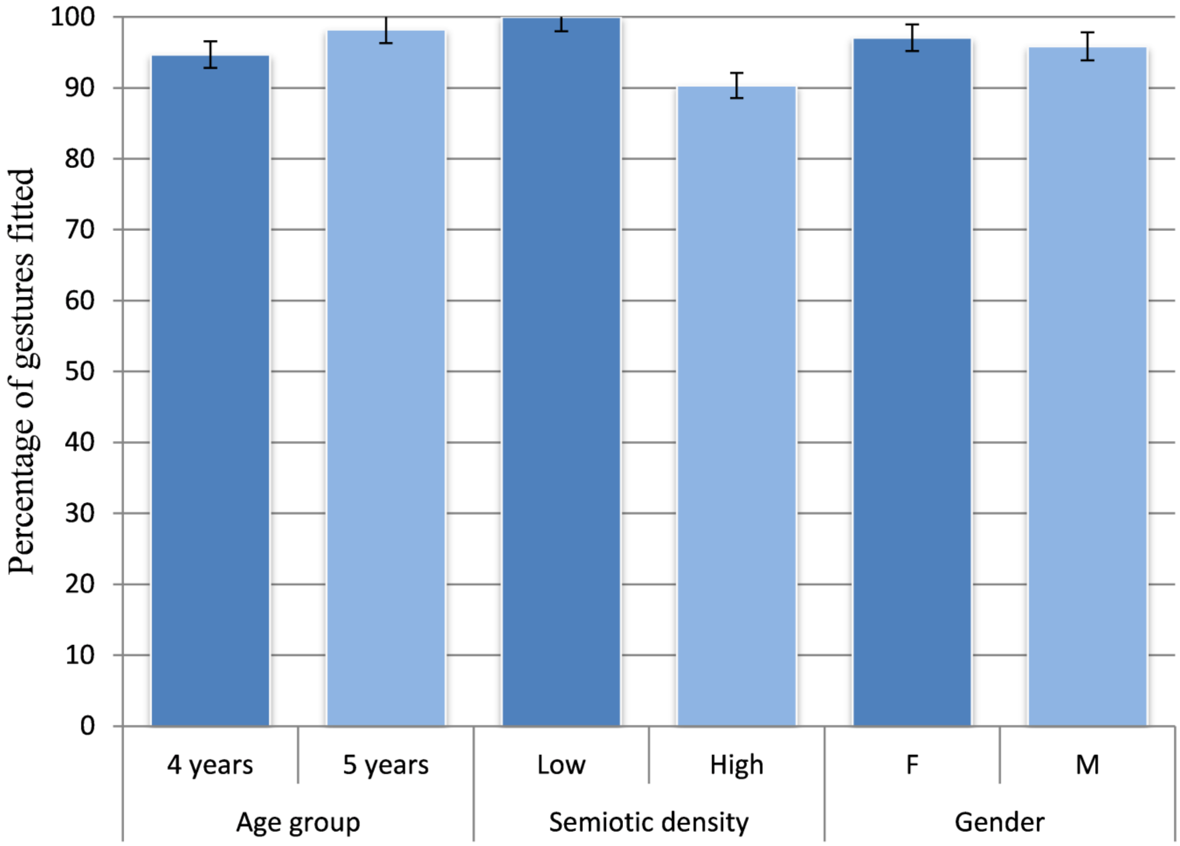

Figure 9. Percentage of gestures fitted by age, semiotic density and gender.

The ANOVA revealed significant effects on the percentage of gestures fitted of the factor *Semiotic density* being the percentage 100% when it was low and 90.34% when it was high. However, despite the differences, both settings have a percentage of gestures fitted over 90%. Hence, children are able to perform the evaluated gestures in sequences with high success rates and the prompts used to point out the required gestures to be performed to fit the bridge are still effective in co-existence with the directional awareness prompts.

Moreover, the analysis revealed that the age group and gender factors did not have a significant impact in the percentage of gestures fitted (see Table 1).

Hence, the results show that kindergarteners are able to successfully perform sequences of different basic multi-touch gestures and they understand the visual prompts even when several interactive objects requiring different gestures are placed in the virtual world and when the interference of the directional awareness prompts are present.

4.4 Observational findings

In addition to the automatic data logging, throughout the experimental sessions, notes were taken about children's actions, dialogs and behaviors while interacting with the application. These observational findings are not quantified since the impossibility of recording the sessions prevents us from reporting precise measures but valuable information regarding the behavior of children during the experiments can be extracted from them.

The observation revealed that the game fostered different types of conversations. For example, while playing the game, children talked to the instructors to explain them some issues related to the game topic (e.g. "The panda likes to eat bamboo", "The lion is dirty because he has played in the mud"), talked about their future actions (e.g. "Now I am going to help the panda because he is sad", "I am going to visit the lion and then the giraffes"), sometimes they ask for help or ask for permission to do something (e.g. "How do I have to clean the lion?", "Can I visit the gorilla again?"), and, finally, children also make comments about being a doctor or a vet in the future; they also talked about their pets, and some of them also recognized the zoo infrastructures and talked about previous visits to it with their family or school.

On the other hand, one of the most observed children's actions during the experiment was to ask for more animals when they have visited all the available ones of the task. This situation usually happened when children played with the low semiotic density game setting (i.e. three animals available to visit). However, despite asking for more animals to watch, none of the participants wanted to leave the task before they spent all the time given by instructors. This fact points out that using a high semiotic density does not have negative effects in children perception of the game but the more animals to visit the more engage and fun perceived by children.

The observation also reports that most children wanted to visit all the available animals in the game as fast as possible. Hence, children usually left the video observation stage as a secondary task and, usually, they visualized only a short part of the video and went back to the *Exploration & Curiosity* stage in order to guide the vehicle to all the available animals. However, once children had visited all the animals, helped them and realized that there were no more different animals to visit; they revisited the animals that they liked the most and spent more time watching the videos and asking or speaking about them.

Another frequently observed action was children speaking to the animals. They usually speak to the animal they want to help (e.g. “Hey giraffe! Take your food, I will clean you and I will give you your medicines”, “I am going to take care of you because you have a cold”, “It’s done gorilla, now you are fine!”) showing that they empathize with the animals and try to help them.

Finally, most of the children asked for playing more time or expressed their feelings about the game time being too short since they wanted to play more. This happened independently of the stage of the game in which they were in that moment; if the time run out when a children was in the *Exploration & Curiosity* stage they used to ask for visiting the last animal, if the time ended in the *Problem-solving Reasoning* stage they asked for additional time to finish the care actions that they were doing, and, finally, if the time ended in the *Observation* stage children used to ask for additional time to finish watching the video.

5 Discussion

The experiment explored and answered the comprehensive set of research questions that had been posed. The first research question (RQ1) about whether kindergarten children found the game engaging and played along all the time predefined for the experimentation is affirmatively answered as none of the children left the task before the time limit. Children used all the available time to play and they interacted with the application until the instructors ask them to stop. Although the experimentation showed that children found more attractive visiting new animals each time than revisiting animals previously reached, they continued playing when they were told that there were no more different animals to visit and they invested more time in the *Observation* game stage. Moreover, many children asked for playing a bit more showing that the game resulted engaging and fun for them.

If we consider RQ2 in terms of the time spent in the *Exploration & Curiosity* stage, it is answered affirmatively for the factors *Semiotic density* and *Age*. The results showed that when playing with a low semiotic density setting, children spent less time in the *Exploration & Curiosity* stage ($M_{low} = 41.46\%$ vs $M_{high} = 46.72\%$). It is an expected result since the more interactive elements scattered in the virtual world the more time children need to reach all of them. Regarding the *Age* factor, the results showed that younger children aged 4 years spent significantly more percentage of the total time than those aged 5 years in the *Exploration & Curiosity* stage ($M_{4\text{-years}} = 48.40\%$ vs $M_{5\text{-years}} = 40.03\%$). This happens since younger children spent less time in the *Observation* stage of the game as they were less developed and have a more limited attention span (Hanna, Risden, & Alexander, 1997), they lose the attention in the video visualization activity and come back to the *Exploration & Curiosity* stage earlier than the older age group.

RQ3, on whether the time spent in the *Problem-solving Reasoning* stage is affected by any of the evaluated factors, is answered negatively for all the factors. As expected, the *Semiotic density* does not have an impact in this stage of the game since only the latest visited animal appears independently of the game density setting. Regarding the *Age* factor, it can be expected that no differences between the two age groups will arise in terms of usability since the task is based on performing drag gestures with precision in the termination phase of the gesture. Previous studies have showed that even children aged 2 years old are able to perform this type of gesture with high accuracy (Nacher & Jaen, 2015b). Moreover, the results showed that the cognitive load of performing the matching activity is equally overcame by children in both age groups since no time differences were found between them when performing this part of the task. This is consistent with previous literature which shows that matching and sorting activities are feasible for young children since the age of three (Pemberton & Road, 2009).

Regarding the RQ4 on whether the time spent in the *Observation* stage is affected by any factor, it is affirmatively answered for the factors *Semiotic density* and *Age*. The results showed that when playing with a high semiotic density setting, children spent less time than when they play with a low density. As reported in the observational results, children prioritized visiting all the animals to help them. Hence, they left the video observation stage in a second level of priority. Hence, when playing with a high semiotic density, children required and used more time to visit all the animals in the game and the time remaining when all the animals were visited was lower than when a low semiotic density was set. This prevented children to invest much time watching the videos. Regarding the *Age* factor, the results showed that the youngest age group (those aged 4 years) spent significantly less time than the older group in the *Observation* stage of the task. This is the case because the more developed children are, the more patience they have being able to wait watching the video and avoiding the eagerness of the younger. This is consistent with the literature which shows that preschoolers have a limited attention span which is increased with age (Hanna et al., 1997) and get distracted too quickly (Egloff, 2004). Consequently, the less developed children used to get distracted when visualizing the videos and returned to the *Exploration & Curiosity* stage in order to interact with the game.

In response to RQ5, on whether the spatial exploration scope is affected by any factor, it is answered negatively for the *Age* factor in terms of the virtual space covered and the exploration efficacy. The absence of significant differences in terms of the virtual space covered shows that the effectiveness of the visual prompts to provide spatial awareness of all the animals scattered along the virtual world is high and, despite development differences, no differences were found between groups (above 90% of the virtual elements reached for both age groups). In terms of exploration efficacy, the results showed that the visual prompts were equally effective with both age groups when helping them to reach different points of the virtual game repeatedly. On the other hand, the RQ5 is answered affirmatively for the factor *Semiotic density* in terms of the virtual space covered since the results showed that when the semiotic density was low children visited a higher percentage of the available cameras (100%) than when the density was high (90.70%). However, despite these significant differences the effectiveness of the semiotic when providing spatial awareness of all interactive elements scattered along the virtual world was high for both settings and the differences may appear because children do not have the required time to visit all the animals when a high density was set and not due to a communication problem. Hence, these results show that the spatial directional awareness semiotic can be used in both scenarios (i.e. scenarios with low or high density of interactive elements). In terms of the exploration efficacy, no significant differences were revealed in the *Semiotic density* factor since children visited a similar number of animals independently of the setting. Hence, cluttering a virtual space with several interactive elements does not have a negative impact on the effectiveness of the spatial awareness visual prompts so they can be used in scenarios with both, low and high density of interactive elements.

If we consider RQ6 in terms of the effectiveness of the gestural semiotic, then RQ6 is negatively answered for the *Age* factor. The effectiveness of the gestural semiotic has been previously tested and resulted effective when communicating dynamic gestures to children aged 30 months and elder (Nacher et al., 2017). However, this result shows that despite the usage of the semiotic simultaneously with another type of visual prompts the effectiveness is not affected negatively and no differences between children aged 4 and 5 were found. Moreover, the need of communicating sequences of gestures did not have a negative impact on the performance in none of the age groups. Regarding the *Semiotic density* factor, significant differences were found between the two settings. However, in both settings children performed over the 90% of the gestures to be done to fit the bridges. This result is interesting since, firstly, it shows that children are able to perform sequences of basic touch gestures without having a negative impact on the success rate and, secondly, it shows that children are able to effectively understand the prompts to communicate gestures when being displayed simultaneously with another type of visual prompt and they are able to interpret sequences of communications of different gestures without major issues.

Finally, regarding the impact of gender, the results showed that in general there were no differences between males and females in any of the evaluated dependent variables, so that all the research questions (RQ2, RQ3, RQ4, RQ5 and RQ6) are answered negatively for the *Gender* factor. This is an interesting result since it shows that even though previous studies with pre-kindergarten children have found that, on average, preschool boys are more accurate than girls in spatial tasks and suggests that males develop visual-spatial cognition abilities before females (Levine et al., 1999). These possible development differences do not affect children in any aspect (effectiveness of the visual prompts, time spent distributions, gesture usability) when interacting with the game.

6 Conclusions

In this work we have evaluated the suitability of using two different types of visual prompts displayed simultaneously and communicating information with several purposes in applications targeted to kindergarten children. The goal was to find out whether this approach is feasible with this specific type of user and to preliminary assess the usefulness of these visual prompts for giving technical support when interacting (giving cues about which gestures need to be performed and giving cues about the location of the different interactive elements placed in the virtual world).

The results confirmed that kindergarteners are able to effectively understand these visual prompts despite being used simultaneously and they are able to interact with the application without major issues. Moreover, the evaluation has been carried out with an actual game with several activities and the results showed that children effectively achieved the game goals.

On the other hand, the evaluation also has shown that the use of visual prompts to communicate information about the gestures to be performed and to provide directional awareness reduces the number of interferences about technical nature of the game (i.e. explain the gestures needed to complete the task or the interactive elements location in the virtual world) fostering dialogues related to the learning activity guided by the instructors or caregivers.

In addition, the experimentation revealed that kindergarten children are able to perform sequences of touch screen gestures with the same success that they have when performing them in isolation.

Our findings also showed that no differences were found in the times spent in each stage of the game by children and in the efficacy of the visual prompts in terms of gender.

Finally, the application tested in this work is a gamified version of a multimedia application targeted to hospitalized children aged between 8 and 18 years and the results showed that it fits with kindergarteners' development and skills, they found it engaging and fun and dialogues with caretakers about the learning content to be acquired are fostered. In this respect, our plan includes the evaluation of this game with actual hospitalized children who are not able to leave their bed for long periods of time and are not prone to engage in conversations in order to assess whether the application usage promotes dialogues between children and their caregivers in an isolated sterile room or even with children in contiguous beds if the application is used collaboratively.

Lastly, it would also be worth evaluating other applications with different purposes and more cognitively complex tasks to assess whether prekindergarten children are able to understand the different visual prompts in other contexts.

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Appendix

Table 1. Statistics of the conducted ANOVA for all the dependent variables.

Dependent Variable	DoF	Gender		Age group		Semiotic density	
		F	p-value	F	p-value	F	p-value
% of *Exploration & Curiosity* time	(1.76)	.934	.337	8.137	.006	5.317	.024
% of *Problem-solving Reasoning* time	(1.76)	2.120	.150	.376	.542	.260	.612
% of *Observation* time	(1.76)	1.822	.181	7.422	.008	4.871	.031
% of cameras visited	(1.76)	.424	.517	4.230	.044	11.433	.001
Total cameras visited	(1.76)	.002	.962	3.373	.071	2.764	.101
% of gestures fitted	(1.76)	.158	.693	1.654	.203	4.609	.035

Table 2. Value of the evaluated dependent variables by age group.

Dependent variable	Age Group	Average	SD
Exploration & Curiosity time	4	48.40	11.30
	5	40.03	14.02
	Overall	44.43	13.26
Problem-solving Reasoning time	4	14.28	3.99
	5	13.71	5.43
	Overall	14.01	4.70
Observation time	4	37.31	12.24
	5	46.26	16.27
	Overall	41.55	14.89
Total camera visited	4	7.60	2.85
	5	9.31	3.58
	Overall	8.41	3.30
% of available cameras	4	92.08	15.09
	5	97.69	7.07
	Overall	94.74	12.24
% of gestures fitted	4	94.69	14.40
	5	98.26	7.41
	Overall	96.38	11.69

Table 3. Value of the evaluated dependent variables by semiotic density.

Dependent variable	Semiotic density	Average	SD
Exploration & Curiosity time	Low	41.46	13.82
	High	46.72	12.50
	Overall	44.43	13.26
Problem-solving Reasoning time	Low	13.75	5.16
	High	14.21	4.38
	Overall	14.01	4.70
Observation time	Low	44.79	15.08
	High	39.07	14.42
	Overall	41.55	14.89
Total camera visited	Low	7.64	3.39
	High	9.00	3.15
	Overall	8.41	3.30
% of available cameras	Low	100	0
	High	90.70	15.13
	Overall	94.74	12.24
% of gestures fitted	Low	100	0
	High	90.34	18.47
	Overall	96.38	11.69

Table 4. Value of the evaluated dependent variables by gender.

Dependent variable	**Gender**	**Average**	**SD**
Exploration & Curiosity time	Male	45.10	15.08
	Female	43.89	11.75
	Overall	44.43	13.26
Problem-solving Reasoning time	Male	14.93	5.43
	Female	13.28	3.94
	Overall	14.01	4.70
Observation time	Male	39.97	16.71
	Female	42.83	13.31
	Overall	41.55	14.89
Total camera visited	Male	8.29	3.25
	Female	8.50	3.38
	Overall	8.41	3.30
% of available cameras	Male	93.63	14.80
	Female	95.64	99.78
	Overall	94.74	12.24
% of gestures fitted	Male	97.06	8.74
	Female	95.83	13.71
	Overall	96.38	11.69

Bio

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