Game Technologies for Kindergarten Instruction: Experiences and Future Challenges

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Abstract. Games are an ideal mechanism to design educational activities with preschool children. Moreover, an analysis of current kindergarten curricula points out that playing and games are an important basis for children development. This paper presents a review of works that use games for kindergarten instruction and analyses their underlying technologies. In addition, in this work we present future challenges to be faced for each technology under consideration focusing on the specific needs and abilities these very demanding users have. The end goal is to outline a collection of future research directions for educators, game designers and HCI experts in the area of game-based kindergarten instruction supported by new technologies.

Keywords: Games, Kindergarten, Pre-Kindergarten, Education, Serious games, Review, Multi-touch, Robots, Tangible User Interfaces (TUI)

1 Introduction

According to Huizinga play is innate to human culture [7] and children play in many ways and with different types of artifacts [5]. The importance of game play in early childhood education is also recognized by multiple national and international organizations. For instance, according to the Spanish Education Law (LOE) passed in 2007, the working methods in childhood education "will be based on experiences, activities and games" with the purpose of "contributing to the physical, affective, social and intellectual development of children" [8]. Hence, playing is a basic pillar in children education and development.

However, despite the huge number of works addressing children play [17, 2] and the presence of games in children educational curricula, there is a lack of works that address the relations between play and learning in environments based on new emerging technologies such as interactive surfaces and robots.

Therefore, in this paper we provide a review of works that use technologies to develop games that help children to improve the three dimensions of their development already mentioned: physical, socio-affective and intellectual. The analyzed works demonstrate that there are technologies with suitable mechanisms to support very young children instruction based on play but the analysis also reveals that there are still missing aspects that need to be addressed. Therefore, in this paper we provide a set of future areas of work that can be developed in the near future. The end goal is to define a research path to give educators appropriate guidelines for each technology and to design games and activities that foster pre-school children development.

2 Developing Technology-Based Games for Pre-School Children

Many previous works have used technology-aided learning activities to support pre-school (aged 2-6 years) children development. In this section, these works are presented by technology.

2.1 Traditional Computers

A few years ago, traditional computers were used to develop mainly intellectual and cognitive aptitudes among very young children. Jones and Liu [10], for instance, studied how kids aged 2-3 interact with a computer. They designed a videogame which used visual stimuli, animations, and audio to capture the kid's attention. For example, the computer told the child to press a certain keyboard button, and informed the user whether the interaction had been successful. For simplification purposes, only a few buttons of the keyboard were used, disabling the rest. The game contained educative contents in order to enhance vocabulary through learning colors, toy names, food, computer parts, etc., and also to learn mathematical concepts such as big/small, or logical relations like cause/effect (e.g., if a key is pressed, something will happen on the screen). In their study, the researchers observed that meaningful interactions with this kind of technology do not appear before two and a half years of age.

Because computers were at first fixed to a single location, it was difficult for children to engage in games that encouraged mobility and physical exercise. However, other types of physical development, such as the improvement of fine motor skills, could be trained using this kind of technologies. As an example, Ahlström and Hitz [1] evaluated precise pointing interactions using mouse on children aged 48-58 months. In order to do so, they proposed a game that consisted on selecting and dragging colored elements on the screen. Results showed that an assistive technique can improve children's pointing accuracy. Similarly, Strommen et al. [23] devised a videogame to evaluate which input device improved precision tasks on three-year-olds, namely mouse, joystick, or trackball. The associated videogame consisted on directing a Cookie Monster through a path up to a given target cookie for him to eat and results showed the trackball as the more accurate, but the slowest, way to interact. These two works were not aimed at training any specific capacity, however, in our opinion, videogames that require this type of precision could be used to improve the fine motor skills on children.

2.2 Interactive Surfaces

The natural and intuitive way of interaction provided by the multi-touch technology [20] makes it ideal for preschool children. As pointed out by Shneiderman et al. [19], the three basic ideas behind the direct manipulation style that enable a natural interaction are: 1) the visibility of objects and actions of interest; 2) the replacement of typed commands by pointing-actions on the objects of interest; and 3) the rapid, reversible and incremental actions that help children to keep engaged, giving them control over the technology and avoiding complex instructions. Supporting this idea the Horizon report [9] placed tablets and smartphones as one of the two emerging technologies suitable for children aged under 2 years.

The suitability of multi-touch technology has motivated several works focused on kindergarten children and the use of tablets and smartphones. The works by Nacher et al [15, 13] reveal the huge growth in the number of existing educational applications targeted to pre-kindergarten children and evaluate a set of basic multi-touch gestures (tap, double tap, long pressed, drag, scale up, scale down, one finger rotation and two finger rotation) in a tablet with children aged between 2 and 3. Their results show that pre-kindergarten children are able to perform successfully the tap, drag, scale up, scale down and one-finger rotation gestures without assistance and the long pressed and double tap gestures with some assistive techniques that fit the gesture to the actual abilities of children. Another interesting study was conducted by Vatavu et al [27] who evaluated the tap, double tap, single hand drag and double hand drag gestures (see Fig. 1) with children between 3 and 6 years with tablets and smartphones. On overall, their results show good performance except for the double hand drag gestures, which are affected by some usability issues. Moreover, the results show a correlation between children with higher visuospatial skills (i.e. having better skills for understanding relationships between objects, as location and directionality) and both, a better performance in the drag and drop tasks and the accuracy when performing tap gestures. Although these applications are developed for experimental purposes, these or similar applications could be used as games in order to help children in their fine motor skills development and visuospatial skills through interactive surfaces. A step further goes the work by Nacher and Jaen [16] who present a usability study of touch gestures that imply movement of the fingers on the tablet (drag, scale up, scale down and one finger rotation) requiring high levels of accuracy. Their results show that very young children are able to perform these gestures but with significant differences between them in terms of precision depending on their age since they are in the process of developing their fine motor skills. Finally, the authors propose as a future work an adaptive mechanism that fits the required accuracy to the actual level of development of each child, this mechanism could be used to help children to exercise and develop their fine motor skills.

Fig. 1. Child performing simple and double drag gestures (extracted from [27]).

Another interesting work with pre-kindergarten children and tablets is the study by Nacher et al [14] which makes a preliminary analysis of communicability of touch gestures comparing two visual semiotic languages. The results show that the animated approach overcomes the iconic. Hence, basic reasoning related to the interpretation of moving elements on a surface can be effectively performed during early childhood. These languages could help children in identifying direct mappings between visual stimulus and their associated touch gestures. Therefore, the use of these languages could be particularly interesting in the development of games in which pre-school children could play autonomously.

Several studies have evaluated the suitability of multi-touch surfaces to support educational activities with children. Zaranis et al [29] conducted an experiment to evaluate the effectiveness of digital activities on smart mobile devices (tablets) when teaching mathematical concepts such as general knowledge of numbers, efficient counting, sorting and matching with kindergarten children. Their results confirm that the tablet-aided learning provides better learning outcomes for children than the traditional teaching method. Another study provided by Chiong and Shuler [4] conducts an experiment involving audiovisual material on touch devices adapted to children aged three to seven years and their results show that children obtain remarkable gains in vocabulary and phonological awareness. Another work using tablets is the study by Berggren and Hedler [3] in which the authors present CamQuest. CamQuest is a tablet application that enables children to move around and recognize geometric shapes in the real objects that they see. The tablet shows the images from the camera and the application integrates the geometric shape to look for (see Fig. 2). This application combines the learning of shapes (such as circle, square, rectangle, and triangle) with active play since children are investigating their surroundings. Moreover, the application can be used in pairs fostering collaboration between children and defining roles between them, so that children develop their social skills.

Fig. 2. Child interacting with CamQuest (extracted from [3]).

On the other hand, other studies have focused on the use of tabletops with educational purposes. For example, Yu et al [28] present a set of applications for children aged between 5 and 6 years. The applications contribute to the development of intelligence, linguistic, logical, mathematical, musical and visual-spatial aspects with activities such as listening a word and picking out the picture that represents it; shooting balloons with the right numbers, etc. Following the same research path, Khandelwal & Mazalek [11] have shown that this technology can be used by pre-kindergarten children to solve mathematical problems. The work of Mansor et al [12] conducts a comparison of a physical setting versus a tabletop collaborative setting with children aged between 3 and 4 years and suggests that children should remain standing during these operations because, otherwise, they find it difficult to drag objects on the surface due to bad postures.

2.3 Robots and Technologically-Enhanced Toys

Unlike computers or surfaces, tridimensional toys and robots have the capacity of being grasped, hence serving as a sort of tangible user interface (TUI), which present an added value in childhood education "as they resonate with traditional learning manipulatives" [22]. Research concerning robots for pre-kindergarten and kindergarten children has focused on building technology to develop intellectual capacities such as linguistic aptitudes. In this respect, Ghosh and Tanaka [6] design a Care-Receiving Robot (CRR) to help the kids learn English. This robot adopts the role of the pupil and the children play with it acting as teachers. This way, they can learn as they teach the robot. The researchers propose two games with this platform: a game to learn colors and another to learn vocabulary about animals. In the first one, called "color project", the kids show a colored ball to the robot and tell it which color it is. Then, the robot touches the ball and guesses its color. In the second game, "vocabulary project", a series of flashcards are shown to the robot, and it has to guess which animals they represent. In both cases, the purpose of the kid is to correct the robot when it is wrong, or to congratulate it when it answers correctly. Experiments performed with the children through observation reveal that they are very motivated at first, but tend to feel bored and frustrated quickly if the robot is too often right or wrong, respectively, since the game becomes monotonous. Tanaka and Matsuzoe [25] posteriorly revealed that kids aged 3 to 6 are capable of learning verbs by playing with the CRR, and they even suggested that learning through playing with the robot might be more effective than not involving such a tangible artifact.

Shen et al. present Beelight [18], a bee-shaped robot and a tabletop serving as its honeycomb (see Fig. 3) aimed at teaching colors to children aged 4 to 6 years, which is reported to cause excitement and astonishment on the kids. The authors present two games implemented with this approach. On the one hand, "color sharing", in which the kids would grab the robot and show a color to it. Then, the bee would glow in said color and, if placed on the honeycomb, it would be colored as well. The second game, "color searching", would consist of the bee being illuminated with a given color and the children having to search for some object of said color and place it on the honeycomb. In case of success, the honeycomb would play a song.

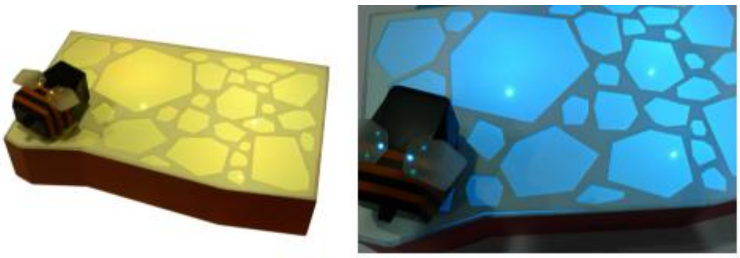

Fig. 3. Beelight (extracted from [18])

Also aimed at improving language and literacy skills, Soute and Nijmeijer [21] design an owl-shaped robot to perform story-telling games with children aged 4 to 6. This robot (see Fig. 4) narrates a partial story which the students must complete showing some flashcards to it. A small study is also conducted during a game session and the results show the system is engaging for the kids.

Fig. 4. A girl playing with an owl-shaped robot to foster language skills (extracted from [21])

Besides training linguistic abilities, other robots could also be used to develop spatial capabilities. For example, Tanaka and Takahashi [26] design a tangible interface for kids aged 3 to 6 in the form of a tricycle (see Fig. 5) to remotely control a robot. The movements performed on the tricycle (i.e., forward, backward, left, right) are mapped to movements of the tele-operated robot. Although not specifically built for this purpose, in our opinion this kind of interface could be used to stimulate spatial mappings on kindergarten children.

Fig. 5. Tricycle interface (extracted from [26])

Another advantage of using robots is that they can move. Therefore, they can be used to enhance physical development. QRIO [24] is a humanoid robot introduced in a toddlers' classroom to make the kids move and dance, hence encouraging physical exercise. The robot would dance autonomously to the music (see Fig. 6) and react to the movements of a dancing partner (i.e, to his/her hand movements or clapping).

Fig. 6. Children dancing with QRIO (extracted from [24])

3 Discussion

In **Table 1**, the works listed above are classified in terms of several factors: the age of the users involved; the capacities, inferred from [8], that the works can improve, i.e., physical development (P), socio-affective development (S) and cognitive and intellectual development (I). For each capacity there are several areas; related to physical development the analyzed works address physical exercise (P-p) and fine motor skills (P-f) areas; in the social development we can identify the collaboration area (S-c); and in the cognitive and intellectual development we can find the spatial (I-s), the linguistic (I-l), the logic and the mathematic (I-m), and the exploration and discovery skills (I-e) areas. The works are also categorized by the technology used; computers (C), tablets (T), mobiles/smartphones (M), tabletops (TT) or robots (R). Finally, the last dimension covers the type of interaction; tangible (T), keyboard (K), mouse (Mo), joystick (J), multi-touch (M), body gestural (G) or vocal (V).

Table 1. Comparison of works

Work	Age (years)	Capacities	Areas	Technology	Interaction
Khandelwal et al [11]	3-5	I	I-m	TT	T
Tanaka et al [24]	0-2	P	P-p	R	T, G
Tanaka et al [6,25]	3-6	I	I-l	R	V, G
Jones & Liu [10]	2-3	I	I-l, I-m	C	K
Tanaka & Takahashi [26]	3-6	I	I-s	R	T
Soute & Nijmeijer [21]	4-6	I	I-l	R	G
Ahlström et al [1]	4-5	P	P-f	C	Mo
Shen et al [18]	4-6	I	I-l	R	T
Strommen et al [23]	3	P	P-f	C	Mo, J, B
Nacher et al [15]	2-3	P	P-f	T	M
Nacher et al [13]	2-3	P	P-f	T	M
Nacher et al [14]	2-3	I	I-l	T	M
Nacher & Jaen [16]	2-3	P	P-f	T	M
Vatavu et al [27]	3-6	P	P-f	T-M	M
Chiong & Shuler [4]	3-7	I	I-l	T	M
Zaranis et al [29]	4-6	I	I-m	T	M
Yu et al [28]	5-6	I	I-l,I-s, I-m	TT	M
Mansor et al [12]	3-4	I	I-e, S-c	TT	M
Berggren & Hedler [3]	4-5	I, S	I-m,S-c	T	M

The review of all the works that use new technologies to help pre-school children development shows that there is a great number of works focused on the development of the physical and intellectual capacities of children. Focusing on the physical capacities, most works present activities and games that address the development of fine motor skills. However, few works have been proposed with preschool children when developing games that support their gross motor skills or promote health and wellbeing through performing physical activity and active play. In our opinion, the most appropriate technologies for these types of applications are tablets, smartphones and robots due to their ability to be moved from one place to another. Regarding the cognitive and intellectual dimension, most works focus on games that foster the logic, mathematical and linguistic skills. Nonetheless, there are no works fostering the development of spatial abilities or supporting exploration and discovery.

On the other hand, despite the suitability of the new technologies, such as tabletops, tablets, smartphones and robots for collaborative playing, the development of social and affective skills is not fully exploited with preschool children. Hence, a future work to be addressed is the use of these technologies for the development of games that support and foster the relationships with others. In addition, there are unexplored areas in the social-affective dimension. An interesting future challenge is the use of new technology games to improve the self-awareness, self-regulation and emotional intelligence of pre-kindergarten children.

Finally, it is also worth mentioning that looking at the year of publication of the works listed there is a trend to leave the traditional computer and tabletop technologies behind and select the tablets, smartphones and robots as the preferred technologies for developing games for the youngest. This makes the multi-touch and tangible interactions as the most promising techniques that will need further research efforts to analyze their adequacy and limitations when applied to preschool children.

To sum up, the contributions of this paper are twofold. The first one is a review of the state of the art of technology-aided activities that support the three dimensions of kindergarten children development. The reviewed studies show the suitability of game technologies for the improvement and development of very young children capacities. The second contribution is a set of future challenges listing the unexplored areas of preschool children development in which game technologies may have a real and measurable impact. These areas will have to be the focus of intense research in the near future to create games that support all the dimensions of preschool children development.

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