Multi-touch Technology in Early Childhood: Current Trends and Future Challenges

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ABSTRACT
The advantages of the direct manipulation style make the multi-touch technology an ideal mechanism to support learning activities for children. Moreover, although pre-kindergarten children are becoming frequent users of the technology little work has been done in the area to assess their actual abilities. This paper goes over the state of the art of multi-touch technology targeting pre-kindergarten children and its use for educational purposes. In addition, in this work we present future challenges that should be faced in the area in the near future to establish the basis on which designers will develop educational applications for children that fully exploit the multi-touch technology according to the actual abilities of pre-kindergarten children.

Categories and Subject Descriptors
H.5.2. [Information interfaces and presentation]: User Interfaces - Interaction Styles.

General Terms
Performance, Design, Experimentation, Human Factors, Standardization.

Keywords
Multi-touch interaction; pre-kindergarten children; gestures; future challenges

1. INTRODUCTION
Multi-touch technology has rapidly evolved in recent decades and nowadays it has widespread acceptance [5] because it provides users with a more natural and intuitive way to interact [23]. As pointed out in [7] children between zero and eight years old are frequent users of digital media in the USA and they meet with touch technology often before they can even speak. Supporting these ideas the Horizon report [12] places mobile devices, such as tablets and smartphones, as one of the two emerging technologies suitable for children aged under 2 years.

The three basic ideas behind the direct manipulation concept were listed by Shneiderman and Plaisant [21]: (1) the visibility of objects and actions of interest; (2) the replacement of typed commands by pointing-actions on 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.

A detailed analysis of applications in the Apple store made by Shuler [22] reveals the growing use of educational applications for children based on touch devices. This is specially the case for preschool children (Figure 1) who were the target users of nearly 60% of these applications by 2011.

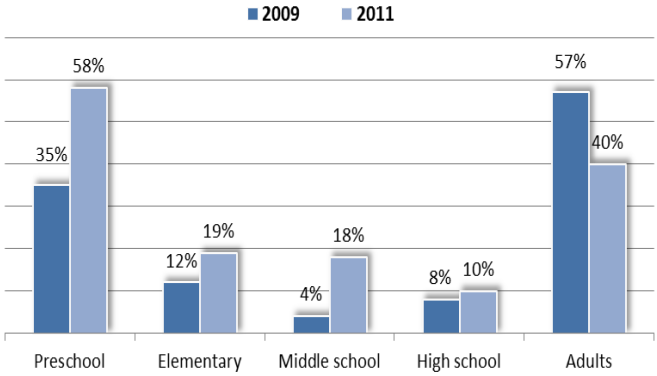

Figure 1. Target age 2009 vs 2011 for Education cat. in the Apple Store [22]**.**

However, the increasing interest in multi-touch technology has not given rise to studies on the design of multi-touch systems for the youngest age range [10]. Moreover, the lack of standardized and universally accepted interactions for these challenging users makes the design of well-designed multi-touch interactions even more crucial [11].

According to these facts, in this paper we carry out a review of the current state of the literature of multi-touch technology with pre-kindergarten children and provide a set of future challenges to be addressed in the future. The end goal is to define a research agenda to make this technology usable by pre-kindergarten children and give application designers the necessary guidelines to develop touch applications according to the actual skills of pre-kindergarten children.

2. STATE OF THE ART
Until very recently, there have been no research efforts addressing multi-touch interaction with pre-kindergarten children (aged less than three years). Possibly this has been the case because age is a limiting factor for experimental studies; young children do not have the verbal and cognitive skills to express their likes and preferences [15] and, they are not able to carry out tasks for long periods or are easily distracted [8]. However, according to Piaget [19], children are in a preoperational stage from 2 years old onwards, i.e., they begin to think in terms of images and symbols, and develop symbolic play with imaginary objects, which means they could be candidates for multi-touch technology. In addition, being aware of children developmental abilities is critical when designing software for the very young [26].

This has motivated recent studies that assess the abilities of pre-kindergarten children to perform basic touch gestures. The work by Nacher et al [18] reveals that the advantages and features of multi-touch technology is not being fully exploited in existing commercial applications since only the drag and tap gestures are being used and no support for collaboration is given. Hence, the

work evaluates a set of basic touch gestures with children aged from two to three years (Figure 2) concluding that even these young users are able to perform a set of basic touch gestures such as tap, drag, scale (up & down) and one finger rotation. In addition, in this work a set of design guidelines is proposed to deal with complex gestures such as double tap and long pressed. These assisted strategies were evaluated later in [16] and results show that even these more complex gestures can be successfully performed by pre-kindergarten children with basic assistance.

Figure 2. Examples of scale up and drag tests (extracted from[18]**).**

In the experimental studies in [1, 2] four applications are considered and the interaction needed to play with them is evaluated. The gestures under test are the tap, drag, rotate, drag and drop, pinch, spread and flick and the experiment involves children aged 2 to 4 years. According to the results, the authors conclude that children aged four are able to perform all the evaluated gestures. Those aged three only find problematic the spread task. Finally, those aged two are able to perform the tap and drag gestures properly, learn quickly the flick gesture but they are less effective with the more complex gestures such as drag and drop and pinch.

Another interesting study is the work of Vatavu et al [24] who evaluate touch gestures with children between 3 and 6 years using tablets and mobile devices. They conclude that despite there is a significant performance growth with age, in general, children have good performance with the tap, double tap and single hand drag and drop gestures. However, in the case of the double hand drag and drop gesture (see Figure 3) they do not reach these good results and the success rate drops to 53.7%. In addition, authors correlate the results with a sensorimotor evaluation based on children's finger dexterity and their graphomotor and visuospatial processing abilities. The correlation shows that children with higher visuospatial skills (i.e. having better skills for understanding relationships between objects, as location and directionality) perform better in the drag and drop tasks. Furthermore, the study also reveals that children with more developed visuospatial skills tap closer to the center of targets in the tap and double tap tasks since they have a better understanding of the targets' geometries.

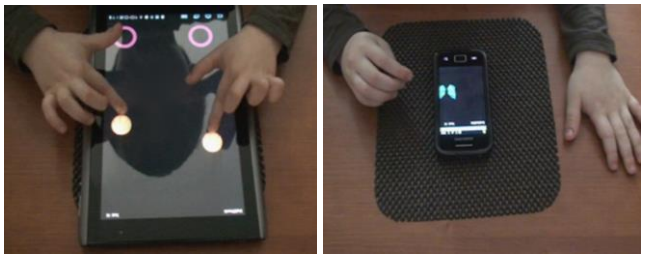

Figure 3. Child performing double drag gestures (extracted from [24]**).**

Usability is not the only dimension that has been addressed by recent studies in the field. Another topic of interest is that of communicability when pre-kindergarten children are considered. The work in [17] report a first approach to evaluate mechanisms for applications to communicate pre-kindergarten children the expected multi-touch gestures at a given moment. In this study, the authors present and evaluate two visual approaches (iconic and animated) to communicate touch gestures (see Figure 4). Three touch gestures are considered: the tap representing in-place gestures (i.e. those in which the hand does not actually describe a trajectory but taps at a very specific pace or in a specific way); the drag representing one-contact point gestures that require a movement following a specific trajectory; and the scale up gesture representing two-contact point gestures that require movement. The results show, firstly, that none of the evaluated languages is effective to communicate in-place gestures and, secondly, that the animated approach overcomes the iconic one for gestures that require movement of contacts reaching success rates above 85%. This fact suggests that even pre-kindergarten children are able to interpret the direct mapping between the visual stimuli (i.e. a hand sliding on the surface) and the gesture to be performed. Therefore, this work suggests that visual languages could be an effective way to enable pre-kindergarten children autonomous interaction.

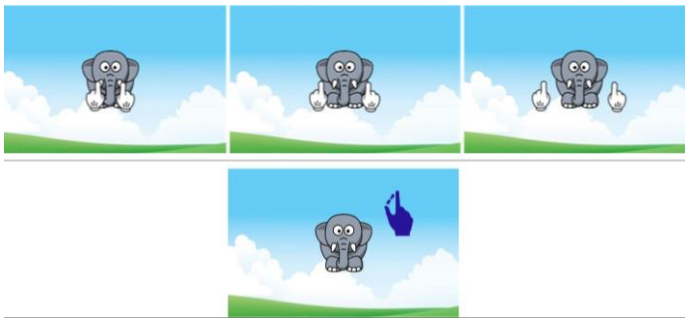

Figure 4. Description of the animated visual (top) and the iconic (bottom) language for the scale up gesture (extracted from [17]**).**

Exploring the educational dimension and the suitability of multi-touch surfaces to support educational activities there are several works that strengthen the idea that this technology provides benefits for pre-kindergarten children education. For example, the work by Bebell et al [4] shows a nine week study comparing the improvement of kindergarten children taking early literacy lessons when using tablets for learning or using a traditional non-technological method. Their results show that the group that learned with tablets scored higher on early literacy assessments, particularly these higher scores are present in the ability to recognize sounds and represent sounds and letters. Following the same line, Chiong and Shuler [6] conduct an experiment involving touch devices and audiovisual material adapted to children aged

three to seven years and their results show that children obtain remarkable gains in vocabulary and phonological awareness. Moreover, Knoche et al [14] point out that the interaction of children aged between 16 and 33 months with interactive elements in a tablet does not reduce their comments in dialogic reading activities. Another example is provided by Zaranis et al [27] who conduct an experiment to study the effectiveness of digital activities on smart mobile devices (tablets) to teach mathematical concepts such as general knowledge of numbers, efficient counting, sorting and matching with kindergarten children. Their results show that the tablet-aided learning provided better learning outcomes for the students than the traditional teaching method. Kammer et al [13] present three applications to foster the development of cognitive and motor skills on a multi-touch tabletop with children aged from four to six years. The conducted experiment shows that even preschool children are able to use this technology and they enjoy the task and collaborate in the multi-user activity.

The results of these works suggest that pre-kindergarten children are prepared to use multi-touch technology and the intuitive and natural interaction of direct manipulation style of the multi-touch technology makes it ideal to support pre-kindergarten children interaction and, hence, educational activities targeted to them. Moreover, these works conclude that these particular users are able to perform a set of touch gestures successfully and future applications designed for them do not need to be restricted to only basic interactions such as the drag and tap gestures. However, these works reveal that there is no consensus or standardization of the multi-touch interaction style for users in these early ages.

3. FUTURE CHALLENGES

In this section we present a compilation of future works that we consider interesting and necessary to complete the literature and shed light on the specific needs of pre-kindergarten children when using multi-touch technology.

On the one hand, according to Hinrichs and Carpendale [9] who point out that there is evidence that some events are affected by previous and subsequent ones and given that all the analyzed studies consider and evaluate the gestures in isolation, an interesting strand of future work would be to evaluate these same gestures that pre-kindergarten can do in isolation but when several interactive elements are shown simultaneously. Users should perform different preset sequences of these gestures in order to determine whether the cluttering of elements in the interaction or the task chaining affect their performance. These results will help to develop more complex applications which are not restricted to only one possible interaction in each phase of the game.

Another interesting issue that remains to be addressed is the processing of the unexpected touch events when children are holding the tablet with a finger resting on the display or when part of the palm also touches the surface. This issue is difficult to address because children may not be aware of such unintentional contacts with other parts of their body when their fingers approach the screen resulting in an unexpected effect. It would therefore be interesting to explore potential improvements in multi-touch usability, for instance by determining and filtering out unexpected blob contacts wherever applicable.

Addressing the topic of the definition of effective mechanisms to communicate which actions are expected from the user; and taking as a starting point the work in [17], there is still a great deal of work to do to assess the best approaches. This preliminary study points out that animated languages can be effective to communicate touch gestures to pre-kindergarten children and help them to be autonomous when using the multi-touch devices. However, as pointed out by the authors, only three gestures were evaluated, hence, it remains to be evaluated whether the inclusion of additional gestures has an impact on the overall performance and effectiveness of the languages. Moreover, the gestures were tested in isolation; therefore, languages should be studied when the interaction area is cluttered with many touchable elements and their corresponding visual cues or with elements that may be manipulated with several different gestures. With respect to communicability of touch gestures, another possible future work can be the evaluation of other languages both iconic and animated in order to find out which type of language fits better to communicate touch gestures to infants. In addition, an interesting future work could be to design and evaluate a similar approach to the method used by Balonian et al [3] for children between five and six years old. In this work, each gesture was associated to a specific character in a way that the gestures were "recallable". Metaphors such as a walking ladybug for a drag gesture or a jumping grasshopper for a double tap were used. Finding suitable metaphors that pre-kindergarten children can understand could be very useful to develop autonomous educational applications.

The studies in the literature point out that pre-kindergarten children have the necessary skills to make use of multi-touch technology. However, these works implement assistive techniques to deal with precision issues during the initiation and termination phases of gestures since they assume that pre-kindergarten children are no able to perform the gestures with high accuracy. This causes that the implemented interaction styles do not allow children to have the control over the termination of the gestures despite they are in the process of developing their motor skills and some of them may have already the proper cognitive abilities to perform the gestures with higher levels of precision. As a result, existing applications designed under these assumptions do not benefit from the use of multi-touch technology to help children to develop their precision-related cognitive and motor skills. According to this observation it would be interesting to evaluate dynamic gestures (those that require movement of contacts over the surface) demanding high levels of accuracy to users, specifically, it would be interesting to evaluate how accurately they can rotate an object, how close they can drag an object to a target and whether they are able to perform scaling gestures (up and down) with enough accuracy to stop the stroke of the gesture in a specific moment to reach a desired size. This would certainly help in understanding the limitations on accuracy that should be fulfilled in applications targeting pre-kindergarten children. In addition, the data collected during the experimentation could be used to develop assistive strategies to deal with precision issues in an adaptive way for the users that actually need it and not in an exhaustive way for every child as current systems do.

Finally, once known the actual capabilities and abilities of pre-kindergarten children, the gestures that they can perform, the accuracy that they can achieve and evaluated the communicative strategies suitable for them; interesting future works could be developed for the definition, construction and evaluation of environments based on multi-touch technology that foster creativity and allow collaboration between peers. These environments could be integrated into classrooms and be used with educational purposes to allow children to develop their creativity skills and allow educators to monitor the progress of their students and create appropriate content for them. As Rushton [20] points out, the

creation of classroom environments that enhance students expression and selection opportunities provides a proper atmosphere towards helping children to learn at their own pace. A starting point could be taking advance of (1) the portability of tablets that allow children and teachers to use various locations in the classroom enabling the creativity and collaboration of small groups of children; and (2) the more sophisticated interface of tablets that allows both individual and mutual interaction between two or more users [25].

4. CONCLUSIONS

The contributions of this paper are twofold; firstly, a review of the state of the art of multi-touch technology for pre-kindergarten children was made. The literature suggests that the use of this technology is an ideal way to develop applications for these very young users. In addition, the presented studies show that pre-kindergarten children are able to perform more touch gestures than could be expected when analyzing existing commercial applications. On the other hand, pre-kindergarten children are developing their motor skills and, hence, in order to use the multi-touch technology, designers should be aware of the actual capabilities of children when developing interfaces for them. The second contribution is a collection of future challenges to be faced in the near future when building multi-touch technology for preschool children. These challenges are related to communicability, adaptability and usability of multi-touch applications designed for these challenging users. We hope that the usability studies and design guidelines compiled from these works and the future challenges discussed in this paper will allow designers of future applications for pre-kindergarten children to fully exploit the potential of multi-touch technology to support their cognitive and motor development.

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