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An Analysis of the Interaction Design of the Best Educational Apps for Children Aged Zero to Eight

Análisis del diseño interactivo de las mejores apps educativas para niños de cero a ocho años

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Abstract
The proliferation of mobile devices and their use by children of all ages raise issues among families and educators with regard to their quality and appropriateness. Given the absence of an industry standard or an official ratings system for children's apps, specialist websites or blogs are frequently consulted when choosing apps. This article presents the results of a content analysis of the visual and interaction design features of 100 educational applications recommended by international experts for children from six months to eight years old. In addition, the adaptability of an application's content to children was taken into account as a qualitative measurement. Four researchers participated in the definition of variables and the design of the observation instrument. This study focuses on child-computer interaction (HCI-CCI) from a pedagogical and developmental perspective, with the aim of discovering and promoting quality in mobile applications for children. The intention is to provide information on key criteria related to the design of applications for entertainment and learning. The results of the statistical analysis indicate a generally low-quality visual and interaction design in the sample group and content that mirrors problems in the school curriculum. Even applications with both content and design that are specifically targeted at children reveal issues that may impede user comprehension and interaction.

Resumen
La proliferación de dispositivos móviles y su uso por parte de niños de todas las edades crea dudas acerca de su calidad y adecuación entre familias y educadores. Ante la falta de un sistema acordado u oficial de clasificación de aplicaciones infantiles, se suelen consultar webs especializadas o blogs de expertos para escoger las apps. Este artículo presenta los resultados de un análisis de contenido de las características del diseño visual e interactivo de 100 aplicaciones educativas recomendadas por expertos internacionales dirigidas a niños entre seis meses y ocho años. Se analiza además la adaptabilidad al target infantil, a partir de una ficha de análisis diseñada por cuatro investigadores. Con la finalidad de buscar y promover la calidad en las aplicaciones móviles para niños, esta investigación se enmarca en los estudios de la interacción niño-ordenador (HCI-CCI) desde una perspectiva pedagógica y de la psicología del desarrollo. Quiere ser una aportación sobre los criterios clave en el diseño de aplicaciones infantiles para el entretenimiento y el

aprendizaje. Los resultados del análisis estadístico indican una escasa calidad del diseño visual e interactivo de la muestra y unos contenidos que reproducen los problemas del currículum escolar. Incluso algunas aplicaciones que se caracterizan por adaptar su contenido y diseño al target infantil, presentan también errores que pueden obstaculizar la comprensión y las interacciones del usuario.

Keywords / Palabras clave
Child-computer interaction, mobile devices, interaction design, graphical user interface, adaptability, content analysis, apps, quality.
Interacción niño-ordenador, dispositivos móviles, diseño interactivo, diseño, adaptabilidad, análisis de contenido, apps, calidad.

1. Introduction

Mobile devices (smartphones and tablets) are tools for communication, gaming, creativity and learning for children as predicted by Papert (1993), and they have become part of our daily environment in a manner unlike any other previous technology (Granic & al., 2014; Read & Markopouolos, 2013; Gramigna & González-Faraco, 2009). The most recent report by the Reynolds Journalism Institute (RJI) on mobile media (Fidler, 2014) states that more than 50% of American households have tablets and three-quarters have smartphones; it also reveals that households with children have more mobile devices than those without children (70% have tablets and 88% have smartphones). This data concurs with the study «Kids and CE» from the NPD Group (2014) which showed that more than 70% of families with children owned smartphones and tablets, when in 2012 it was no more than 55%, and in the case of tablets the number had doubled in two years.
A report by Common Sense Media (2013) in the US estimates that 72% of children between two and eight years old assiduously use mobile devices, as well as 38% of children under two years old, thus demonstrating a growing tendency toward an increase in the use of mobile technology and touch screens in early childhood, to the detriment of other technologies such as television and computers.
In Europe, a study by Mascheroni and Kjartan (2014) involving more than 3,500 children under the age of 16 in eight countries reveals how, depending on the country and the age range, between 30% and 60% of children use tablets or laptops daily. Approximately 10% of children under ten years old use smartphones daily, often connected to the internet.
Outside the home, mobile devices are also replacing computers in schools, especially in the case of tablets. As these devices are increasingly adopted and integrated into educational settings the methodology and content of the applications for children are increasingly seen as lacking in terms of quality, and they do not meet age-appropriate pedagogical standards (Chiong & Shuler, 2010; Neumann, 2014; Rideout & Saphir, 2013). Content quality in interactive children's applications is directly related to whether they are appropriate to the target age and specifically to the child's development (Guernsey, 2013); thus content in games and educational applications should clearly align with the interests and abilities of potential users. In addition, Grané (2012) demonstrates that multimedia content is not separate from format, but that the interaction design of the applications for mobile devices determines the accessibility of content for users, especially for preschool-aged children. The quality of mobile applications targeted at early childhood thus depends on two conditions: taking into consideration the developmental stage of the child when formulating content and activities and employing an interaction design that is appropriate to the child's cognitive and psychomotor development. The formal characteristics of the audiovisual and multimedia message may promote or inhibit comprehension and interaction on the part of younger children (Crescenzi, 2010).
Considering the weight of these facts, the objective of this study is to provide a snapshot of the current state of mobile applications that concerned parents and educators can use in the selection

of quality applications for children. The child-computer interaction will be addressed from an educational development perspective as set out in earlier research (Amy, Alisa, & Andrea, 2002) and continuing through to today (González & Navarro, 2015; Radesky, Schumacher, & Zuckerman 2015). The research will consider aspects of the applications including communication design, graphical user interface (GUI) and interaction design (HCI), in addition to examining the context and child development typical of CCI (Read & Bekker, 2011).

2. Material and methods

2.1. Sample

The investigation involved a content analysis of 100 apps targeted at children under 8 years old and which were considered to be educational according to educators and experts. Selection of the applications was intended to replicate the experience of the general public facing the problem of choosing educational applications for their children or students. For this reason, the sample was picked by means of a sampling technique that included «the best educational apps» according to educators and experts in seven highly regarded international websites and blogs[1]. The selection of the «best apps» for younger children offered on these sites are currently the primary source of information available for parents and educators and are used as a basis for choosing an app.
The websites were selected based on quality and the system employed for evaluating the apps began with an initial web search performed in January 2014 using keywords in English and Spanish, for example «young children», «kids», «babies», etc. The most popular websites were further filtered so that only independent sources were included, and media groups or any organization associated with developing apps were excluded.

2.2. Observation instrument

The observation instrument[2] included variables specifically related to communication and interaction design in each application as well as the content and learning activities present, thus generating a new focus that combines educational ideas, CCI, developmental psychology, and pedagogy. The guiding questions of the investigation were: Do apps for children under 8 follow basic principles of interaction design? Do they take into account the user's profile, adapting to his or her specific needs?
In November 2013 the first version of the instrument was created based on Grané's model (2012), including interaction design principles studied by Tognazzini (2003), Norman (2003), and Shneiderman and Plaisan (2010). In particular, the aspects of the design put forward by Grané were adapted with reference to children under 8. The development of the observation instrument and codebook followed an inductive, as well as deductive, process. Utilizing the first version of the instrument, two researchers, who are experts in interaction design and education, independently carried out an analysis of a random sample of five educational children's apps. Next, they compared and discussed the results with two other experts in developmental psychology and pedagogy in order to decide on the elimination or inclusion of additional variables and to refine the definitions in the codebook. This process (independent observation of a reduced sample of apps followed by discussion) was performed five times, until agreement on the defining of variables was reached. Lastly, a pilot study with a researcher unaffiliated with the study was carried out and the results did not lead to any changes in the instrument.
In the final version of the instrument[3] the following design parameters were included:

- Visual design: including the organization and distribution of the screen elements, visual attention and user perception, as well as visual simplicity that is necessary with regard to young users.
- Adaptability: design elements including accessibility and attention to group or individual needs, legibility, clarity, and visibility of textual content.

- Interaction design: including usability and simplicity of interaction (CCI), sound, music, verbal communication and sound effects.
- Organization and navigation: organizational design, navigation and screen consistency.

Additionally, some aspects of content related to mental models, cultural referents, and existing knowledge of the target age group were evaluated. A group of variables were generated with reference to Gardner's theory of multiple intelligences (2006), activities and processes based on Bloom's taxonomy (1973), and UNESCO standard classifications.

2.3. Method and procedure

One researcher carried out a content analysis by means of a structured observation of 100 sample applications during the early months of 2014. The observations were registered in a spreadsheet template and the data was processed with the statistical analysis program SPSS. Due to the study's objective, the data analysis was descriptive.

The reliability of the encoding was measured with the assistance of a second encoder that independently analyzed ten apps; this represented 10% of the material evaluated (Tabachnick & Fidell, 2007). Cohen's kappa coefficient was used and a high concordance, greater than .61, was found for all the variables, following the classification of Landis and Koch (1977). The high number of variables and measurements explains why only 78% of the variables achieved consistency superior to 0.81 (very high). Finally, the same researcher performed another analysis on a random selection of five apps from the sample one month later; the results indicated a perfect concordance on the responses.

3. Results

3.1. Sample characteristics

The sample turned out to be heterogeneous; a revealing aspect for the exploratory nature of the research, reflecting a diverse image of the market in educational apps and a lack of agreement on the classification of «the best apps» for children. In particular, 100 educational apps were reviewed, all of which were developed between 2010 and 2013 by 55 software development firms from distinct countries, including Australia, Ireland, Canada, the USA (the origin of 11% of the apps, the highest representation), various European countries including Ukraine, as well as China, Japan, Russia, Singapore and South Korea. Seven apps from the firm «TocaBoca» were part of the sample, six from «MyFirstApp» and various others from «A&R», while 38% were from other design firms. With regard to language, English was the most common (96%), followed by Spanish (41%), German (39%), French (38%), and Portuguese (21%). Other languages made up a smaller percentage of the sample (Arabic, Japanese, Basque, and others). Nearly all of the sample was compatible with the iOS operating system (91%) and 25% were designed for use with Android; Kindle was supported on 11% of the apps, 7% on Windows, and 2% on Chrome.

A significant observation noted in the review of the apps concerned the recommended age for each application. In more than a third of the sample (39%), the developers did not provide any guidance on age-appropriateness for their product. An additional 8% classified their applications as being «for all ages» (without regard for the unique characteristics of each age and the differences between a 2 year old and an 8 year old, for example). More than 3% of the applications reviewed were considered appropriate for children under 1 year old, and 6% for children over 1 year old even though there is still no consensus on whether audiovisual and interactive content should be recommended before 18 months, while children are still developing in terms of perception and attention.

With young users in mind, the study also took into account whether the apps contained parental controls so that children could not link to external sites or make purchases within the app (present in 50% of the sample). Only 16% of the sample was free of both advertisements and links to exter-

nal websites, although 87% of the apps could be used without an internet connection, which made it possible to eliminate that type of interference. Two-thirds of the sample (66%) included information for parents and educators as well.
Little more than half (54%) of the apps evaluated were free or offered a free version (with limited features or a trial version). Nevertheless, 84% of the applications reviewed were for purchase or had an optimized version for sale, costing less than 3 euros in 74% of the cases, or between 3 and 10 euros (10%).

3.2. Results of the interaction design analysis

3.2.1. Visual design (GUI)

Equilibrium in the screen layout is the strongest visual reference in human perception (Dondis, 1973). However in 14% of the sample the gaming screens were not symmetrical, causing ambiguity in the user's visual perception which directly interfered with communication between the child and the device. This is especially true as problems were detected related to both placement and organization of screen elements that did not allow for an optimal visual design overall.
Although the majority of the apps studied emphasized or highlighted the active elements of the game, 22% did not do so effectively. The applications' design should take into account that highlighting can serve as an efficient aid for perception in the youngest users, as it draws their attention to the element and is particularly helpful when using an application for the first time.
Similarly, with respect to contrast between visual components and the background, visual perception of the content is key (Parrish & al., 2004) and some of the apps did not feature contrast between background and foreground (4%) or it was not effective (10%).
The firms designing the children's apps did show an interest in maintaining visual simplicity and 60% of the applications were as simple as possible. They did not contain any elements or actions beyond those necessary to play the game, which is an important aspect of interaction design where «eliminating unnecessary elements and reducing necessary ones as much as possible» is key (Butler, Holden, & Lidwell 2005: 182). This is in marked contrast with the fact that in 78% of the apps the objective of the game is not clear, either because it is not intuitive or it is not clearly indicated. This raises an even larger issue in light of the fact that they are indicated for pre-readers.
With reference to this problem, system interference during the game was studied (when two or more processes are in conflict and design errors can cause interference in communication). The presence of design elements that interfere with interaction and other extrinsic interference were analyzed (for example: advertisements or links), and were found in 50% of the apps. As seen in figure 1, unnecessary text that may complicate interaction with the device was present in 36% of the apps. The presence of advertisements or other messages were seen in a third of the apps, and only 4% included the option to eliminate the ads. In addition, some apps (9%) included links to websites that force the user to leave the application (for updates, purchases, or advertisements).

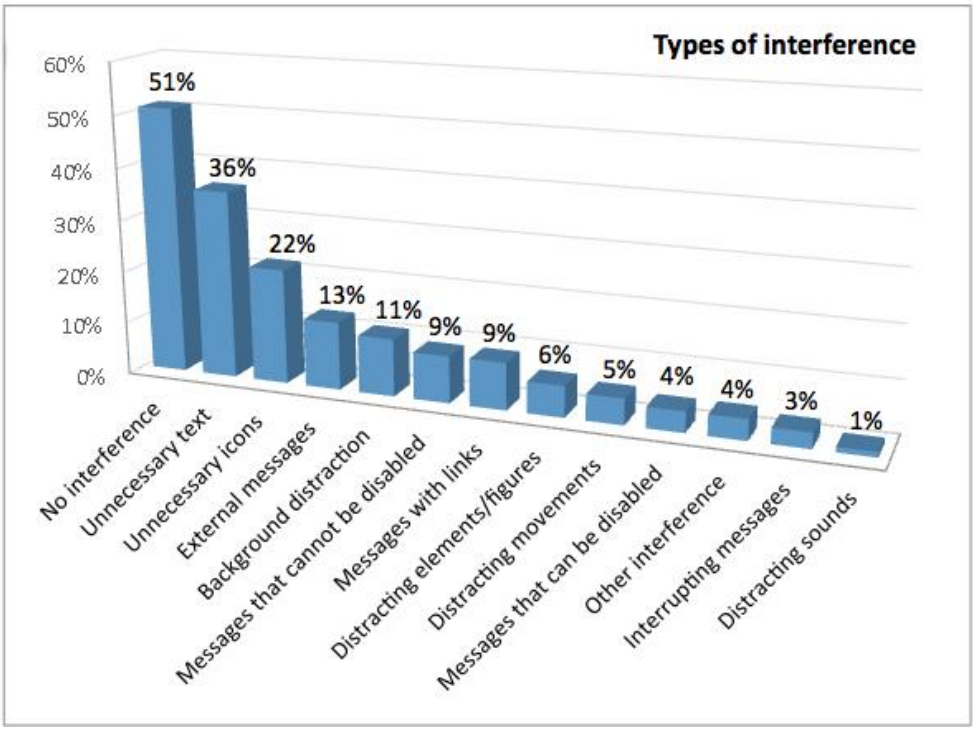

Figure 1. Types of interference present in the sample.

The help feature was also evaluated, both in terms of whether it was required as well as its layout and use. The feature can be counterproductive, as it was not required to play the game in 24 of the applications. Furthermore, the format was not always consistent with the age of the intended user, requiring reading skills in 32% of the apps.

Text is an important element and in many cases (23%) it was necessary to play the game and carry out the required actions. This correlates with a previous study by Rockman (2010) where the repeated use of written language was found to be a basis for interaction (CCI). In 96% of the apps text was present on the start screen (including in applications for children under four years old) and in the game screens of 63% of the apps, especially as information (53%), feedback (26%), and instructions (23%). In 39 cases the textual content was not present alongside an audible message and reading was the only way to access the information.

In relation to audible messages, 58% of apps included them as part of the game screen to give feedback (33%), information (20%), or instructions (16%), and in 13% of the cases they were required throughout the game in order to play.

Feedback on success or failure was present in 57% of the apps as a form of interaction. The use of feedback in interactive educational materials is a strategy defined by Kemp and Smellie (1989), but just as important as its presence is its adaptability. There was textual feedback in 23 applications, although it was only present as verbal feedback as well in five cases. A screenshot of an application that was very highly-reviewed by experts and recommended for children under 3 years old is seen in figure 2. It provides textual feedback but lacks audible reinforcement, resulting in confusion on the part of the child.

Figure 2. Textual feedback without audible reinforcement in «Numberland» (Les Trois Elles-Edoki).

Feedback was also present in other formats: 13% of the sample included musical responses, 50% employed sounds and another 50% visual cues. The majority of the responses have an emotional connotation, which was positive in 35% of the cases and both positive and negative in 11%.

3.2.2. Adaptability

Along the same lines, the data indicates that users between 0 and 8 years old are considered a homogeneous group, while their development and abilities actually change radically during those early years. Only 22% of the educational apps studied contain different play options depending on the age or previous knowledge of the user.

Certain physical characteristics of mobile devices turn out to be especially useful for preschool-aged users: automatic screen rotation, multi-touch options and the ability to interface with the device using alternative gestures (for example moving an object either by touching a point on the screen or by dragging it). Nevertheless, only 9% of the apps permitted alternate gestures for a given action and only one of the 100 apps made it possible for the orientation to change between horizontal and vertical automatically, following the natural movement in very young children.

Additionally, a review was made of gestures that are particularly complex for children under the age of 3, as seen in previous studies (Crescenzi, Jewitt, and Price, 2014). Examples include items such as a click and hold (extended touch) or scrolling. Very young children tend to touch the screen repeatedly instead of dragging, a gesture that was required to play in 62% of the sample apps, as seen in figure 3.

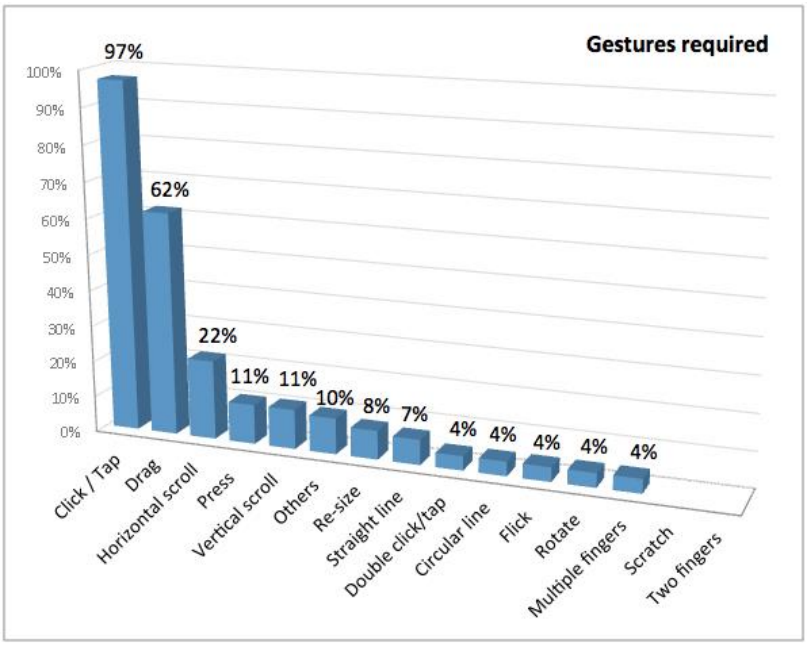

Figure 3. Gestures required in the sample apps.

Although mobile devices are valued for their potential use in groups, the apps studied did not contain options for individual versus group use. The sample did include multi-touch capabilities in 29 cases (17 included simultaneous interaction of more than two fingers), however only two apps were designed for two or more players. Another 10 applications did not include multi-touch but they were intended to be used for group play.

With regard to accessibility, one result that stands out is the almost complete absence of options for the adaptation of visual (93%) and sound (91%) elements in the apps studied. A striking example is that only one out of 100 of the apps reviewed allowed for the adaptation of the keyboard according to the visual and physical abilities of children.

Characters or elements in the applications tended to be familiar to the target user (in 88% of cases). Humanized objects or animals (28%) were frequently seen, as well as children (26%) and adults (10%). Of these characters, 41% expressed some type of emotion (23% were negative emotions), a small amount considering that emotions can aid in comprehension and support the child's interaction with the device.

Finally, the majority of the applications employed icons or buttons with a symbolic meaning (84%) to play the game, which takes for granted a previous knowledge of multimedia language that is not consistent with the age of the target audience (for example a magnifying glass, a speaker, a planet, or gears).

3.2.3. Interaction design

The number of elements present simultaneously on the screen was greater than the minimum number for an app appropriate for use by a preschooler. Only 8% of the apps had less than three visible elements on the home screen and 47% had three or four active elements, a configuration that is acceptable for users between three and eight years old. However, more than half of the sample contained more than four and up to 39 active elements on the home screen.

An even more complex environment was often present on the screen while playing the game. Figure 4 shows an application focusing on visual perception, observation and memory for children between three and five years old (according to the game developer) that has more than 18 active elements on every screen.

Figure 4. Crazy Fun Lab by Playtoddlers.

The results indicate that active elements were limited to only one or two items in only 15% of the apps studied and another 23% contained between three and four active elements on the screen, but that 62% of the sample could have between 5 and 56 different elements, thus complicating the child's interaction with the application.

These questions are key for simplicity, which is necessary for assuring quality in the usability of apps. This is a principle of interaction design that supersedes visual objects and is evidenced in the interactions between the child and the device. For the user, everything that is not a direct signal is noise, complicating communication with and the use of the application, a principle which is all the more important when the target audience is a child.

The role of music and sound is essential in a review of applications for children. The data show that 36% of the apps did not include any type of music and 7% of the sample did not contain music or sounds. Music was activated after touching an active element on the screen in only 14% of the cases, a feature utilized more for sounds (80%). Music was a response to the user's actions in 16% of the apps, while the response was a sound effect in 70%. In addition, music reaffirmed the visual information in 22% of the cases while sounds were used for this in 94%. This strategy facilitated comprehension of the content on the part of children.

3.2.4. Layout and navigation

The actions required for navigation were not the minimum necessary in 14 of the applications (navigational options that were not necessary to play the game were present). In some apps (18%), children tended to touch the screen between three and five times before beginning to play. Children under three years old should not have to touch the screen more than once in order to access the game (50% of the sample conformed to this standard) and those under six no more than two times (this was the case for 32% of the apps studied). Another, related result involved the number of screens that had to be navigated through before starting the game. In 54% of the sample it was only one screen, in 31% it was two screens, and in 15% of the apps the preschooler had to go through between three and seven screens before beginning the game.

With regard to layout, 59% of the apps permitted free navigation according to the user's preferences, while in a minority (16%) of cases the action took place in only one screen, and in the same percentage there were gradual systems where the level of difficulty determined the advancement of the user. Lineal (more like e-books) or hierarchical systems were used in 12% of the apps. Finally, it was observed that 39% of the applications did not allow the user to repeat an activity without leaving the game, even though repetition is a learning strategy that is captivating for very young children.

3.3 Results of the content analysis

The content of the sample set places nearly all of the apps (96%) in the area of cognition (information processing, prior knowledge, and mental abilities), 70% in psychomotor development (manipulative and motor) and only 22% in the area of affective-emotional development (attitudes and feelings).
With regard to multiple intelligences (Gardner, 2006) this was not demonstrated homogeneously. In particular, eight out of ten apps operated in the sphere of spatial and logical/mathematical intelligence, while linguistic intelligence was seen in 41% of the sample. Psychomotor and interpersonal competencies were present in 23% and 21% respectively, although they are developmentally essential for children under eight years old. One result that stood out was that very few apps attempted to focus on intrapersonal (10%) or musical (6%) intelligence.
Learning activities present in the games reflected the educational objectives of the children's apps. As seen in figure 5, in 94 of the 100 apps studied the objective was to recognize content, explore it (64%), or memorize it (44%). In general the applications focused on conceptual content. Actions associated with mathematical processing were also frequently present, even in apps that did not have mathematical learning listed as an explicit objective, thus logical operations and ordering were seen repeatedly in the majority of applications. However, actions and objectives related to creativity and the construction of knowledge were a minority with less than 30% of the apps oriented at imagination or the formulation of hypotheses, 13% at audiovisual creativity, less than 10% at writing, and only 3% at creating music.
Figure 5, «Learning activities» can be found on Figshare (http://goo.gl/osYJkn).
Finally, and contrary to the researchers' expectations, gender stereotyping was seen (in 20% of the sample) as well as racial stereotyping (8%). In addition, using a contingency table it was found that racial and gender stereotyping occurred in the same application 5 times.

4. Discussion and conclusions

Despite the fact that the market is saturated with applications for children, the label «educational» or «for children» does not indicate that an app has been validated and tested (Guernsey, 2013). In this context, the purpose of this research is to contribute to ensuring quality design and content in children's apps and their adaptation to different developmental stages in children.
This design analysis of 100 applications considered by educators and parents as potential educational resources illustrates clear issues related to visual and interaction design, adaptability, layout and navigation, making it evident that there is a lack of quality and adaptation in terms of child development. An example of this is textual messages that often accompany key information, instructions, and feedback in applications for preschoolers.
The interaction design presents key difficulties in the search for simplicity due to the elevated presence of distractors and active elements on the screen that are often unnecessary.
In addition, the content of the apps studied indicates a hegemony of curricular content (common in all Western countries) to the detriment of the other learning areas including socio-affective, artistic, and creative, as well as the construction of knowledge. The presence of stereotypes was another conspicuous element.
Although research in the areas of education, psychology, and CCI clearly demonstrate the potential of quality interactive resources for learning, the apps reviewed did not adapt to the needs of the target group. As such, a need can be seen for the transfer of the results to the video-gaming industry. In future research it will be necessary to complement the results of the heuristic analysis with observations of the interaction of children with the apps, define the direct implications of those results in terms of educational practice, and establish a relationship with developers to improve interactive materials and their adaptability, all of which will result in an improvement in the definition of quality in educational apps for children.

Notes

[1] International websites that review children's apps that were used in the selection of the sample: Smatoos (http://goo.gl/Z9UL78), A Matter of App (http://goo.gl/DxPpwz), Mind Shift: (http://goo.gl/o7Fu6o), Children's technology review (http://goo.gl/zRmGSy), Common Sense Media: http://goo.gl/paAc9t), Technology in (SPL) education (http://goo.gl/5NOQKM), Best apps for kids (http://goo.gl/EeFDis).
[2] The observation instrument can be seen at www.lmi.ub.edu/apps4kids/analisis.html.
[3] The results presented in this article are part of a study that included the participation of other authors, including: Carol Ibáñez and Marta López (UB).

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