MONTESSORI IN THE MOBILE ERA: BUILDING NEW LEARNING EXPERIENCES THROUGH TANGIBLE USER INTERFACES

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Abstract

The growing prevalence of smartphones in the daily lives of many children has enabled new learning scenarios. An overwhelming supply of educational applications is designed to facilitate their autonomous learning in painting, counting, spelling and so on. Apparently, this approach is in line with the principles of Montessori education (independence, freedom and respect for the natural psychological development of the children). However, the well developed GUI interaction skills (tapping, swiping or pinching items through multi-touch gestures on a screen) of the 21st century children are useless for manipulating physical objects. Exploring the real world requires a different set of capabilities (e.g., fine prehensile skills), often developed through traditional toys and games. For this reason we have developed 3DU Blocks, a proposal that combines traditional toy blocks with the features provided by mobile devices to create new gaming experiences and open the door to explore new educational scenarios. 3DU Blocks is a library for color recognition in arrangements of traditional toy blocks, allowing to use them as a Tangible User Interface. As an early example of the capabilities of this library, we have developed 3DU Blocks Music, an educational game where players have to recreate simple melodies using toy blocks to represent musical instruments and notes. Therefore, the emphasis of Montessori in physical materials to help the autonomous learning process is combined with the immediate feedback and scaffolded challenges provided by the mobile application.

Keywords: educational programs, educational technology, image color analysis, learning, user interfaces, TUI, toy blocks, mobile applications, Montessori.

1 INTRODUCTION

Major advances in technology over the last decade have greatly influenced the way we live on an everyday basis. Blogs, wikis, and more recently Social Networking Sites (SNSs) have radically transformed today's journalism: from the currents of opinion by famous journalists to endless *life-streams* provided by millions of people in real-time. Peer-to-peer networking protocols and streaming services (e.g., YouTube, Spotify) caused a similar effect on the entertainment industry: from general-interest broadcast networks to on demand multimedia services. The rising popularity of cloud computing has encouraged the creation of new services that have revolutionized our way of life in terms of travelling (i.e., social mapping sites, recommendations, geo-tagging of user-generated content), shopping (i.e., secure payment gateways, consumer-to-consumer online auctions, electronic commerce companies that virtually cover the whole Long Tail of customers [1]), or social interacting (e.g., Facebook, Twitter, WhatsApp).

In this scenario, Education appears to have been impervious to these radical changes. This is not the case. The new ways of interacting with others mentioned before have been slowly adopted by educational institutions. Learning Management Systems (LMSs) have evolved from mere content servers to social learning platforms connected to a wide range of social media. Some of these new platforms allow deep methodological changes. Personal Learning Environments (PLEs, see [2]) and Personal Learning Networks (PLNs) focus on the needs of the students, rather than of those involved in the educational process (i.e., teachers or administrators). Learner-centered teaching places the emphasis on the person who is doing the learning [3] and enables learners to experience the world beyond the classroom as an essential part of their learning and personal development [4]. More recently, Massive Online Open Courses (MOOCs, see [5]) and other initiatives like Khan Academy are taking advantage from Cloud Computing services and social media for the dissemination of educational content on a global scale. However, as mentioned before, improving Education is not only about delivering educational content in better ways but also implies a methodological shift.

The undoubted success of mobile devices and online application stores has encouraged the development of a vast number of educational applications designed for children. Shortly after using these kinds of applications, 21st century kids find out that real world objects do not behave in the same way Graphical User Interfaces (GUI) do. Their well developed GUI interaction skills (i.e., tapping, swiping or pinching items through multi-touch gestures on a screen) are useless for physical objects manipulation.

Exploring the real world requires a different set of capabilities (e.g., fine prehensile skills). A century ago Montessori arrived at a similar conclusion [6]. Her methodology emphasizes the use of physical materials to facilitate self-learning of abstract concepts. Original wooden-made materials proposed by Montessori can be upgraded to the mobile world using new user interfaces. During the last decades there has been an evolution from the Graspable User Interfaces [7] and the first versions of programmable building blocks [8] to the popularization of several categories of Tangible User Interfaces (TUIs): digitally augmented paper, physical objects as icons (phicons), manipulatives, and digital sensors / probes [9, 10].

However, many of these proposals (e.g., Phidgets [11], TagTiles [12], multi-touch boards [13], or projector-based augmented reality [14]) require a high initial investment that hinders experiences of casual gaming. With the aim of popularizing TUI-based mobile applications we have developed 3DU Blocks, a library which provides color pattern recognition in arrangements of standard construction blocks. 3DU Blocks' approach is in line with the principles of Montessori education (i.e., independence, freedom and respect for the natural psychological development of the children) and its emphasis in using physical learning materials [15, 16]. Releasing 3DU Blocks under an Open Source license we expect to encourage the development of new toy blocks-based games that explore new gaming scenarios where physical and digital interactions are combined and shared between children and adults.

2 MONTESSORI IN THE MOBILE ERA

Progressive education pedagogical movement tried to renew the traditional curriculum of the 19th century, shifting the focus from traditional teacher-centered methods to student-centered and task-based approaches [17, 18, 19]. Similarly, the underlying philosophy of the Montessori education can be summarized in the following principles: a) the student as the center of school activities, b) the teacher as a helper in learning events, situations and processes, and c) the school as a prelude to the inclusion of the subject in social life.

According to Montessori, an optimal learning experience requires autonomy, competence and relatedness of the learner [6]. Physical objects allow self-directed and purposeful learning activities [10, 20], and enable collaborative experiences in shared contexts with adults [21] or peers [22]. On the other hand, abstract concepts and metaphors -often used by GUIs- are disentangled from the present experience and may not be suitable for the first sensitive periods defined by Montessori (i.e., 0-3 and 3-6 years old).

Montessori's materials are self-correcting (i.e., students can use them independently and check their learning without the need of a teacher), promote multi-sensorial interactions (i.e., visual, auditory, haptic, olfactory, gustatory), and grouped by difficulty (i.e., students freely choose what to do, but they are not able to exceed the limits of their stage). The main aim is to explode the potential of each learner to improve autonomously in a structured environment.

Educational activities developed using 3DU Blocks meet these principles. First, real-time feedback enables self-learning of the player and autonomous self-correcting mechanisms without supervision. Second, using physical toy blocks as the material to interact with the educational activity encourages visual and haptic skills that can be complemented with sounds (olfactory and gustatory stimuli are difficult to generate through electronic equipment). Finally, the task can be presented as a scaffolded set of challenges of increasing difficulty.

3 NEW LEARNING EXPERIENCES TRHOUGH 3DU BLOCKS

3DU Blocks is a JavaScript library designed to allow the development of new gaming experiences, mixing both physical and digital worlds. Using 3DU Blocks visual pattern recognition library mobile

applications are able to detect the layout of a set of colored toy blocks, using device's camera. This process involves several steps, depicted in Figure 1.

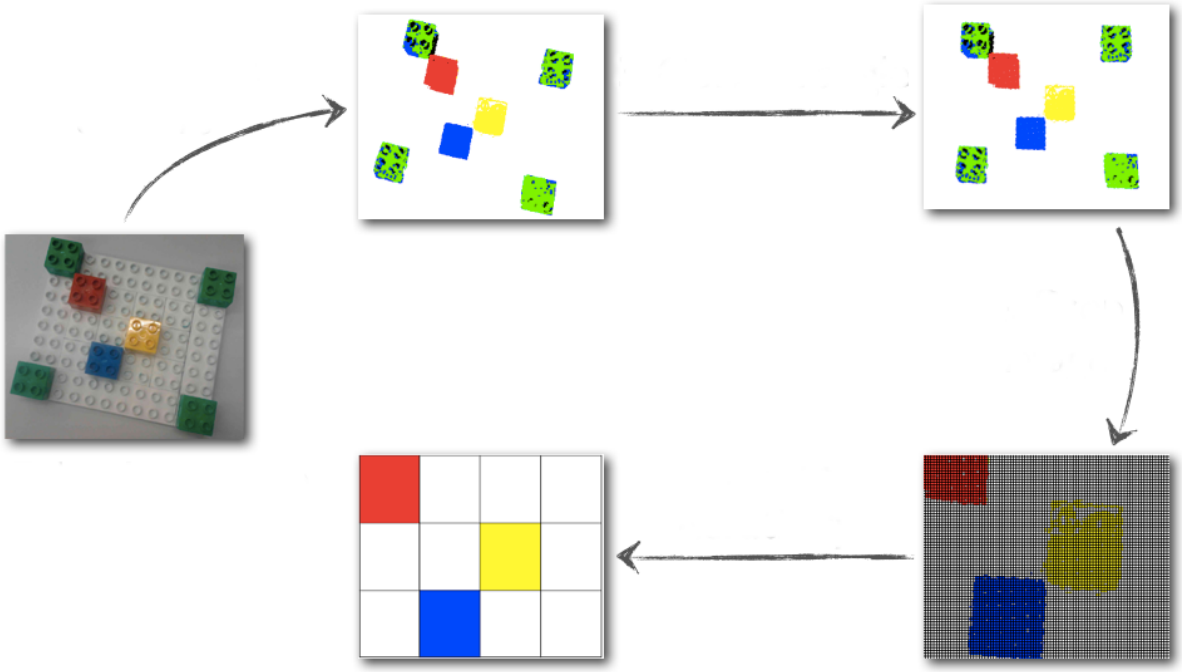

Figure 1. 3DU Blocks visual patter recognition process: (a) take a picture of the set of toy blocks using the camera; (b) detect the borders of the layout and correct its perspective and inclination if needed; (c) determine the most predominant color for each region of the layout; and (d) generate the digital representation of the physical layout of toy blocks.

3DU Blocks library has been developed using widely adopted web standards (i.e., HTML, CSS, and JavaScript) to cover a large range of mobile devices available in the market. As long as the current status of standardized web APIs for camera recording and audio playing are not stable yet, we decided to rely on PhoneGap -a framework designed for the development of multiplatform mobile applications- for these purposes.

The accuracy of 3DU Blocks library has been tested under several light conditions (during the daylight / night, with or without artificial light, using flash or not) [23]. The bi-dimensional representation of the toy blocks' colors (i.e., an array of color values) provided by 3DU Blocks library can be used to develop many kinds of TUI-based games and learning activities. Moreover, 3DU Blocks library has been published under an open source license [24], and therefore can be included as part of existing applications to enhance them with TUI-based interactions. Table 1 shows some of the new self-learning experiences based on 3DU Blocks we are working on. Despite showing an example of activity for each of Montessori's areas, is fair to say that 3DU Blocks is best suited for sensory, math or language areas. The daily life area should be developed with less symbolic materials such as cleaning, sewing, or carpentry equipment, and other different materials proposed by Montessori.

App	Area	Skills	Description
3DU Blocks Music	Sensory	Musical composition, auditory, haptic, visual interactions.	Musical Game where players have to recreate simple melodies using different colored toy blocks on the board.
3DU Blocks Shopping	Math	Counting, adding, subtracting, auditory, haptic, visual interactions.	Shopping game where players have to pay for items (i.e., toys, food, clothes, etc.) using toy blocks as coins of

			different values.
3DU Blocks Do-mi-no	Language	Reading, spelling, listening, auditory, haptic, visual interactions.	Spelling game where players have to arrange syllables of words using toy blocks to generate the word corresponding to the object shown on the screen.
3DU Blocks Island	Daily life	Planning, giving indications, auditory, haptic, visual interactions.	Programming game where players have to define all movements needed to help a monkey to grab all bananas in an island full of obstacles.

Table 1. New self-learning experiences based on 3DU Blocks ordered by Montessori's areas.

4 THE 3DU BLOCKS MUSIC GAME

3DU Blocks Music is a simple TUI-based musical game. To play 3DU Blocks Music the following items are necessary: (a) a mobile device compatible with 3DU Blocks (i.e., all devices supported by PhoneGap), (b) a board to place the toy blocks, and (c) a set of toy blocks of different colors, including the 4 colors corresponding to each instrument and the color used to define the bounds of the playing board. These markers must be placed on the corners of the playing board before start a game. Once this step is done, the playing board will allow to place up to 12 toy blocks in a 4 x 3 layout.

3DU Blocks Music presents two different game-modes: normal and freestyle. In the normal mode, the player has to solve different musical challenges on a level-by-level basis. At the beginning of each level a simple musical composition (i.e., a combination of any of the 4 instruments and 3 different tones) is played. To solve each level, players have to place the toy blocks corresponding to the previously listened melody. Positive or negative feedback is provided at each attempt, fostering self-learning (see Figure 2). The freestyle mode works in a similar way. The main difference with the normal mode is the absence of a musical composition to be recreated. The playing board can be used as a simplified pentagram where a large variety of new melodies can be composed and played just by taking a picture of it.

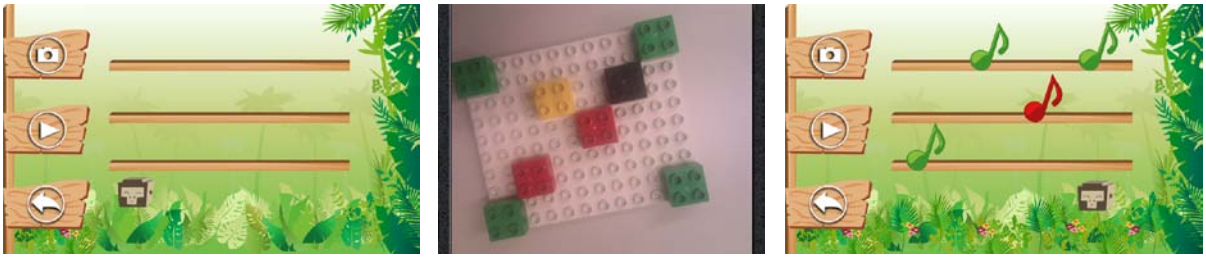

Figure 2. A 3DU Blocks Music challenge: a) Musical composition is played, b) Player places toy blocks on the playing board (note the four marker blocks on the corners), c) feedback is provided (three notes where correctly placed, but there is one mistake in the third note).

Currently, 3DU Blocks Music is freely available on the Apple App Store for devices running iOS (i.e., iPod, iPhone, iPad) and Google Play for devices running Android (see Figure 3).

Figure 3. QR Codes of iOS and Android versions of 3DU Blocks Music at Apple Store and Google Play.

5 THE 3DU BLOCKS PROGRAMMING GAME

Over the years programming has been gaining ground in the educational curriculum. Rushkoff stated that *"it's time Americans begin treating computer code the way we do the alphabet or arithmetic."* [25]. Similarly, Kurzweil claimed that *"The only second language you should worry about your kids learning is programming."* [26]. The underlying ideas of Montessori's daily life area are more tightly connected to physical experiences like pouring liquids into appropriate containers, cleaning and tidying the classroom, sewing clothes or doing woodwork. Nevertheless, programming skills will have a key role in the near future.

There are several alternatives available for learning programming by students that are able to read. One of the best known for their excellent design and large number of users worldwide is Scratch [8]. Once mastered the basics of programming thanks to these custom development environments, novice programmers can try with more complex -and similar to the real source code- proposals like Alice [27]. Another option is to take advantage of their block-based programming knowledge to develop mobile applications through Google's App Inventor [28] or create Arduino-based automations using Scratch for Arduino [29].

However, none of these proposals is aimed for younger ages. For this reason we developed 3DU [30], an online platform where each player can solve or propose simple programming challenges. In all 3DU's challenges players have to have to guide a monkey through an island to collect all the bananas and avoid the obstacles (see Figure 4). Later, we decided to take advantage of the features provided by 3DU Blocks library to develop a TUI-based of the game: 3DU Blocks Island. In this application each color of the toy blocks represents a command in 3DU (i.e., turn left, turn right, go forward), and the levels are slightly simpler. Players are provided with immediate feedback, so they are able to iteratively refine the instructions given to the monkey to grab all the bananas. Therefore, this educational game also meets Montessori's requirements for a proper educational material, as long as it is self-correcting, promotes multi-sensorial interactions and its challenges are grouped by difficulty.

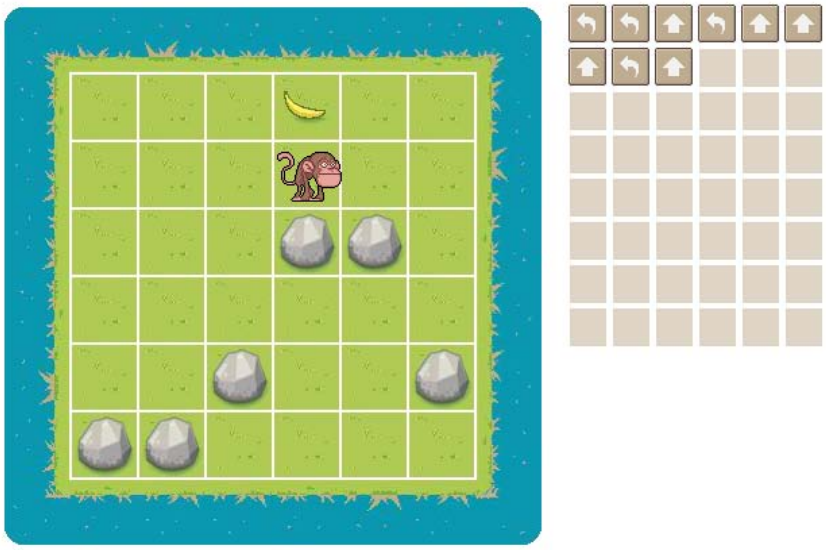

Figure 4. 3DU programming game at http://3du.es. 3DU Blocks Island is a port of this game to use toy blocks as input through 3DU Blocks library.

6 CONCLUSIONS

Over the past century, the Montessori materials have supported the learning of thousands of children worldwide. With the emergence of educational mobile applications, many of these materials have been replaced by two-dimensional digital versions with different physical properties. However, using physical materials in learning activities has proven very beneficial. They reduce the cognitive requirements in terms of working memory for tasks like counting, ordering, or classifying. Using explicit content is a well-known approach to ease the access to non-trivial knowledge. Moreover, tri-dimensional materials promote and enhance haptic and proprioceptive skills. From a motivational perspective, physical materials play a key role in engaging learners with difficulties in processing abstract contents.

3DU Blocks library promotes the development of applications that mix physical and digital objects in new gaming and learning experiences. Closely linked with Montessori's pedagogy, we have presented two examples of this kind of applications which take advantage from using toy blocks as a TUI. All these projects are freely available on the Web are released under an open source license to foster the creation of a wider range of learning activities based on this approach [24]. Although it is still early to talk about the suitability of these approach to port Montessori's ideas to the mobile era, these scenarios ease Social and Learning Analytics studies that will provide enough data to draw conclusions about it.

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