Swiping fingers on a screen is not enough! Dusting off toy blocks to build new gaming experiences through mobile apps

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***Abstract*—Smartphones have become everyday objects for many children. They learn how to count, spell or paint by swiping their fingers on a screen, using some of the thousands of applications specially designed for them. However, real world interactions also need other kind of skills for physical object manipulation, often developed through traditional toys. In this paper we present 3DU Blocks, a proposal to take advantage of both approaches, combining traditional building blocks with the features provided by mobile devices to create new gaming experiences.**

Keywords- educational programs; educational technology; image color analysis; learning; user interfaces;

I. INTRODUCTION

Both smartphones and tablets [1], together with the big success of online application stores, have encouraged the creation of a vast number of educational applications that are changing the way children process information. Parents are amazed by the skills shown by children in the use of these devices, while children are surprised to find out that real world objects do not behave in the same way Graphical User Interfaces (GUIs) do. The well developed GUI interaction skills (i.e., tapping, swiping or pinching items through multi-touch gestures on a screen) of the 21st century kids are useless for physical objects manipulation. Exploring the real world requires a different set of capabilities (e.g., fine prehensile skills) that should not be overlooked by educators.

Combining traditional toys with electronic devices is not a new idea [2]. During the last decades there has been an evolution from the Graspable User Interfaces [3] and the first versions of programmable building blocks [4] to the popularization of several categories of Tangible User Interfaces (TUIs): (a) digitally augmented paper, (b) physical objects as icons (phicons), (d) manipulatives, and (d) digital sensors / probes [5, 6]. However, many of these proposals (e.g., Phidgets [7], TagTiles [8], multi-touch boards [9], or projector-based augmented reality [10]) require a high initial investment that hinders experiences of casual gaming.

For this reason we have developed 3DU Blocks, a library which provides color pattern recognition of arrangements of standard toy blocks to develop learning games and activities. Moreover, as a living example of the use of 3DU Blocks, we present 3DU Blocks Music, an educational game where players have to recreate simple melodies using construction toy blocks patterns where each color represents a musical instrument and each position a certain tone. This approach is in line with the principles of the Montessori education (i.e., independence, freedom and respect for the natural psychological development of the children) and its emphasis in using physical learning materials [11, 12].

II. AIMS AND SCOPE

Our proposal addresses multiple goals. First, we expect to encourage the development of new toy blocks-based games releasing the 3DU Blocks library. Second, we want to show the features provided by this library through a simple game, 3DU Blocks Music. Third, we target at exploring new gaming scenarios where physical and digital interactions are combined and shared between children and adults.

An optimal learning experience requires autonomy, competence and relatedness of the learner [13]. The concepts of flow [14] and fun [15] are close to this kind of experiences, and they are maximized when a task is presented as a scaffolded set of challenges. Well-designed GUIs and gesture-based interactions allow learners to experience flow and high self-confidence. However, most of the skills gained interacting with digital devices are far from being usable in the real world [16]. Moreover, abstract concepts and metaphors often used by GUIs may not be suitable for younger children, lacking the cognitive skills needed to work with them [17, 18].

Many authors during the last century have explored several ways to define self-directed and purposeful learning activities playing with physical objects [11, 19, 20]. Real world objects are perceived and understood more readily through haptic and proprioceptive perception of tangible representations rather than through visual representation alone [21], and enable learning experiences in shared contexts with adults [22] or peers [23].

Therefore, our goal is to take advantage of the multimedia features offered by current mobile devices to enhance traditional toy blocks gaming, allowing the development of new gaming experiences that merge both physical and digital worlds.

III. THE 3DU BLOCKS LIBRARY

The main purpose of 3DU Blocks library is to identify the layout of a set of colored toy blocks gathered from the camera of a mobile device. This process involves several steps: (a) take

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a picture of the set of toy blocks using the camera; (b) detect the edges of the layout and correct its perspective if needed; (c) determine the most prominent color for each region of the layout; and (d) generate the digital representation of the physical layout of toy blocks.

With the aim of covering a wide range of mobile devices available in the market, 3DU Blocks library has been developed using widely adopted web standards (i.e., HTML & CSS for the content and visual features, and JavaScript for the behavior of the application). The access to the camera of the mobile device has been provided by a framework designed to develop multiplatform mobile applications called PhoneGap [24]. As the current status of standardized web APIs for audio playing is not stable, we decided to use this framework for that purpose too.

Four marker toy blocks (i.e., standard toy blocks of a predefined color) must be placed in each corner of the layout to ease the border detection when using 3DU Blocks library. Considering that most users will be prone to take out off-position pictures, these marker blocks are also used to correct the aspect and orientation of the gathered layout. As construction blocks are square sized, detecting their edges permits the algorithm to determine the rotation angle of the image and correct it applying a rotation matrix, which allows to calculate the new x' and y' coordinates of each pixel from the original picture:

$$\mathcal{R}(\theta) = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \qquad (1)$$

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \qquad (2)$$

$$x' = x \,\cos\theta - y \,\sin\theta \qquad (3)$$

$$y' = x \,\sin\theta + y \,\cos\theta \qquad (4)$$

Once the layout is properly detected and oriented, 3DU Blocks library proceeds to detect the colors of the toy blocks through the following steps: (a) adjust each pixel's color from the picture to match one of the predefined toy block colors, normalizing them to the closest one; (b) split the picture in proportional regions; (c) identify the predominant color in each region; (d) repeat previous steps with several region sizes (number of pixels inside each region) to improve the accuracy of the color detection process.

Finally, the detected layout is converted to a bidimensional representation of the colors of the toy blocks (i.e., an array of color values). This data 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 [25], and therefore it can be included as a part of an existing application to provide a TUI-based interaction.

The accuracy of 3DU Blocks library has been tested using two different mobile devices: an HTC Desire HD running Android 2.3.5 and an Apple iPhone 4S running iOS 6. As shown in Figure 1, four different toy blocks arrangements were analyzed (layout 1: a red block at C2; layout 2: a blue block at A2 and a black block at C3; layout 3: a black block at B2, a yellow block at C1, and a red block at D2; layout 4: three yellow blocks at A1, C1, and D3, three black blocks at A3, C2, and D2, three red blocks at A2, B3, and D1, and three blue blocks at A2, B2, and C3) under several light conditions (i.e., during the daylight / night, with or without artificial light, using flash or not).

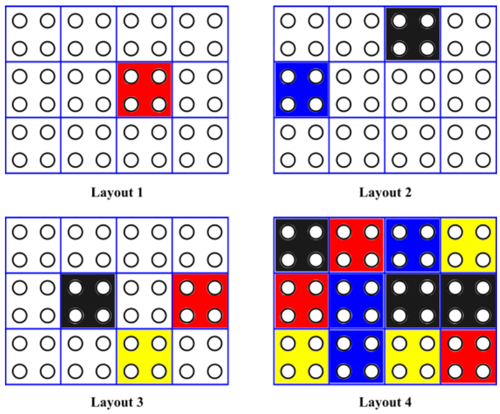

Figure 1. Toy blocks arrangements used in 3DU Blocks library's tests.

TABLE I.
HTC DESIRE HD (ANDROID 2.3.5)

Layouts 1, 2, 3, and 4						
Daytime	**Light**	**Flash**	**Angle**	**Accuracy (%) M**	**Accuracy (%) SD**	**Errors**
Day	No	No	0º	100	0	0
			15º	100	0	0
			-15º	83.30	19.28	0
		Yes	0º	100	0	0
			15º	91.65	16.70	0
			-15º	83.30	19.28	0
Night	Yes	No	0º	100	0	0
			15º	91.65	16.70	0
			-15º	74.98	31.93	0
	No	Yes	0º	50	57.73	0
			15º	41.65	49.99	0
			-15º	58.30	41.93	1
	Yes	Yes	0º	75	50	1
			15º	58.30	41.93	0
			-15º	58.33	50.01	0

Each layout was tested and analyzed three times under each light condition. Tables 1 and 2 show the results of 3DU Blocks library running these tests under the HTC Desire HD and the Apple iPhone 4S respectively.

TABLE II.
APPLE IPHONE 4S (IOS 6)

Layouts 1, 2, 3, and 4						
Daytime	**Light**	**Flash**	**Angle**	**Accuracy (%)**		**Errors**
				M	SD	
Day	No	No	0º	100	0	0
			15º	91.65	16.70	0
			-15º	74.95	16.70	2
		Yes	0º	100	0	0
			15º	83.30	19.28	1
			-15º	83.30	19.28	1
Night	Yes	No	0º	100	0	0
			15º	83.30	19.28	1
			-15º	58.28	16.65	1
	No	Yes	0º	49.95	19.23	0
			15º	41.63	31.88	2
			-15º	33.30	27.19	2
	Yes	Yes	0º	100	0	0
			15º	74.95	16.70	0
			-15º	66.65	30.51	2

As can be seen, light conditions had a prominent influence in overall accuracy and the number of raised errors while analyzing the gathered images. These impressions were confirmed by a 2 (Device: HTC Desire HD vs. Apple iPhone 4S) x 2 (Daytime: Day vs. Night) x 2 (Flash: Yes vs. No) x 3 (Rotation: -15º vs. 0º vs. -15º) analysis of variance, which yielded a main effect of Daytime, $F(1,119) = 12.195$, $p = 0.001$, $\eta_p^2 = 0.113$, as was the main effect of Flash, $F(1,119) = 6.131$, $p = 0.015$, $\eta_p^2 = 0.060$, and Rotation, $F(2,119) = 5.096$, $p = 0.008$, $\eta_p^2 = 0.096$. The interaction of Daytime x Flash was also significant, $F(1,119) = 4.935$, $p = 0.029$, $\eta_p^2 = 0.049$. Therefore, using 3DU Blocks library in proper light conditions seems to be crucial to get an adequate user experience. Interestingly, the main effect of Device and all interactions involving Device failed to reach statistical significance. These results are in line with the consideration of 3DU Blocks as a multiplatform library.

IV. THE 3DU BLOCKS MUSIC GAME

As mentioned before, the 3DU Blocks library provides a platform-agnostic mechanism to use toy blocks arrangements as TUIs for many kinds of applications. Taking into account that parents and educators should design environments that encourage and enhance problem solving from a young age [26], we decided to use 3DU Blocks library to develop an educational game that combines spatial reasoning and music.

Technologically, 3DU Blocks Music takes advantage from the computational capabilities of current mobile devices to enhance the inherent simplicity of construction toy blocks, used by generations of kids in their playing routines. This approach opens the gate to new shared gaming experiences where a player (e.g., a kid) performs the required manipulations to arrange the toy blocks in a proper way to solve the level, whilst another player (e.g., another kid, an adult or a learning supervisor / tutor) interacts with the mobile device to check the correctness of a proposed answer and offer new challenges.

There are many other technological approaches for the generation of musical tones and melodies using physical objects. Some of them use sensors embedded in toy blocks (e.g., Neurosmith Music Blocks [27]), and some others rely on blocks labeled with custom visual patterns to ease the automatic recognition process (e.g., audio d-touch [28]). However, we consider that traditional toy blocks are the best choice in terms of availability, pricing and robustness, and the use of a smartphone can make up for their lack of interactivity

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.

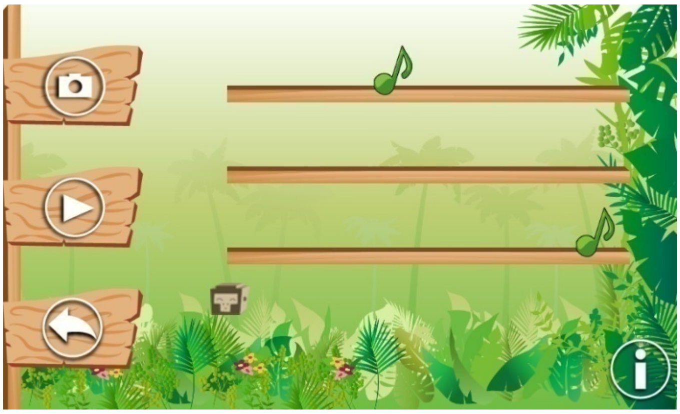

Figure 2. 3DU Blocks Music.

The initial splash-screen of 3DU Blocks Music is designed to start playing easily, but it also provides a couple of buttons to show general information about the game and how to play it. These buttons are also present along the next screens of the application.

3DU Blocks Music presents two different game-modes: normal and freestyle. In the normal mode, the player has to solve musical challenges on a level-by-level basis. In each level, the player listens to a simple musical composition (i.e., a combination of any of the 4 instruments and 3 different tones) and is asked to recreate it. Considering that the main purpose of 3DU Blocks Music was to focus on the development of haptic skills and not on working memory, this composition can be replayed as many times as needed. Once a challenge is achieved, the next three levels are unlocked, allowing going forward in the game even if one level is not completed. Moreover, failing at recreating the musical composition has no bad consequences in the game (e.g., no score loss, no loss of a life). Instead, 3DU Blocks Music fosters self-directed learning providing hints for success in the game.

To complete each level, the player has to use the camera of the mobile device to take a picture of the playing board. If the algorithm is able to digitalize the layout of toy blocks, the result is shown on the screen. Finally, the proposed solution is compared with the correct solution. For each of the toy blocks properly placed a green colored note will be displayed on the screen (see Figure 2). Similarly, red notes will be displayed if there is an error guessing the tone, the instrument or the moment of the sound. This feedback is very helpful to solve each challenge progressively.

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 taking a picture of it.

Currently, 3DU Blocks Music is available for free 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.

V. CONCLUSIONS

In this paper, we have presented a library for the visual recognition of color patterns created using regular toy blocks (3DU Blocks). This library promotes the development of applications that mix physical and digital objects in new gaming and learning experiences. As a living example of this kind of applications, we have presented a simple educational game which takes advantage from using toy blocks as a TUI to develop the musical skills of the player (3DU Blocks Music). Both are released under an open source license to foster the creation of a wider range of learning activities based on this approach [25].

The benefit of using physical materials in learning activities is twofold. Firstly, it reduces 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. Secondly, it promotes and enhances haptic and proprioceptive skills. This is also closely linked to the motivational aspect of the learning process, where physical materials play a key role in engaging learners with difficulties in processing abstract contents.

Considering the low cost of toy blocks and the popularization of mobile devices (more than 100 million smartphone owners in the U.S. in 2012 [28]), it seems feasible to catch a glimpse of a future where TUI-based learning games –through 3DU Blocks or similar approaches– are ubiquitous.

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