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Virtual Blocks: A Serious Game for Spatial Ability Improvement on Mobile Devices

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Abstract This paper presents a novel spatial instruction system for improving spatial abilities of engineering students. A 3D mobile game application called *Virtual Blocks* has been designed to provide a 3D virtual environment to build models with cubes that help students to perform visualization tasks to promote the development of their spatial ability during a short remedial course. A validation study with 26 freshman engineering students at La Laguna University (Spain) has concluded that the training had a measurable and positive impact on students' spatial ability. In addition, the results obtained using a satisfaction questionnaire show that *Virtual Blocks* is considered an easy to use and stimulating application.

Keywords *Spatial Abilities, Mobile Gaming, Multimedia Applications, Education and Training*

1 Introduction

Spatial ability is an important human aptitude which plays significant roles in how individuals perceive, organize, and interact with their environments [1]. There are many definitions of spatial ability, but it is generally accepted to be related to skills involving the retrieval, retention and transformation of visual information in a spatial context [2]. Clements and Battista [3] explain spatial reasoning as consisting of "cognitive processes by which mental representations for spatial objects, relationships, and transformations are constructed and manipulated". Linn and Peterson [4] similarly state that spatial reasoning "refers to skill in representing, transforming, generating, and recalling symbolic, nonlinguistic information". According to Thurstone [5], spatial ability itself can be further divided into three skills: recognizing an object from different angles, imagining movement or displacement of internal parts of a spatial configuration, and determining spatial relationships with respect to one's own body. During the middle of the 20th century, research focused on determining the factor structure of spatial ability. Investigators such as Guiford and Lacey [6], Zimmerman [7], Thurstone [8] and French [9] all found that large batteries of spatial tests yielded evidence for separable subcomponents of spatial ability (spatial visualization, spatial relations, spatial orientation..).

As it has repercussions in almost all scientific and technical fields, spatial abilities remain an active field of study, especially in the engineering domain and they may be associated with success in scientific areas [10]. Studies have shown that past experience affects an individual's spatial ability. Non-academic activities, such as playing with construction toys as a young child and playing three dimensional computer games seem to have a strong relationship with spatial visualization ability. The interest of video or computer games for improving spatial skills has been analyzed by several researchers [11-12].

Several studies have indicated that spatial abilities can be improved through training. Many

1 computer applications (e.g., computer-aided design and drawing) and computer games require
2 spatial processes such as mental rotation and spatial visualization [13]. Baartmans and Sorby [14]
3 also believe that experience in computer games is beneficial to developing spatial skills. For
4 example, playing the “Tetris”, which requires rapid rotation and placement of seven differently-
5 shaped blocks, and the game “Blockout”, which requires mental-rotation of geometric figures [15],
6 improve spatial-test performance [16].

7 In recent studies, the role of computer games has been examined for its impact on the gender
8 differences in spatial skills. Terlecki and Newcombe [17] found that computer experience
9 substantially mediates the gender difference in spatial ability observed on the Mental Rotations
10 Test (MRT). Terlecki, Newcombe and Little [18] conducted a study with college age students
11 using 3-D Tetris as a spatial skills training aid. Undergraduates participated in repeated testing on
12 the MRT or played the videogame Tetris. The analysis showed large improvements in mental
13 rotation with both repeated testing and training; these gains were maintained several months later.
14 MRT scores of men and women did not converge, but men showed faster initial growth and
15 women showed more improvement later. Feng, Spence and Pratt [19] found that playing an action
16 video game can virtually eliminate gender difference in spatial attention and simultaneously
17 decrease the gender disparity in mental rotation ability. In summary, research consistently shows
18 that video game exposure is related to improvements in spatial skills, but so far they have not
19 developed specific tools on mobile devices.
20

21 Given this context and based on our experience in developing multimedia spatial ability training
22 tools [20-21], the present work tries to join the potential of mobile games and interaction with 3D
23 mobile environments on touch screen handheld devices to enhance spatial visualization abilities.
24 This study presents a novel spatial instruction system, using a 3D mobile game (Virtual Blocks)
25 that uses construction models using cubes to develop spatial skills. A validation study with 26
26 freshman engineering students at La Laguna University (Spain) has concluded that the training had
27 a measurable and positive impact on students’ spatial ability. In addition, the results obtained using
28 a satisfaction questionnaire show that Virtual Blocks is considered an easy to use and stimulating
29 application. This approach differs from the related work mentioned above in some aspects: we use
30 a 3D mobile game to enhance spatial skills on touch screen devices and we have validated that
31 Virtual Blocks is an effective tool to promote spatial abilities development.
32

33 This game has been designed taking into account the advantages of the implementation on mobile
34 devices, the use of touch screens and learning with games. This work poses the thesis that the link
35 between games and mobility provides opportunities for the development of cognitive skills,
36 improving the learning conditions of students and contributing to the improvement of skills. In the
37 following section, we describe the key technical elements of the mobile spatial instruction
38 proposed to support the experimental study with the game Virtual Blocks. After that, a short
39 remedial course using 3D mobile game for developing spatial visualization abilities will be
40 analyzed, and the paper ends with the analysis of a satisfaction study performed with students to
41 evaluate their opinion about the game. Finally, the conclusions and future work are presented.
42

43 **2 Virtual Blocks: system architecture**

44 The software platform for mobile spatial instruction is based on the system architecture showed in
45 Figure 1 and consists of a 3D mobile game (Virtual Blocks) (1), a PC application (Virtual Blocks
46 Desktop) (2), a server application (3) and a data base (4).
47

48 We need to underline that this project started at the end of 2008, so this point determined the initial
49 choice of the mobile OS as well as the device we began working with. At that moment, the two
50 most widely used APIs used in 3D graphics programming of mobile devices were OpenGL ES and
51 M3G for Java Mobile Edition [22], but the availability of devices with OpenGL ES support was
52 scarce. Most touch screen mobile devices available in the Spanish market in 2008 supported Java
53 Mobile Edition (JME). Because of it, initially we opted for the standard Mobile 3D Graphics API
54 (JSR-184). Later, in 2009 the application was ported to the iOS platform, implementing the 3D
55 graphics programming through the OpenGL ES API. 3D graphics programming used in
56 development of the mobile game may be adapted to mobile operating systems currently available.
57 In particular, in 2011 it was adapted to run as a native iPad app and currently the Android version
58 is under development.
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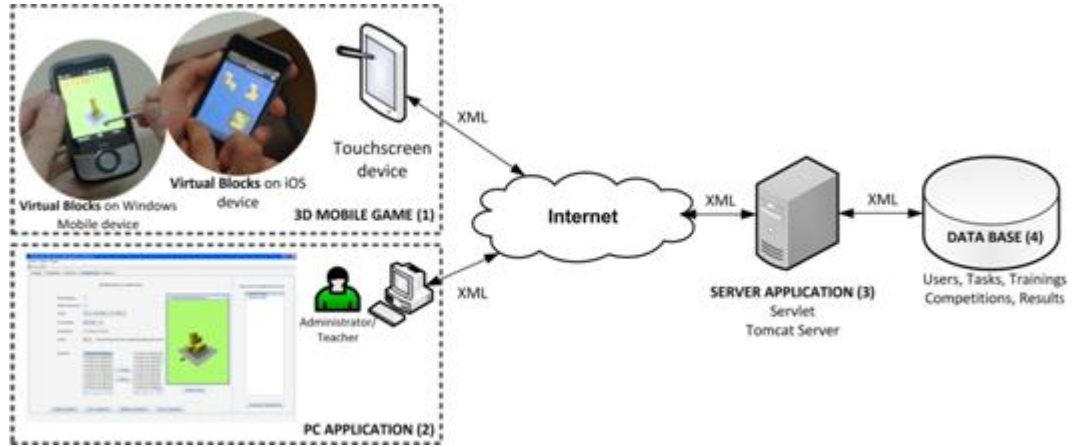


Figure 1. System architecture

Virtual Blocks is a mobile game application where the user must solve a set of exercises about building models with unit-sized cubes in a 3D environment. Figure 2 and 3 show some sample screenshots from the use of the game on both HTC Touch Cruise and iOS devices. Each exercise requires the construction of two 3D scenes (World1 and World2). World1 is intended to build the cubes model in an empty scene with a grid on which we can add cubes by touching the screen. The second world (World2) contains the task exercise which must be solved (Type 1 or Type 2). On this second scene, the user cannot add cubes as both worlds allow rotating and zooming in or out of the scene.

Two types of exercises have been developed so far, which basically consists of building 3D models with cubes in a 3D scene. Type 1 consists of replicate the proposed 3D model (as seen on Figure 2c and Figure 3c). Type 2 consists of building a 3D model using three orthogonal views: front, top and right (see Figure 2d and Figure 3d).

In the game development we focused our efforts on the interaction with the 3D scene, paying special attention to the solutions contributed such as generation and camera manipulation, zoom, objects selection in the 3D scene of exercises sketching so they ease an efficient verification of answers. In each platform, functionalities implemented on own APIs were used but it was also necessary to solve technical difficulties caused by their characteristics.

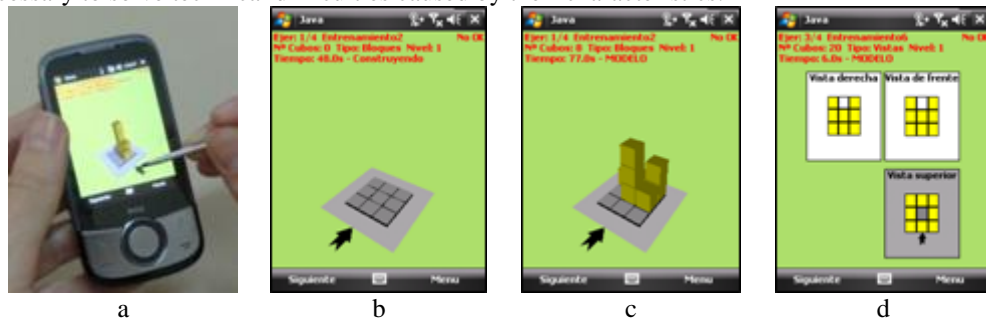


Figure 2. (a) *Virtual Blocks* works on HTC device; (b) Empty 3D Scene to solve exercise (World1); (c) Type 1 Exercise Scene (World2); (d) Type 2 Exercise Scene (World2)

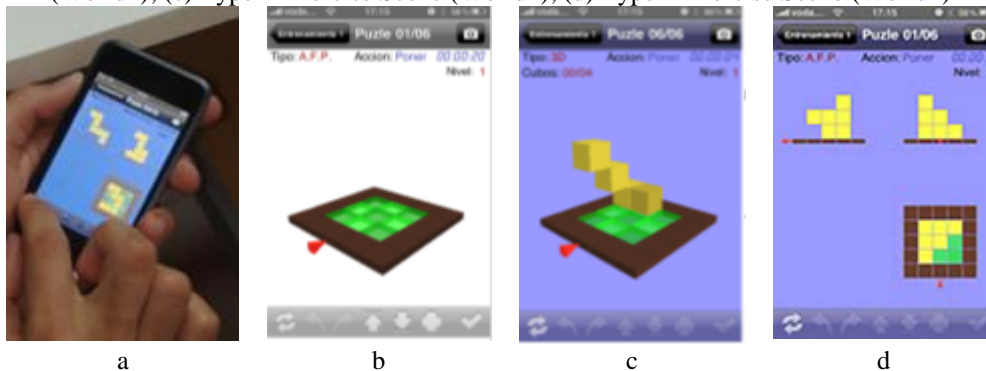


Figure 3. (a) *Virtual Blocks* works on iPod Touch; (b) Empty 3D Scene to solve exercise (World1); (c) Type 1 Exercise Scene (World2); (d) Type 2 Exercise Scene (World2)

The system of operation of *Virtual Blocks* is shown in Figure 4. There are two game modes: training and competition. The training exercises are designed so that the user can become familiarized with the game environment. The competitions are sets of tasks, created by the system administrator, which the user has to download, by logging into the system. Users can complete a new competition when the system administrator activates a new one. Competition results are sent to the server with data on times and scores. The application has a help function to explain how the game works. Each exercise has an overall score of one point if exercise is correct and zero if it's wrong as well as time used for completing it. Each task is evaluated when the user presses "next". One point is awarded if answer is correct and zero if it is incorrect. The score and time required to complete the activity are recorded. When the whole set of tasks is completed, the results are sent to the server.

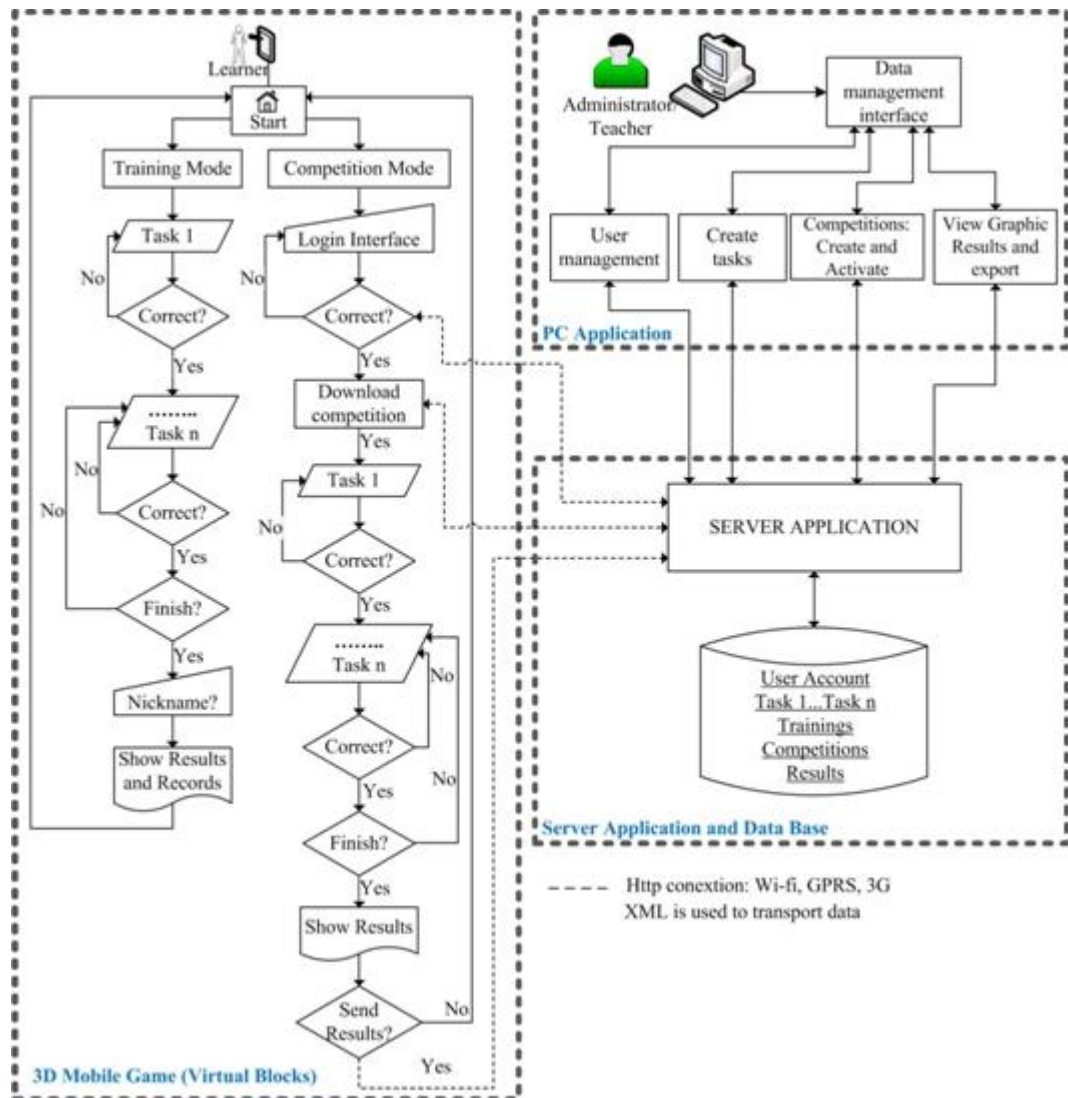


Figure 4. Flow chart of the system

The PC Application allows the creation of tasks and competitions in an interactive 3D environment and activates them so they become available for downloading (see Figure 5). The administrator or teacher also has to settle tasks together in Competitions and activate the Competition that should be made available for downloading with the mobile application. Authorized users can download task collections (Competitions) if the teacher has activated the application for them. The PC Application offers users' statistics (scores and times) in graph format, and allows data to be viewed and exported in ".txt" format, so that they can be processed on a spreadsheet or with statistical software.

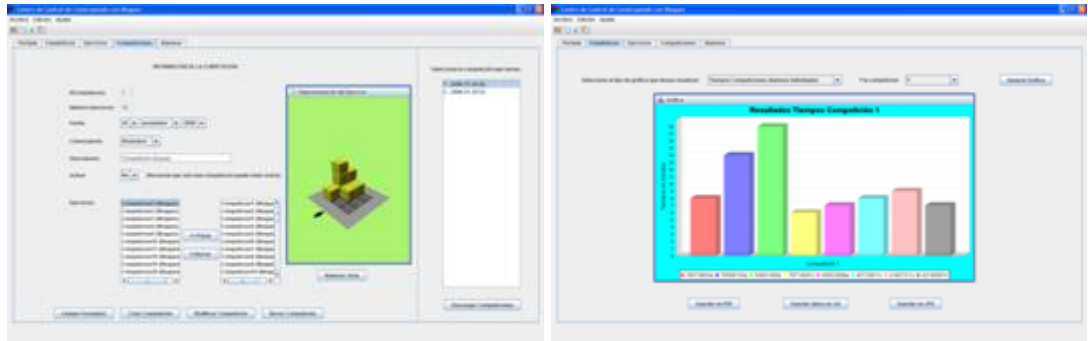


Figure 5. Desktop application screenshots

3 Technical implementation

For the development of the desktop application and the mobile game over Windows Mobile it was used NetBeans 6.0.1 as the development tool and Sun Java™ Wireless Toolkit 2.5.2 for CLDC for emulating the mobile device environment. For the iOS version, the iPhone SDK 4.0 was used. Table 1 shows minimum requirement needed for system implementation

Table 1. Hardware and software minimum specifications

Application	Operative System	Languages	Devices
Mobile Game	Windows Mobile 6.0	Java 2 Micro Edition (J2ME)	LCD touch display, 2.8", 240 x 320 Jbed Smertec Java Virtual Machine
	iOS 4.0	Objective-C	iPod Touch / iPhone
PC Application	Windows XP / Windows Vista/ Windows 7	Java 2 Standard Edition (J2SE)	Java Virtual Machine / Java 3D virtual machine Libraries: iText-2.1.3, jcommon-1.0.13, jdom, jfreechart-1.0.10
Server and Data base	Windows 2003 /2007 server	Java 2 Enterprise Edition (J2EE)	MySQL and Apache Tomcat

Two types of exercises have been developed so far, which basically consists of building 3D models with cubes in a 3D scene as detailed in section 2 (Figure 2 and 3).

The following sections describe the technical implementation details.

3.1 Using M3G API (JSR-184) and stylus

Interaction with the scene

The scene has a 3D grid with the size of the 3D model to create (2x2, 3x3, 4x4, 5x5). The "Picking" method, implemented in M3G, is used to identify the object when the user selected by the stylus. This method allows us to obtain the 3D coordinates of the object projected from the position coordinates of the screen selected by the user. Applications include collision detection and selecting a 3D object based on their input. When the user touches on the grid, you call the function *createCube* and it paints a cube dynamically and the screen refreshes. Picking method allows us to identify which face the user is striking for adding a cube on that side.

This game requires inputs through a stylus. Due to device's very accurate detection of the small movements that the user can perform with the stylus on the screen, it is necessary to distinguish between two actions: if the user is pressing with the stylus on the screen (*pointerPressed* or *pointerReleased*) or if stylus is being dragged (*pointerDragged*). With the aim to discriminate between these two events and after performing various tests with the mobile device, a margin of 3 pixels of difference between the coordinates on which the user clicks (x_1, y_1) and the coordinates on which loses (x_2, y_2) has been chosen. If some of the differences (x_2-x_1, y_2-y_1) are larger than

3 pixels it is considered that an event occurs and the dragged scene is rotated. Otherwise, it is understood that the user may be attempting to build cubes (see Figure 6).

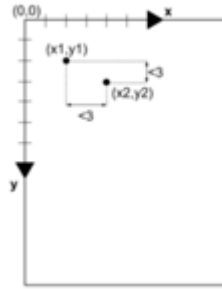


Figure 6. Distinguishing events: pointerPressed vs pointerReleased vs pointerDragged.

Solving exercises check

The exercises are created by the teacher or system administrator in the PC application in a Java 3D environment (see Figure 5). They are stored in the data base in a numeric string as shown in Figure 7a. The first value represents the array size (2x2x2, 3x3x3, 4x4x4, 5x5x5) and the remaining values are one or zero depending on position being occupied by a cube or not. For exercise type 1, each position of the array model created by the user is compared with the array model solution in the exercise (Figure 7b and 7c), in that way, there is only one possible correct answer/result.

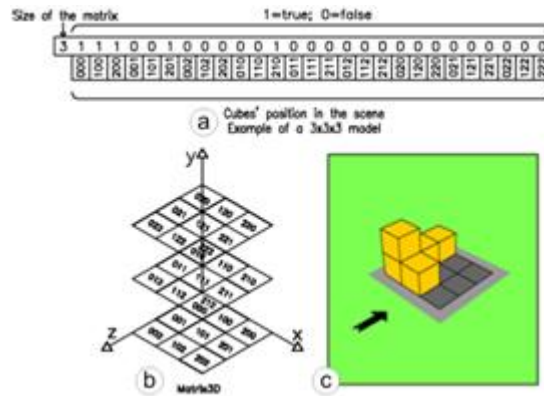


Figure 7. Example of 3x3x3 model.

However, for exercise type 2, the procedure is more complex, because for the same group of views (front, top and right), there may be several 3d models solutions. To solve this problem, two-dimensional arrays are used representing each of the orthogonal views [23]. The estimation equation used is shown below (1):

$$View_{coord_i} = \begin{matrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{21} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{1n} & a_{2n} & \cdots & a_{nn} \end{matrix} \quad (1)$$

where

$$a_{jk} = \begin{matrix} 1 & \text{ocupied for coord}_i \\ 0 & \text{not ocupied coord}_i \end{matrix}, \quad i, j, k \in 1, 2, \dots, n, \quad 2 \leq n \leq 5$$

where

$View \in \{Front, Top, Right\}$

$z \quad View = Front$

$y \quad View = Top$

$x \quad View = Right$

$View = View_{coord_1} OR View_{coord_2} OR \dots OR View_{coord_n}$

For example, for the front view, each one of the possible 2D arrays in z direction is obtained, built by columns. So, solution for this view belong to the result of applying OR operation to all of them. The matching equation is shown on (2).

$n = 3, View = Front$

$Front = Front_{z_1} OR Front_{z_2} OR Front_{z_3}$

$$\begin{array}{c}
 \begin{array}{cccc}
 & \xrightarrow{\dots\dots\dots} & & \\
 \begin{array}{c} \vdots \\ \downarrow \end{array} & \begin{array}{ccc} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 1 & 1 & 0 \end{array} & OR & \begin{array}{ccc} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{array} & OR & \begin{array}{ccc} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{array} & = & \begin{array}{ccc} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 1 & 1 & 0 \end{array} & (2)
 \end{array}
 \end{array}$$

To all possible solution, 2D arrays belonging to each view (front, right and left) will match. So, operation of checking the exercises consists of comparing the arrays obtained from two-dimensional model constructed by the user with the arrays of two-dimensional model proposed in this exercise. If the parent of two-dimensional model constructed by the user and the proposed are equal, the exercise is considered to be correct.

3.2 Using OpenGL ES with iOS devices

One of the main obstacles solved in the iOS was the lack of supporting tools for implementation of a 3D world. For interaction of view it has been used a communication model from the method-event kind. The Objective-C notifications are used for communication between model and view. The practice directs us towards the best strategy for setting up the 3D scene is defining independent functions for each object in scene: grid, model and reference of view's direction. Other available functionalities used in this multitouch device are zooming through fingers and the accelerometer [24].

Interaction with the scene

The operation of adding cubes on scene means new difficulties that should be solved, as OpenGL ES doesn't incorporate the GL_SELECTION mode or GLU library either which may incorporate Picking automatically as we did on M3G. This problem was solved in two phases: it was implemented a gluUnProject function version for OpenGL ES as well as the Kay & Kajiya [25] algorithm for determining the cube's face selected.

The gluUnProject implementation details

The selected pixel is applied the inverted process for each transformation suffered by a vertex through the OpenGL ES pipeline and Pick Ray technique. A ray is generated from the finger position and intersections with the objects on scene are determined. The selection ray is obtained linking the matching points to the pixel in minimum (0.0) and maximum (1.0) depth planes. So, if pixel has screen coordinates (winx, winy), the inverted projection of points should be applied

(winx, winy, 0) as well as (winx, winy, 1). Linking the points obtained when projection's opposite is applied give us the selection's ray (see Figure 8).

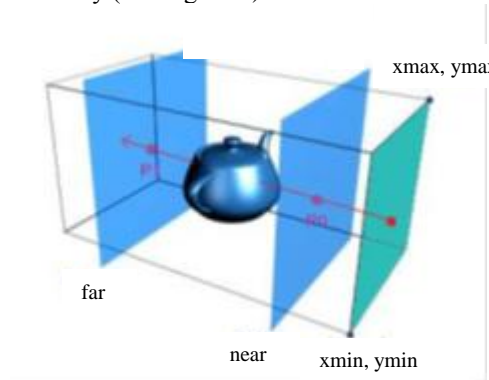


Figure 8. Ray's calculation through gluUnProject

The gluUnProject function's implementation and testing was a critical phase in the project due to key factors that intervene in its proper working such as the calculation of the transformation matrix and the way of executing the matrix's multiplication. At the beginning, the vector and matrix operations were done according to the fact that OpenGL sketch the matrix in arrays ordered by columns. Later on, through the testing phase we realized that multiplication of the transformation matrix by coordinates is carried out reading by rows. Anyway, calculation of the opposite is made reading by columns instead of rows as expected.

In order to determine what face of the cube is selected by the user, we will use a simplified definition of the cube based on six planes set in pairs with the coordinate axes. This arrangement allows using the algorithm proposed by Kay and Kajiya [23], minimizing the number and complexity of calculations that should be made.

Navigating through the scene

The most common choice while examining a scene using the gluLookAt function for manipulating the camera. In the search of a library for iPhone OS contributing with similar functionalities to GLU we found the 1.0.0 iGLU version, which suffered from operation difficulties. That's why we created a new gluLookAt function. The gluLookAt function receives three parameters for camera repositioning (as seen on Equation 3 and Figure 9).

$$eye = (eyeX, eyeY, eyeZ)$$

$$view\ center = (view\ centerX, view\ centerY, view\ centerZ) \quad (3)$$

$$up = (upX, upY, upZ)$$

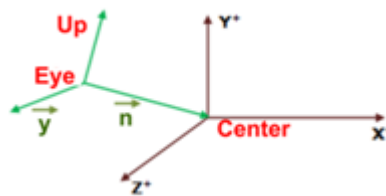


Figure 9. Coordinate system.

When users slides finger over the screen, the camera moves across a virtual sphere surrounding the scene building the coordinate system view which is defined through Equation 4.

$$k = n = eye - view\ center$$

$$l = v = up - n \quad (4)$$

$$j = up = i \times -k = n \times v$$

The transformation matrix is calculated as shown in Equation 5:

$$ModelView = R \times T$$

where:

$$R = \begin{matrix} vX & vY & vZ & 0 \\ upX & upY & upZ & 0 \\ nX & nY & nZ & 0 \\ 0 & 0 & 0 & 1 \end{matrix} \quad T = \begin{matrix} 1 & 0 & 0 & -EyeX \\ 0 & 1 & 0 & -EyeY \\ 0 & 0 & 1 & -EyeZ \\ 0 & 0 & 0 & 1 \end{matrix} \quad (5)$$

where n, vs, up vectors are normalized.

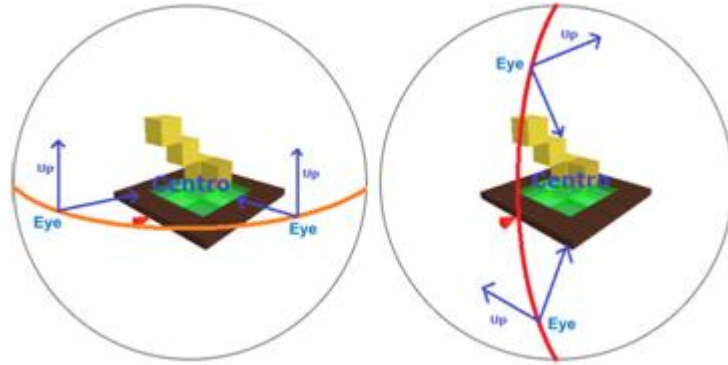


Figure 10. Displacement of camera over the parallel and meridian.

This way, we may manipulate the camera as another object of the scene belonging to device's multitouch events for both navigation and zoom.

4 System's evaluation

The prototype of the game was tested to ensure that is developed according to the specifications. The usability study results of the first phase allowed bugs to be detected and to improve the interface design of the application [26]. The lowest scores were recorded in three items: "Help", "System Speed" and "Easy to Learn". Users reported the need for more assistance in the beginning of the game and too much time between one task and the next. These bugs were corrected and then we could have a stable version of the game for the validation of its influence on spatial skills described below. Users positively valued several features: the good visual aspect and ease of interacting with the touch screen and stylus, users thought it was a fun game and with regard to spatial training, users felt that it could be a good system for improving spatial visualization. This allowed us to have a stable version of the game for the validation of its influence on spatial skills described below.

The mayor goals of the current research were to find an answer to four questions:

- Do 3D educational mobile games improve spatial visualization abilities of Engineering Students?
- Can touch screen Mobile devices provide further support for content oriented to the improvement of spatial skills?
- Would students want to use it again?
- Is it suitable for distance learning on mobile devices in the field of Spatial Skills?

To answers these questions, we carried out an experimental treatment design as described below.

4.1 Design and procedure

Participants

The study was conducted at University of La Laguna (Spain). A total of 280 freshmen engineering students (mean age = 20.17 years; $SD= 4.32$) have completed the Mental Rotation Test (MRT) [27]. Table 2 shows the mean scores and the standard deviations by degree courses and gender, obtained by the participants in the pre-course test (pre-MRT).

Table 2. Descriptive resume of each variable.

	Sample (N)			Pre-MRT (SD)		
	Total	Male	Female	Total	Male	Female
Total	280	236	44	19.98 (8.17)	20.56 (7.99)	17.04 (8.50)
Civil Engineer	46	29	17	16.87 (7.15)	18.10 (6.93)	14.76 (7.23)
Electronics Engineer	92	81	11	21.08 (9.14)	21.60 (8.92)	17.18 (10.20)
Mechanical Engineer	142	126	16	20.28 (7.60)	20.46 (7.48)	19.24 (8.42)

SD = standard deviation

Students with difficulties in spatial visualization skills were selected according to score level on the mental rotation test (MRT) [27]. The treatment group consists of 26 students (17 males and 9 females) who have volunteered to do the training program, with a mean age of 18.50 years ($SD = 1.45$) (see on Table 4).

Materials

Each participant has completed the Mental Rotation Test (MRT) [27] (Figure 11), before and after undergoing this experience, seeking to be able to assess the increase in their spatial visualization skills caused by the course. It contains 20 items divided into two sets of ten. Each item consists of a display figure and four additional ones, two of which match the original figure after being rotated to a certain degree, meanwhile the other two do not match the original display figure. The time limit is 6 minutes, divided into two periods of 3 minutes for every 10 items. The maximum score for the MRT is 40 points. It is interesting to emphasize that the results obtained by Vanderberg & Kuse [27] clearly indicate a difference between men and women, irrespective of their ages. Finally, participants completed a satisfaction questionnaire.

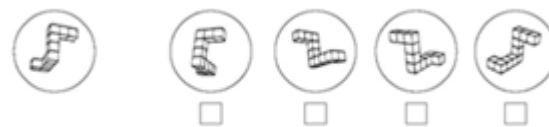


Figure 11. Example of MRT test question

The minimum technical specifications required in the mobile phone for running the application (as shown in Table 1): LCD touch display, 2.8'' (240 x 320), Windows Mobile and Java Virtual Machine. According to this, in our game's evaluation study HTC Touch Cruise mobile phone were selected.

Procedure

Evaluation study performed three evaluation procedures (see Figure 12), including a pre-test, a post-test, and a satisfaction questionnaire, to assess the outcomes for the proposed system. That is, system evaluation includes two parts which are the spatial abilities performance of learners and questionnaire results from learners' feedback responses.



Figure 12. Procedure of experiment.

In the first week of semester, 280 students completing mental rotation test. The students with pre-test scores below the 30% threshold were proposed to enroll in the course. The treatment group was made up of 26 students (17 males and 9 females) who volunteered for undergoing the training course. The training program has been developed in a non-face to face format, for one week. Each day, the students did one competition proposed (from Monday to Thursday). The week before training students do the pre-course test and fill in a user data survey. The treatment group is summoned to meet in a university classroom for performing a short practice session for getting used to the device. Table 3 shows the activities which students attended on the course.

Table 3. Summary of activities

Week	Day	Activities		
1	1	Monday	Pre-testing and user data survey	
			Presentation of the devices and explanation of the course program.	
2	1	Monday	Presentation of the devices and explanation of the course program.	
			Competition 1 (Type 1)	
		2	Tuesday	Competition 2 (Type 1)
		3	Wednesday	Competition 3 (Type 2)
		4	Thursday	Competition 4 (Type 2)
3	1	Monday	Administration of learner satisfaction survey	
			Post-testing	

Participants performed four competitions of 10 exercises each: two competitions with exercises Type 1 and two competitions with exercises Type 2. The average time spent on training with the application was 1.5 hours in four days.

5. Data Analysis and Results

5.1 Measuring the improvement in spatial skills

Table 4 shows the mean scores and the standard deviations by sex, obtained by the participants in the pre-course test (pre-MRT), in the post-course test (post-MRT), the mean gain found (gain-MRT) and the effect size. The scores shown in Table 4 are for the number of correct answers, from a maximum possible of 40 points in this test.

Table 4. Mean and Standard Deviation measures for pre- and post-course test and gain scores

Gender	N	pre-MRT (SD)	post-MRT (SD)	gain-MRT (SD)	Effect Size
Males	17	11.06 (2.90)	19.29 (6.14)	8.24 (5.46)	1.34
Females	9	11.22 (3.07)	18.78 (7.36)	7.56 (6.73)	1.03
Total	26	11.12 (2.90)	19.12 (6.45)	8.00 (5.80)	1.24

SD = standard deviation

For the statistical analysis, the t-Student was used, taking as the null hypothesis (H0) the fact that mean values for spatial abilities did not vary at the end of the training sessions. The result of the comparison of mean pre- and post-tests with the t-Student shown a statistically significant difference (p-value = 0.0000002285) between the before and after values of the group that carried out the *Virtual Blocks* training; therefore the null hypothesis is rejected. We can conclude, with a significance level of higher than 99.9%, that the means scores for the treatment group underwent a positive variation. So, the training with *Virtual Blocks* had a measurable and positive impact on the spatial ability of students, measured by MRT tests. The average increase of values was around 8 points. The calculation of effect's size by Cohen [28], for comparing related samples always showed results above 0.8 regarded as a big effect's size ($d > 0.8$).

Figure 13 shows graphically the obtained scores in the MRT test, taking the population's mean value as a reference (N=280; pre-MRT=19.98). We may observe that training has caused that students with values below 30% reach levels where they become ready to start STEM degrees.

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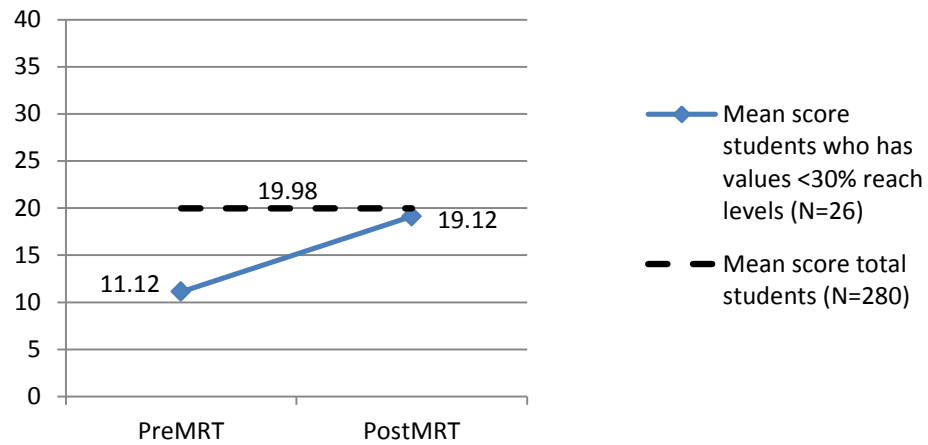


Figure 13. Mean scores in pre-course and post-course test (N=26)

5.2 Students' satisfaction survey

For evaluating student's satisfaction with the proposed system, a questionnaire which involves several questions was designed to measure whether spatial instruction with *Virtual Blocks* satisfies actual learner requirements. Questions focusing on both usefulness of the spatial instruction system (Virtual Block) as well as student satisfaction with the mobile game were asked using a 5-point Likert scale (1=Strongly Disagree, 2= Disagree, 3=Undecided, 4=Agree, 5=Completely Agree). The results from the survey are shown in Table 5, Figure 14 and Figure 15.

As shown in Table 5 there was strong agreement or agreement on all the seven questions. Most students scored the game between 4 and 5 points on a Likert scale of five points ($mean > 4$).

Table 5. Students' answers to attitude questionnaire regarding the game experience (N=26)

Item n°	Statement	1	2	3	4	5	Mean	Std Dev
1	<i>Virtual Blocks</i> was easy to understand	0	0	0	18	8	4.31	0.47
2	I felt capable of solving tasks	0	1	2	16	7	4.12	0.71
3	The game stimulates my interest	0	0	4	15	7	4.12	0.65
4	I think it's a nice tool for development of the spatial ability	0	0	4	12	10	4.23	0.71
5	I would recommend this application to my colleagues	0	0	0	18	8	4.31	0.47
6	I think that mobile gaming is a good learning system.	0	0	1	15	10	4.35	0.56
7	I would have rather performed this course with the teacher physically present	2	7	14	2	1	2.73	2.55

They consider it a game easy to understand ($m=4.31$), quite stimulating ($m = 4.12$) and a good tool for development of spatial ability ($m = 4.23$). It is noteworthy that all the students would recommend it to their colleagues ($m=4.31$).

Also we ask the students regarding the format's preferences while doing this course, highlighting the fact that only 3.9% would agree to do this course using the traditional format of pencil and paper. Around 34.6% of them would prefer to do it on a computer and 61.4% of them prefer to do it on handheld devices (mobile phones, consoles, etc.). We may emphasize that only 7.79% of them would agree to do this course at university.

We have asked for specific assessment of the application's interface, 3D environment's navigation and help. These questions about mobile game interface were also gathered by students pointed in a Likert scale ranging from Confused to Clear (Confused= 1 to Clear =5). The 3D environment's interaction, support and interface have been quite well considered by around 70% of them with three or four points (see Figure 14).

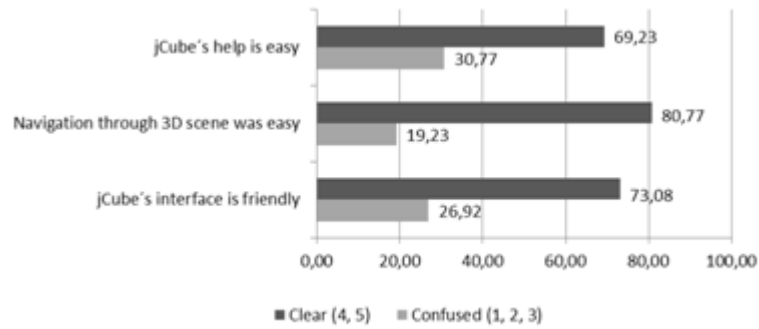


Figure 14. *Virtual Blocks* rating in help, navigation, interface

Figure 15 shows *Virtual Blocks*'s global rating made by 26 users over enjoyment aspects with the game. All items are ranked in a Likert scale where lowest rating is given to the worst consideration (left) while highest belongs to the best considered (right).

Moreover, they were asked to point out the exercises that, in their opinion, presented the greatest difficulty. They consider that Type 2 exercises were more difficult to solve. It is the reason that they rate item "HARD-EASY" as shown in the Figure 15. The rest of the items have been rated by more than 70% of users with scores of 4 (Very) and 5 (Very much) with an 86.6% regarding it as very useful and extremely useful.

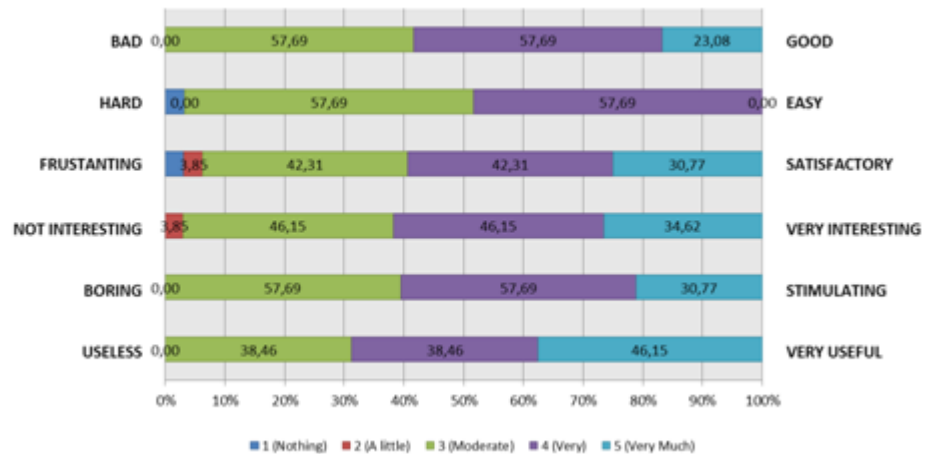


Figure 15. *Virtual Blocks* global rating

6 Conclusions and future works

The new possibilities of using games to develop cognitive skills open up enormous opportunities to connect education to the daily life experiences of learners and their learning styles. Mobile gaming is constantly growing and offers a promising technology to provide students opportunities for enhancing cognitive abilities. In the field of spatial visualization, the use of 3D environments can add value respecting to traditional training programs. Also, mobile devices provide students mobility and opening up new teaching and learning possibilities according to actual student's habits and lifestyle.

Every year, a significant percentage of freshman students entering in engineering degrees and other STEM disciplines face the problem of a lack of proper development of their spatial skills. In the best case scenario, they are provided with remedial courses, to cope with this problem. However, these remedial courses, usually offered as elective, suffer high drop out rates as students have to follow classical pen and paper exercises related to engineering design graphics concepts and require their physical presence in the classroom during several weeks. There is a clear disconnection between the technological way of life of modern students and the nature of these remedial courses that justify their low success rate. The present work opens a new alternative by

1 combining a game based training with the flexibility of mobile platforms to provide training in any
2 moment and in any place, breaking the constraints of the classical classroom activities.

3 This study presents a novel spatial instruction system, using a 3D mobile game designed from
4 scratch to promote some specific mental image construction activities in order to improve the
5 spatial skills of its users. The game “Virtual blocks” is based on the construction of 3D models
6 using single cubes for development of spatial visualization skills. In this work, we have concluded
7 that *Virtual Blocks* is an effective tool to promote spatial abilities development, as the validation
8 study shows. The statistical analysis shows a significant increase of around 8 points in the Mental
9 Rotation Test. It is important to note that results are limited to a specific group: freshmen
10 engineering students with average age 18.5 years.

11 Besides, the problems related to interaction of a small size tactile screen have been solved as well
12 as build and navigation of a 3D environment with efficient exercises’ check for both API M3G and
13 OpenGL ES.

14 Data obtained from user satisfaction survey allows us stating that this interactive game performed
15 on handheld touch screen devices motivated the students that took part in it, generating a high
16 degree of satisfaction, and the participants stated that they would recommend it to their
17 colleagues/friends. This is a very important factor making students willing to take part in it, such
18 as our short remedial course.

19 It is important emphasizing that this game offers a new context for developing spatial abilities: in
20 first place it offers the use of a new hardware device, the handheld touch screen devices, while it
21 also offers mobility for the teaching-learning process and a distance learning course which can be
22 used on the subway, bus, tram or any place where a wireless internet access is available (Wi-Fi,
23 3G, GPRS, etc.). There are many studies and developments done for spatial training, but it is the
24 first one specifically targeting development of spatial abilities with mobile devices.

25 This work has been led by interest in developing material that includes development of spatial
26 visualization related skills, promulgated by the EHEA (European Higher Education Area) and
27 included in the new Engineering degree courses offered by the Spanish Ministry of Education. We
28 believe it is necessary keeping development of material of this kind that provides students with
29 mobility opening up new teaching and learning possibilities according to actual students habits and
30 lifestyle.

31 We continue to work towards improving and complementing the developed application in different
32 aspects, which will form our future lines of research in order to:

- 33 • Test and port the mobile game to other operation systems: Android and Windows Phone.
- 34 • Add further upgrades with additional functions in the future and create new types of task.
- 35 • Assess users’ work overload with respect to the number of exercises and level of difficulty
36 in each competition.
- 37 • Test our tool among middle and secondary school students.

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