



ICTE in Regional Development

Augmented reality to training spatial skills

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**Abstract**

La Laguna University has been offering courses for the development of spatial skills since 2004. Each year since that time spatial ability of engineering students has been measured before and after the courses to check progress after each training session. We have developed a spatial skills training course based on augmented reality and graphic engineering contents, and designed the AR\_Dehaes tool, which is based on its own library the uses computer vision techniques for incorporating visual objects through fiducial markers in the real world.

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**1. Introduction**

Ferguson<sup>1</sup> in “*Engineering and the Mind’s Eye*” indicates that usually an intuitive connection is established between spatial skills and engineering. Besides, most papers about spatial skills or their components refer to the fact that engineering, architecture and most scientific jobs need good levels of spatial ability. Spatial ability has an impact on every scientific and technical field so it’s still enjoying strong development when it comes to engineering, technology, art and many other aspects of life even considering it has not been paid as much attention as other intelligence components such as verbal and numeric abilities.

Many teachers and researchers like P. Connolly<sup>2</sup> suggest the need for developing spatial ability from Graphic Engineering subjects. Barr<sup>3</sup> analysed future academic engineering plans keeping in mind modern tendencies and

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highlighted that the most important subject included in the program should be development of spatial skills. Historically, there has been a great deal of interest in methods of instruction and technology that could potentially increase the spatial skills of its users,<sup>4, 5, 6</sup> Currently, the rise in virtual reality, be it immersive, augmented, or desktop, has fuelled renewed research in spatial ability development.

Over the last years we have created numerous experiences in fast remedial courses to improve spatial abilities of engineering students at the University of La Laguna in Spain. In these courses different tools have been tried out: classic exercises (views) using pen and paper, online multimedia web-based exercises, sketch-based modelling through a calligraphic interface,<sup>7</sup> use of the Google Sketch-up modelling application<sup>8</sup> and videogames as a work tool<sup>9</sup>.

Augmented Reality (AR) technology emerges as a nice resource for the younger population. This is accomplished to the latest developments in technology and entertainment. The cognitive aspect identifies any improvement of the subject's internal concepts through this learning experience. In the following section, we describe the content of a didactic toolkit (AR\_Dehaes) that provides the students with a set of varied exercises for spatial ability training using an augmented book.

## 2. Description application of AR

Our application requires accurate position and orientation tracking in order to register virtual elements in the real world and so we have used a marker-based method. For creating the Magicbook only fifteen different markers have been used. With these markers all one hundred exercises comprised in the training can be codified. Markers have been combined in pairs so every two of them are associated to a 3D model and any two markers in different positions can be associated to another virtual model (see figure 1.).

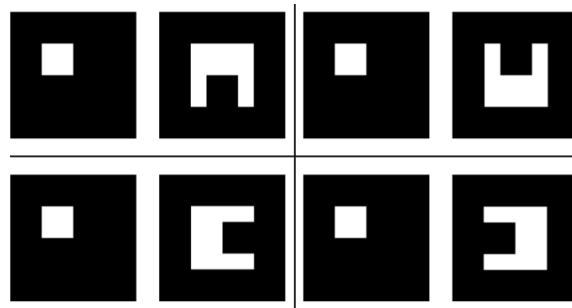


Fig. 1. Combination two markers may be associated with several virtual objects. Above are four combinations.

To capture the video, we have used a USB camera (QuickCam Pro 9000). This camera has the following features: captured image size - 1600 x1200 at 30 fps; focal length - 3.7 mm; automatic focus adjustment and RightLight (technology with the capability to adjust the webcam to take good shots even in dim light settings).

Although there are several public libraries with AR capabilities, we have created a software library called HUMANAR in order to ensure integration of Augmented Reality into our applications and overcome some drawbacks present in some public libraries (ARtoolKit, MRXtoolKit etc.). This library uses computer vision techniques for calculating the real camera viewpoint relative to a real world marker, which calculates integration of three-dimensional objects codified by the camera and captured by itself in real time<sup>10</sup>.

The graphical engine used for the augmentation of a virtual object on the scene is Brainstorm eStudio<sup>11</sup>. This is an advanced, multiplatform, real time 3D graphics presentation tool. In order to include Augmented Reality functionality in Brainstorm eStudio, a plugin has been developed in C++. This plugin incorporates detection and tracking options from the HUMANAR library.

The AR-Dehaes toolkit is comprised of a software application, an explanatory video, a notebook and an augmented book (see figure 2).

- A software application that contains the three dimensional virtual models. These models will be visualized on the computer screen when fiducial markers are received by the webcam.
- A short explanatory video that explains the theoretical contents of orthographic views and freehand sketching.
- A notebook that contains questions and exercises to be solved by the students.
- An augmented book that provides fiducial markers of virtual three dimensional objects.

The students can turn, move or bring the notebook to the webcam being able to see different perspectives of the virtual model and complementary information for exercise resolution.



Fig. 2. Explanatory video, notebook, augmented book and program running





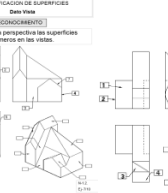
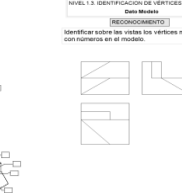
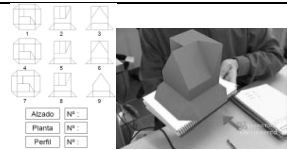
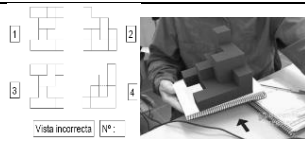


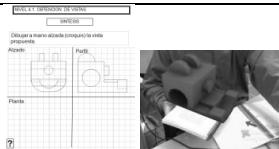
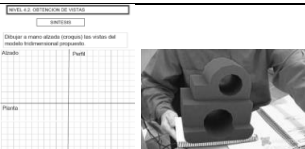
Didactic material was created using Bloom taxonomy<sup>12</sup> being structured on five levels, each one containing several kinds of exercises. All levels are designed for two hour sessions, except level 5 (evaluation), in which six exercises must be completed by students in just one hour without any virtual model help.

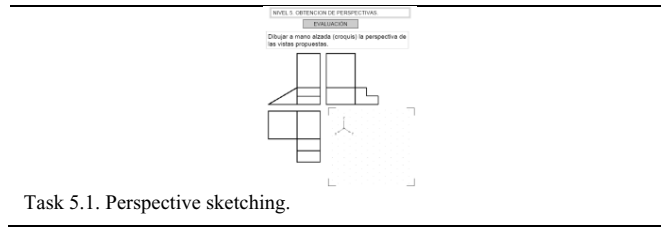
The first exercise of each level and typology has a physical gesture related to it, which must be performed by the student in order to figure out its solution and understand how to solve it:

- Level 1. In this level, the students have to identify surfaces and vertexes in both orthographic and axonometric views of a three-dimensional virtual object, which is created on the augmented book.
- Level 2. In this level, the students have to identify orthographic views of the virtual three dimensional models from the exercise book.
- Level 3 is dedicated to the identification of spatial relationships between objects. This is carried out by means of “recount” exercises, where students are asked to identify how many objects touching the one selected. There are also exercises about the selection of the minimum number of views for complete definition of an object.
- Level 4 has greater difficulty than the previous ones. There are exercises where the students have to sketch a missing orthographic view, knowing two orthographic views of a model. In a second stage, using the virtual model as the only input, they have to sketch all orthographic views.
- Level 5 exercises are the most difficult ones for students, because they require a greater level of spatial ability. Students are provided with three orthographic views of each object, and they have to build the matching three-dimensional model in their minds and then draw a freehand perspective of it.

Students can visualize the three-dimensional model in augmented reality (augmented book) and they can check if their freehand sketches match the three-dimensional virtual models they are viewing. Completion of each level on consecutive days is suggested so it should be finished in 5 days or sessions.

Table 1: Levels and kinds of exercises

LEVEL 1		
		
<p><b>RECONOCIMIENTO</b></p> <p><b>NIVEL 1.1 IDENTIFICACION DE SUPERFICIES</b>                      Dada Perspectiva                      Identificar en las vistas las superficies marcadas en la perspectiva.                      Escribir en las vistas el número que corresponde en la cara marcada en la perspectiva.</p> 	<p><b>RECONOCIMIENTO</b></p> <p><b>NIVEL 1.2 IDENTIFICACION DE SUPERFICIES</b>                      Dada Vista                      Identificar sobre la perspectiva las superficies marcadas con números en las vistas.</p> 	<p><b>RECONOCIMIENTO</b></p> <p><b>NIVEL 1.3 IDENTIFICACION DE VERTICES</b>                      Dada Modelo                      Identificar sobre las vistas los vértices marcados con números en el modelo.</p> 
Task 1.1. Identification of surfaces. Orthographic views.	Task 1.2. Identification of surfaces. Axonometric projection.	Task 1.3. Identification of vertices.
LEVEL 2		
		
Task 2.1. Identification of orthographic views.	Task 2.2. Identification of wrong orthographic views.	
LEVEL 3		
		
Task 3.1. Recount	Task 3.2. Selection of the minimum number of orthographic views to define an object.	
LEVEL 4		
		
Task 4.1. "Missing view" exercises.	Task 4.2. Orthographic view sketching.	
LEVEL 5		



### 3. Study and Result

To check if training has managed to improve the spatial ability of students, we invited 24 first year mechanical engineering students and the course took place on the first week of the academic year to avoid that they could obtain contents from other subjects. We also considered a control group consisting of 25 students (first year) in agricultural engineering who underwent no kind of spatial skills training. At the beginning and end of the course students have performed two tests for measuring spatial skills (Table 2). Those tests measure different aspects of spatial ability: spatial relations and visualisation through Differential Aptitude Test (DAT-5:SR Level 2)<sup>13</sup> and Mental Rotation Test (MRT)<sup>14</sup>.

Table 2: Mean values pre/post test and gain scores

	Pre- test		Post- Test		Gain	Gain
	MRT	DAT 5:SR	MRT	DAT 5:SR	MRT	DAT 5:SR
<b>Exp.Group</b>	19.67	29.17	27.71	38,46	8.04	9.29
<b>n = 24</b>	(7.91)	(7.29)	(7.83)	(7.05)	(5.31)	(4.08)
<b>Control Group n=25</b>	17.44	28.40	22.08	33.52	4.64	5.12
	(9.82)	(10.17)	(9.94)	(11.77)	(4.36)	(7.13)

An analysis of covariance (ANCOVA) was used to study it. The ANCOVA method allows eliminating the difference of pre test scores between groups, and then the adjusted post test scores, revealing the real effects of the experimental treatment. Hence, it eliminates the possible memory effect. This statistical procedure also tested the interaction between groups (Training AR and control). The dependent variables, co-variants and independent variables were post-test measurements, pre-test measurements and type of group respectively. Suitability of using this analysis was tested by first conducting the analysis using a statistical model containing interaction terms between the co-variants (pre-test mean scores of MRT and DAT-5:SR) and the independent variables to assess the assumption of homogeneity of the gradients. After adjusting for covariates (pre-test scores), it is checked again that there was a significant difference between control group and training AR group on the gain scores,  $F_{1,46}=7.47$ ,  $p=0.009$  (MRT) and  $F_{1,46}=6.55$ ,  $p=0.014$  (DAT-5:SR).

We also conducted a questionnaire on usability and satisfaction with the application used. Questions are divided into five blocks: educational material effectiveness, contents' efficiency, technology efficiency, satisfaction and opinion. Having in mind educational material effectiveness, different values are assigned according to Likert's scale to the following aspects: course material presentation quality, comfortable course structure, the clarity and comprehensibility of formative videos, adequate course development (levels and typology), easy location of exercises between design's notebook and fiducially marks' book, proper size of notebooks for completing exercises and manipulating virtual elements, software stability using augmented reality application. All values obtained are quite high and near 5 which show that the material is perfectly suitable for achieving the purpose it was created for. Assessing content learnability (evaluation) earned a medium score of 5.7 over 6 stating the course is a success.

When measuring efficiency in the survey we asked about content efficiency and technology. Both received high scores obtained as well. Participants state that they were capable of resolving all proposed exercises in the allotted

time and also consider that manipulation of virtual objects and performance of gestures has been easy as AR is very intuitive.

Table 3: Usability questionnaire. Blocks of questions.

Block	Questions	Measure kind	What's being measured?
<b>Student data</b>	Several	Several	Personal data
<b>A.- Didactic material value</b>	A1-A7	Likert scale	Didactic material effectiveness
<b>B.- Course material value</b>	B1-B3	Likert scale	Efficiency
	B4	Likert scale	Effectiveness
	B5	Likert scale	Learnability (Proper learning performance measurement)
<b>C.- Used technology value (AR)</b>	C1-C4	Likert scale	Efficiency
<b>D.- Course opinion</b>	D1-D13	simple-dichotomy Multiple choices Semantic Differential	Satisfaction
<b>E.- Course improvement suggestions</b>	E1-E8	simple-dichotomy Multiple choices Semantic Differential open-ended question	Opinion and satisfaction

#### 4. Conclusion

We have presented an AR application for the development of spatial skills. As far as we know this is the first AR application with these characteristics that has been created for improving spatial ability using didactics content of engineering graphics

A covariance analysis (ANCOVA) shows that the experimental group significantly improved its spatial skills after performing this training compared to the control group that had not undergone any spatial skills training.

In educational applications, it is quite important to focus the attention of students on the task at hand and reduce the cognitive overhead needed for application use. This motivated us to design a user-friendly system in an agreeable environment. AR-Dehaes has proven to be an efficient material for developing spatial abilities and for learning engineering graphics contents.

Augmented reality is a cost-effective technology for providing students with attractive contents in respect to paper books, giving new life to classical pen and paper exercises.

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