Mixed Reality for Development of Spatial Skills of First-Year Engineering Students

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Abstract - **This paper follows up on the validation and usability study done on augmented reality, which is based on an application for the development of spatial skills in engineering students. In this phase, the training has been implemented in new Engineering degrees adapted to the new European Higher Education framework at a Spanish University. In this paper, the results obtained by students when improving spatial ability while carrying out their training, are shown and related to academic performance and drop-out rates, which are from current academic courses as well as previous ones. Additionally, a pilot study is introduced where a group of students use Head Mounted Displays (HMDs) for visualizing the real scene with augmented objects, so spatial ability improvement results and time spent, are compared to others belonging to the group using the PC monitor instead. Results confirm the training's validity and technical data which are collected to improve the interface's application as well as the augmented book. This has allowed the training to be made available to education centers which are waiting for the academic implementation through a commercial edition.**

Index Terms – Augmented reality, Engineering Design, Engineering Education, Spatial Ability.

INTRODUCTION

Spatial ability is one of the most studied skills in the field of human cognition. It has consequences in all the scientific and technical fields and it's still quite an active one in both psychology and engineering areas despite the large amount of investigation and scientific references performed. It's very common to find a high level of spatial ability in people working on both engineering and architecture related activities [1].

Development of spatial skills by engineering students is directly linked to future success in their professional field [1,2,3] and is critical for understanding the contents of engineering graphic subjects [4]. This capability can be described as the ability to picture three-dimensional shapes in the mind's eye. Acquiring this ability can be done through an indirect process by means of Engineering Graphics subjects where students perform sketching tasks to create and read orthographic and axonometric projections [5]. However, there is another approach based on the development of specific training for the development of spatial skills.

From our perspective as teachers, we realize what difficulties first year engineering students experience while learning Technical Drawing, this is because of the low level of spatial ability in engineering and that's why we feel the need for creating tools and methodologies to improve that ability.

SPATIAL ABILITY AND TRAINING

Without any doubt spatial ability is an important component of human intelligence but there is no agreement about the sub-factors that consist of this aspect of intelligence [6]. Some of the most accepted theories come from researchers [7,8] who have proposed three major sub-factors for categorizing spatial skills: spatial relations, spatial visualization, and spatial orientation, although some researchers don't recognize spatial orientation as a separate factor. The following classification proposed by researchers on both psychology [9] and engineering fields [10], are now reduced to just two sub-factors:

- *Spatial relations*, defined as the ability for imagining rotations in both two and three dimensions. Authors indicate that this skill includes mental rotation and spatial perception factors.
- *Spatial visualization* which is the ability to recognize 3D objects through the folding and unfolding of their faces. Visualization is defined as the ability of mental management of complex shapes.

To measure these components we use both the Mental Rotation Test (MRT) [11] and the Differential Aptitude test (DAT-5: SR) [12], as they are highly valuable tools for performing measurements of spatial skills (Figure 1).

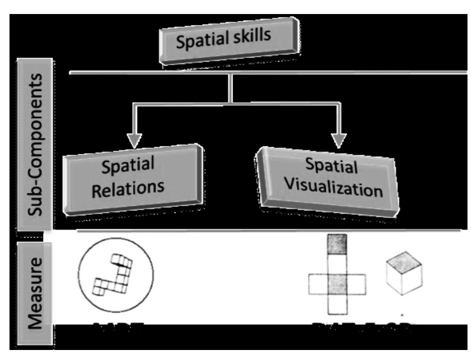

FIGURE 1
FACTORS AND MEASUREMENT TEST FOR SPATIAL SKILLS

Spatial ability is something that cannot be taught but it is possible to develop, being the only way to improve this skill. Some studies in the engineering field demonstrate that spatial abilities can be improved by means of specific training with multimedia exercises, video games, 3D software and other technologies used in graphic engineering [3, 13-15]. According to Mohler [16], spatial ability is the most important out of all the other abilities an individual can possess, which will enable them to carry out all kinds of tasks related to the engineering profession.

In the area of engineering, specifically in technical design and representation of views, there is an obvious connection with spatial reasoning and geometric transformations, both are excellent catalysts for developing perceptive abilities of students [17]. The integration of various orthographic views from the perspective of a student produces a training of spatial visualization, and obtains new orthographic views from view given, is a way that it helps to understand the spatial relationship.

Training of spatial visualization is achieved (among other exercises), proposing the student the choice of the appropriate model, which is reached through a process of mental manipulation from input data. In general, the procedures are the folding and unfolding of object surfaces. The spatial relationship is developed by recognizing a three dimensional object from different angles, which in turn requires the student to recognise spatial position and relation to other objects.

Previous Training of Augmented Reality

Augmented Reality can be defined as an integration of virtual elements in a real environment. We regard augmented reality as an attractive technology which offers necessary tools for the creation of attractive teaching content and development of spatial skill.

At the beginning of the academic year October 2008, we carried out a pilot study where our aim was to improve the spatial abilities of freshmen engineering students through a short training course lasting nine hours. This was based on augmented reality using the basic contents of graphic engineering (representation of objects through standard views). If we can get the students to improve their levels of spatial ability, they are then able to better understand the contents of the graphic engineering subject.

I. Tool development, usability and validation study.

In our work [18], all the experience on development validation and the usability of the didactic toolkit "AR_DEHAES", the first version (Figure 2), is explained in abundant detail. The following gives a general outline of this:

- Although there are several public libraries with AR capabilities, we have created a software library called HUMANAR in order to ensure the integration of Augmented Reality into our applications and overcome some drawbacks present in some public libraries (ARToolKit, MRXToolKit…). HUMANAR uses computer vision techniques to calculate the real camera viewpoint relative to a real world marker, which calculates the integration of three-dimensional objects codified by the camera and captured by itself in real time (figure 2).
- Didactic material was created using Bloom taxonomy [19] being structured on levels *(knowledge, comprehension, application, analysis-synthesis, and evaluation)*, each one containing several kinds of exercises. Purpose training is structured into five levels with a duration of two hours for each one, except level 5 (evaluation) where six exercises must be completed in just one hour without any model help.

On the first level of knowledge, the exercises allow for familiarization and identification of orthogonal views of an object. Several types of exercises are envisaged for this. Firstly the identification of surfaces and views also the identification of vertex forms. On the second level, comprehension is measured and it is envisaged that there will be exercises in which the objects have to be viewed from different angles. On the third level application, will involve carrying out mental calculations to establish the relationship between groups of objects. Also to identify the smallest parts of data which represent an object. On the fourth level it is necessary to analyse and synthesize the necessary information so that It can represent objects according to the piece which is to be used. The student should then draw the image that is required, or the minimum necessary to complete the representation. The last level proposes to evaluate what has been learnt and which will also indicate what has been understood and what spatial skill has been acquired from previous level. Also, both before and after training the spatial capacity of the students will be measured through the MRT and DAT-5 test, with the objective of comparing data.

- Results of the validation study indicated that students which undertook training with AR_DEHAES improved their levels of spatial ability compared to the control group which didn't undertake any kind of training.

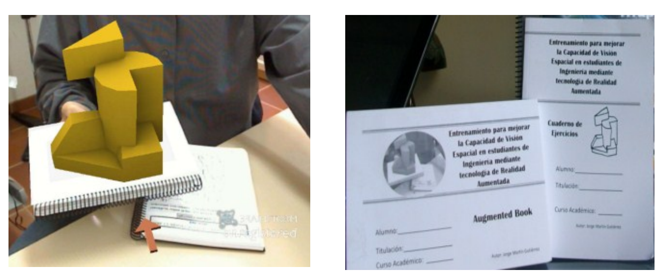

FIGURE 2
AR_DEHAES TOOLKIT BETA VERSION.

In a usability study five aspects where measured: educational material effectiveness, contents efficiency, technology efficiency, satisfaction and opinion. Results show that all students expressed a highly positive attitude to the material and contents. They considered the material was well presented and structured. Overall the appreciation of the training was excellent or good and most students considered it very useful, very interesting and they were satisfied with the technology and methodology. All students considered that AR-DEHAES system was pleasant to use.

INTRODUCING TRAINING ON ENGINEERING DEGREES

University teaching in Europe is currently immersed in a major process of change arising from the creation of the European Higher Education Area (EHEA). In Spain, the Ministry of Education and universities are working to adapt the current teaching system to the European model in the following terms:

- Review and introduce new qualifications based on contents and competences.
- The definition of contents and professional profile by areas of knowledge and the re-evaluation of quality levels [20, 21].

The Spanish Ministry of Science and Innovation has drafted a base line document for each qualification, containing the guidelines for universities to design the syllabus for each qualification. These documents were published in the Spanish State Bulletin [22]. According to these documents, engineering qualifications will have to provide students with *"Spatial ability and command of graphic representation techniques, using both metric geometry and descriptive geometry, conventional methods as well as applying computer aided design"*. Thus, the Ministry of Education considers that engineers and architects should have a command of the main areas and techniques of representation and CAD tools are a support which cannot substitute the command of descriptive geometry. Moreover, it is important to monitor students´ spatial abilities.

In the past, the development of spatial abilities has not been a specific aim when learning engineering graphics. To compensate for this lack of spatial abilities development, like previous authors [3, 13], we have included AR-based training on spatial abilities in the new degrees of mechanical engineering and chemical engineering at the University of La Laguna. These have been adapted to the European Higher education framework.

While describing this experience we will go over the following points:

- Introducing on engineering degrees résumé, an autonomous training scheme for improving students´ spatial abilities and the measurement of these improvements whilst comparing them to academic results.
- Testing applications with many users for data compilation of any app issues aiming to improve It.
- Performing a pilot study to compare spatial ability levels achieved by students depending on which output display they use be it the PC monitor, or a Head mounted Display (HMD). We consider that It is possible that the use of the HMD could influence positively the improvement in the majority of spatial skill levels, rather than the use of a monitor or PC.
- Compiling degrees of satisfaction about HMD use.

I. Study's description

The study has been carried out with the beta version which has been tested on 235 students. Training was done at home and independently and the information was collected on the existence of bugs to improve the program which will reach the user trouble free. Besides this, the target is obtaining results about spatial ability improvement.

With this experience and bearing in mind the good results obtained through AR_DEHAES validation, we have focused on the development of commercial versions for training, which will show many improvements with respect to the initial version. It will be available for distribution in June 2011.

The study was performed during the first week of the academic year 2010/11 in October so, at the time of taking part in the experience, these students had not attended any Engineering Graphics classes in their degree courses. Spatial abilities of engineering students were measured before and after training through both Mental Rotation Test (MRT) and Differential Aptitude Test (DAT-5:SR).

It's intended that students carry out training five times in sessions on their own at home as no teacher assistance is needed. In first briefing with students, they were updated on the purpose and need for undertaking the training as well as obligation of submitting back to the teacher the training's notebook with all solved exercises when it's finished as guarantee that they have completed it. Later tests will be run to measure spatial skill and supplying AR_DEHAES toolkit (exercise book, augmented book and website where AR_DEHAES is available for download). Afterwards instructions are explained on how to carry out training: "five levels, which will be completed in five consecutive days". It is considered that two hours work is required for each level with the exception of the fifth which requires just one hour. They will need to record the completion times on a form with an e-mail address which is supplied to communicate any issues that they may have had while installing or using the application. Once training is finished, students hand the completed exercise book to the teacher whilst spatial ability levels are measured once again for comparison with pre-training levels.

To undertake the training, only a standard PC and a webcam are required. Students will visualize virtual elements on the monitor. We intend to perform a comparison study between the results of the spatial ability levels and propose forming a training group consisting of ten randomly picked students using Head Mounted Displays (HMDs) and a general group using the computer screen as a display device. We will provide each student with an HMD to complete the training. We believe that the HMD makes the user more comfortable creating a more relaxing experience.

Also that viewing on the HMD should be different from seeing It on a computer screen.

Besides the spatial ability data, time spent on the levels is acquired at each training session because there is a chance that there may be a more statistically significant difference regarding performance times for each task, depending on which display device is used. Also, we will consider a control group consisting of engineering students who have never undertaken any kind of spatial skills training.

II. Measures and results

In TABLE I, MRT (spatial relations) and DAT-5:SR (spatial visualization) values can be found before and after training for the three groups: general, experimental and control group. Mean values prior to training are quite similar in all three groups. The analysis of variance (ANOVA) for MRT and DAT-5:SR measured in the three groups (general group, experimental group and control group), shows there was no significant differences between groups prior to spatial training ($F_{2,257}$=1.54, p=0.21 on MRT and $F_{2,257}$=1.91, p=0.15 on DAT-5:SR). So, all groups were statistically equivalent in spatial visualization and spatial relation at the outset of this study.

TABLE I
VALUES PRE/POST TEST AND GAIN SCORES

	Pre- test MRT	**Pre- test DAT 5:SR**	**Post- Test MRT**	**Post- Test DAT 5:SR**	**Gain MRT**	**Gain DAT 5:SR**
Training Gen.	20,2	31,71	28,37	40,78	8,15	9,07
Group n = 225	(7,27)	(7,87)	(7,18)	(6,24)	(3,28)	(3,15)
Exp.Group	20,50	30,40	29,20	40,00	8,70	9,60
(HMD) n=10	(6,67)	(9,32)	(6,98)	(6,66)	(3,88)	(3,53)
Control	17,44	28,40	22,08	33,52	4,64	5,12
Group n=25	(9,82)	(10,17)	(9,94)	(11,77)	(4,36)	(7,13)

We compared the mean values obtained in pre and post tests using the *t-Student paired series test:* the training general group scores show t=11,99 for the MRT; p-value=0,0 and DAT-5:SR t=13,55; p-value=0,0; the experimental group showed t=2,84 for the MRT, p-value=0,01 and DAT-5:SR t=2,64; p-value=0,016. In the MRT test, the control group obtained t=1,66; p-value=0,103 and in the DAT-5:SR t=1,64; p-value=0,106.

Groups that underwent training show a statistical improvement in spatial ability levels. P-values are around 5% of statistical significance, which indicates that the students have a probability of over 95% of improving their levels of spatial ability by training as proposed by Augmented Reality. Besides this, results show there is no improvement in control group levels. To compare, and to see if there is any difference between spatial ability levels obtained by groups that underwent training, a contrast analysis post-hoc LSD Fisher is performed, this allows multiple comparisons between the three groups with a different number of individuals in each group as seen on results TABLES II and III.

TABLE II
COMPARISON BETWEEN GROUPS FOR GAIN MRT

(I) group	(J) group	Difference between averages (I-J)	Typical error	Sig.	Confidence interval at 99%	
		Lower limit	Upper limit	Lower limit	Upper limit	Lower limit
1	2	-,54444	1,10370	,622	-3,4086	2,3198
	3	3,5155(*)	,71997	,000	1,6472	5,3840
2	1	,54444	1,10370	,622	-2,3198	3,4086
	3	4,0600(*)	1,27782	,002	,7439	7,3761
3	1	-3,5155(*)	,71997	,000	-5,3840	-1,6472
	2	-4,0600(*)	1,27782	,002	-7,3761	-,7439

1 (General Group), 2 (Experimental Group), 3 (Control Group)
* Difference between averages is significant at ,01 level.

TABLE III
COMPARISON BETWEEN GROUPS FOR GAIN DAT5:SR.

(I) group	(J) group	Difference between averages (I-J)	Typical error	Sig.	Confidence interval at 99%	
		Lower limit	Upper limit	Lower limit	Upper limit	Lower limit
1	2	-,52444	1,20227	,663	-3,6445	2,5956
	3	3,95556(*)	,78428	,000	1,9203	5,9908
2	1	,52444	1,20227	,663	-2,5956	3,6445
	3	4,48000(*)	1,39195	,001	,8678	8,0922
3	1	-3,95556(*)	,78428	,000	-5,9908	-1,9203
	2	-4,48000(*)	1,39195	,001	-8,0922	-,8678

1 (General Group), 2 (Experimental Group), 3 (Control Group)
* Difference between averages is significant at ,01 level.

The results confirm that there is a significant difference between each one of the training and control groups but there is no difference between the training groups, so we may state that the improvement doesn't depend on any kind of display used for visualizing virtual objects.

With respect to the time spent by each training group on completing each session, the results show there is no significant difference between groups as well (TABLE IV).

TABLE IV
COMPARISON OF TIME SPENT DURING TRAINING FOR EACH GROUP

Session	t. General group (SD)	t. Experimental group (SD)	*t-student* P-value
1	117,6 (11,2)	124,3 (9,9)	t=1,86 p= 0,064
2	104,3 (12,1)	108,2 (8,6)	t=1,03 p= 0,301
3	111,2 (8,4)	116,4 (6,3)	t=1,93 p= 0,054
4	121,4 (7,5)	117,1 (5,7)	t=1,79 p= 0,075
5	25,1 (5,4)	26,5 (7,1)	t=0,79 p= 0,429

(t) Time in minutes

In Table V we show academic results from a Graphic Engineering subject in the last academic years. Through visual comparison, it's notable that in this academic course (2010-2011) the drop-out rate is less than previous years while the pass rate increased.

TABLE V
DROP-OUT RATES AND SCHOOL FAILURE

Academic course	Drop-out rate	Academic performance rate
2010-11	11%	89%
2009-10	39%	54%
2008-09	36%	59%

Participants in the experimental group took a short survey at the end of their training where data was collected about user's satisfaction of HMD. The user satisfaction has been measured using an adapted version of the QUIS Questionnaire [23] using a 10 point scale from 0 to 9. The questions are presented in Figure 3. In general, all participants expressed a low positive attitude towards HMD use.

FIGURE 3
USERS SATISFACTION MEASUREMENTS.

III. Registered issues

Regarding the application itself, 13 bugs in total have been reported to date, being quite a small amount bearing in mind that it was installed in 235 different computers. Incidents reported by students belonged to three kinds which have been solved in the application's most recent version:

- The graphic engine couldn't be executed on 64-bits OS.
- The Program could not be run showing messages of missing files MSVCP71.dll and MSVCR71.dll
- The graphic engine window splits in half between opposite corners where one half shows webcam image while other half remains black.

For the AR_DEHAES latest version we used a new graphic engine supporting 64 bits OS, added both MSVCP71.dll and MSVCR71.dll files to the installation so they could be recorded on folder c:\windows\system32 and lastly, a third bug which we switched culling distances from the simulation's virtual camera (graphic engine's parameter).

RESULTS DISCUSSION

The training of spatial ability based on Graphic Engineering contents and AR technology improves spatial abilities for those who perform them and consequently lower the numbers of students who drop out of the subject. Good spatial ability levels allow students better understanding of engineering graphic content. So, if more students follow the subject, academic performance rates will be greater.

A priori, we thought that use of a HMD would provide a better overall experience to the user but the results of the acquired improvements have been no different from the users who visualized the object on the monitor. The Point of view for visualizing virtual objects in a HMD is store at user's eye height so mental rotation process become more natural as hands coordination for moving and rotating virtual objects are the natural ones. However, using a monitor screen with a camera placed over the monitor makes the point of viewing right in front of the user, so mental processes that should be made by the user to understand rotations will be far more elaborated. Thus, mental work in the general group is greater than experimental group. In contrast, the HMD use is not comfortable: users are bothered by cables linking the glass and camera with the PC, as they interfere with movement. The glass has no camera integration so a webcam has been fitted on It, meaning more weight and a certain discomfort as the camera should be repositioned as well as requiring the occasional rest, as weight over the nose is too uncomfortable. This makes users unsatisfied with the use of HMD while training.

COMMERCIAL APPLICATION

AR_DEHAES new version has improved not only the screen interface but the augmented book as well with respect to the beta version. When the application executes, a short 4 minute video starts where a teacher explains the basic content of the representation systems through orthographic views –*Figure 4 down right*-. Once the video is over (or by pressing ESC), the image is captured by the webcam and will be visualized on the screen where its upper part will also show the information about the training level related to the exercise. The augmented book is configured so an exercise is suggested on each page and has to be solved by the student, while the marker on the upper right part will be identified by the program as the level and exercise number when captured by camera–*Figure 4 down left*-. The Book is provided with a paddle as a general marker. The student will use this paddle to visualize the virtual object–*Figure 4 up*-. So the process will be to identify the exercise with the page's marker and afterwards bring the general marker closer to work on a virtual object without any need for making movements on the book.

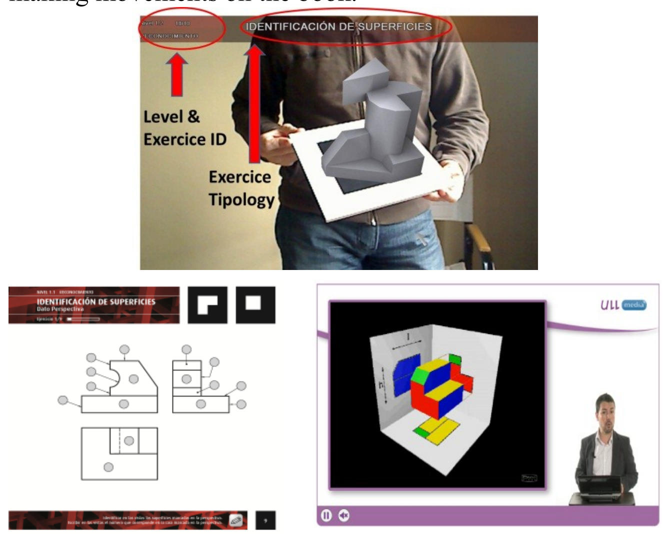

FIGURE 4
AR_DEHAES TOOLKIT COMMERCIAL VERSION LOOK AND APPEARANCE.

CONCLUSION

Testing the new AR_DEHAES tool for its use and control by engineering students in an independent way, has helped define the final setup for this tool which will allow for the launch of the commercial version.

The aim is to supply this tool to teaching centers in both universities and schools. AR_DEHAES has improved in quality regarding the augmented book because of its attractive user friendly interface. The graphic engine used on app has been improved as well with all three bugs detected by beta testers and have been corrected.

Results obtained regarding the spatial ability levels show that training with this app, based on augmented reality has a positive effect on the user who improves their spatial skills whilst working on their own.

Statistic results show that use of the HMD device doesn't provide any difference when obtaining spatial ability upgrades with respect to the PC monitor, although this value may be caused by the fact that HMD use is not the most suitable as participants stated that glass and camera set was not comfortable. We believe this comparison study between HMD vs. monitor should be repeated using a more comfortable HMD for users to be carried on their heads.

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